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# Bistatic Configuration Reading for Sub-Millimeter Displacement Chipless Tag Sensor

Raymundo de Amorim Jr, Nicolas Barbot, Romain Siragusa and Etienne Perret  
Université Grenoble Alpes, Grenoble INP, LCIS, 26000 Valence, France

{raymundo.de-amorim-junior,nicolas.barbot,romain.siragusa,etienne.perret}@lcis.grenoble-inp.fr

**Abstract**—A phase measurement technique for millimeter wave chipless tag  $\mu$ -displacement sensor considering bistatic configuration is presented. For this purpose, a bistatic antenna configuration is employed, where the angle between the incident wave and the backscattered signal is chosen to increase the useful part of the tag signal. The displacements are analyzed along the 1D axis parallel to the alignment of the antennas. The validity and accuracy of the displacement method have been verified by moving the tag to different positions considering static antennas. The measured displacement deviations achieved based on the proposed approach are around  $5 \mu\text{m}$  for a  $30 \mu\text{m}$  step. It indicates precise and low-cost displacement chipless tag sensors for millimeter-wave applications.

**Index Terms**—Displacement sensors, chipless RF identification (RFID), millimeter wave circuit, bistatic measurement.

## I. INTRODUCTION

Identifying and capturing physical information are significant matters in modern societies. Radio-frequency (RF) is one of the most effective technologies for retrieving an object's physical information. RF identification is experiencing considerable growth in the Internet of Things (IoT) industry, and the demand for positioning technology in the IoT framework follows that tendency. The RFID system aims to retrieve the objects' physical information on which the tags are placed. Among the RFID systems, one of the largest implemented is UHF RFID, in which each tag is composed of an antenna that backscatters a signal modulated by a chip. Therefore, the cost of the application is directly associated with the chip cost. In this context, chipless technology is employed as a cost-reduction alternative instead of mandatory chip solutions. Chipless RFID tags can be identified remotely due to scattering signal characteristics related to their electromagnetic signature. The reader transmits a RF interrogation signal towards the chipless tag, which impinges and excites the tag resonators; thus, the reader captures the backscattered chipless tag signal.

Millimeter-wave (mmWave) chipless resonant tags have been designed considering the trade-off between RCS signal level, losses, and design constraints [1]. Compared to UWB applications, the mmWave chipless tag can achieve better displacement accuracy. In addition, millimeter-wave scatterers are less impacted by coupling since resonant elements may be spaced further apart relative to the wavelength compared to classical designs. Additionally, mmWave allows drastically miniaturizing the total structure size, and it is more sensitive to displacement variations imposed on an object on which

the tags are placed. In this sense, mmWave chipless RFID tags pave the way for new implementations that improve displacement sensing capabilities.

Several types of displacement sensors based on chipless tags have been reported in the literature: phase acquisition in monostatic configuration [2], [3], round-trip time of flight [4], [5], angle-of-arrival AoA [6], angular rotation [7]. This paper proposes a distance calculation method based on phase measurement that provides a sub-millimeter positioning accuracy for millimeter wave chipless RFID tag in an office environment. The feasibility of a displacement sensor in which the position is evaluated considering the tag resonance frequency in a bistatic configuration. Furthermore, practical implementation issues considering the bistatic configuration are assessed. The scatterer used for the design of this paper is an E-shape tag [1]. It is a single-layer structure, potentially compatible with a low-cost printing process.

## II. DISPLACEMENT SENSOR BASED ON MMWAVE CHIPLESS RFID TAG

The tag backscattering response retrieves the signal complex information. Additionally, the phase information from the backscattering response measured by the reader contains the tag information and the multiple paths clutter contributions. Therefore, it is necessary to separate the useful part of the signal (tag phase contribution) from the other clutter contributions. In this context of mmWave communications, where the signal wavelength is generally much lower than the size of the surrounding objects, the objects mainly scatter a high quasi-optic mode. Indeed, when the tag orientation is located in the plane perpendicular to the incident wave, quasi-optic reflections are backscattered in the same direction of the excitation, contrary to the resonant mode that will be backscattered in different directions [8]. So, bistatic reading configuration considering an angle between the two antennas allows isolating the contribution of the RFID chipless tag from its nearby environment.

A one-resonance frequency tag has been fabricated to assess the proposed method's effectiveness. Notably, a structure without a ground plane requires only one conductive layer, which makes it compatible with direct printing processes on the product. The E-shape scatter is shown in Fig. 1(a), the substrate used is the Rogers RT5880 with  $\tan \delta = 0.0009$ , permittivity  $\epsilon_r = 2.2$ , copper cladding  $t = 50 \mu\text{m}$  and substrate thickness  $h_s = 127 \mu\text{m}$ . Two main parameters drive

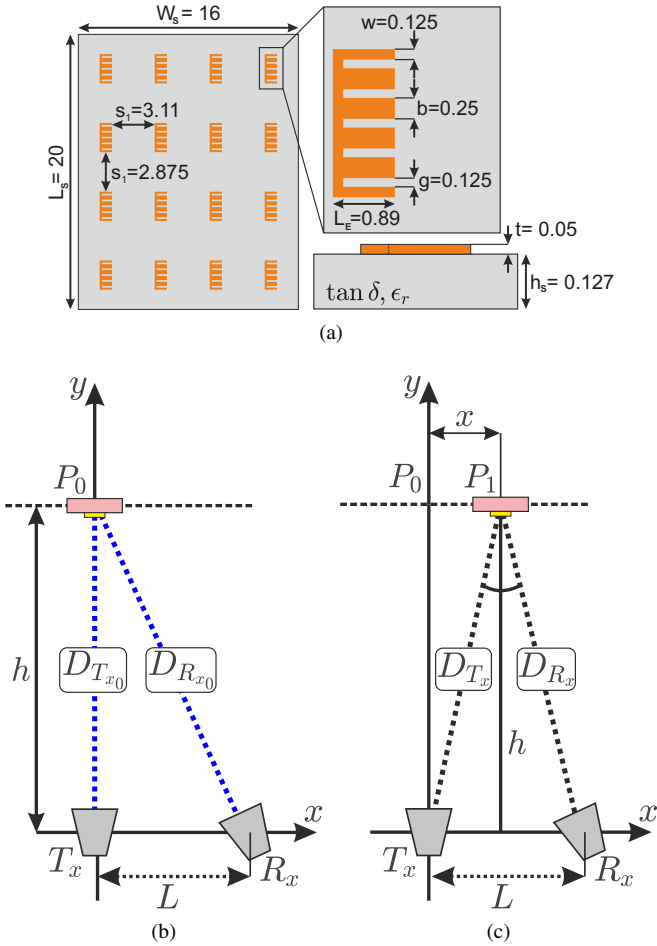


Fig. 1. Geometrical parameters associated with bistatic configuration for tag reading. The  $T_x$  and  $R_x$  are positioned at  $(x_{T_x}, y_{T_x})$  and  $(x_{R_x}, y_{R_x})$ , respectively. The tag is located at  $(x, y)$ . (a) mmWave chipless tag for location sensing applications. Multiple resonators are used to increase the RCS scatter level. All the dimensions are in millimeters. (b) Initial position, *i.e.*, the reference position. (c) The tag was moved by a distance  $x$ .

the EM tag resonant response: the spacing between the two arms  $g$  and the length  $L_E$ . The tag is composed of multiple E-shape structures, the model of the backscattered phase by tag structure is represented as a single target since each E-shape element has approximately the same frequency.

#### A. Bistatic configuration geometry

Bistatic co-polarization configuration improves the signal-to-noise since transmitted wavelength values are much smaller than the object's size. It is important to note that it is possible to read tags even in highly reflective environments without a calibration method. The bistatic setup is shown in Fig. 1(b)-(c).  $L$  and  $h$  express the bistatic angle between the transmission and reception antenna.  $D_{T_x}$  and  $D_{R_x}$  are the distances from  $T_x$  and  $R_x$  antennas to the tag.

#### B. Bistatic chipless tag displacement method

The tag moves along the  $x$ -axis as shown in Fig. 1(b)-(c).  $x$  is noted for this displacement, and the objective of the approach is to show that this displacement can be extracted

from the measurement of the phase of the field backscattered by the tag. As in [2], we are only interested in the resonant frequencies of the scatters that made the tag. To obtain  $x$ , a reference position ( $x = 0$ ), with  $SD_{x=0} = D_{T_{x_0}} + D_{R_{x_0}}$  is used as shown in Fig. 1(b) for which we have the measurement  $\angle S_{21_{x=0}}$ . When the tag moves, the optical path between the two antennas in relation to the tag ( $SD_x = D_{T_x} + D_{R_x}$ ) changes and a new S-parameter  $\angle S_{21_x}$  can be measured for a  $x$  position. The  $(T_x - \text{tag} - R_x)$  phase is relating to the distance  $(D_{T_x} + D_{R_x})$ . Then, the displacement  $x$  is proportional to the phase difference between the two positions. It is expressed by,

$$SD_x = \frac{1}{2k_r} \left( \frac{\angle S_{21_x}(f_r)}{\angle S_{21_{x=0}}(f_r)} \right) + SD_{x=0}, \quad (1)$$

where  $k_r = 2\pi/\lambda_r$  with  $\lambda_r = c/f_r$  and  $f_r$  the resonance frequency of the tag, Considering the scheme shown in the Fig. 1, the relation between the unknown position ( $x$ ) and the geometrical parameters is expressed as,

$$D_{T_x} + D_{R_x} = \sqrt{x^2 + h^2} + \sqrt{(L-x)^2 + h^2}. \quad (2)$$

If  $L$  and  $h$  are known, we can solve the roots from (2),

$$x = \frac{SD_x \sqrt{(SD_x^2 - L^2)(SD_x^2 - 4h^2 - L^2)} - L(SD_x^2 + L^2)}{2(SD_x^2 - L^2)}. \quad (3)$$

Therefore, from two measurements and the *a priori* known of the tag position ( $x = 0$ ) for any tag displacement  $x$ , it is possible to extract the position with (3).

### III. EXPERIMENTAL SETUP AND MEASUREMENTS

The measurements were performed with an Agilent N5222A (0.01 GHz–26.5 GHz) PNA with Virginia Extensions (VDI modules) to operate from 65 GHz to 72 GHz and a power of 0 dBm. The VDI module is a frequency multiplier combined with a mixer with a WR<sub>15</sub> wave-guide output connected to horn antennas on co-polarization configuration with a gain 10 dBi. The measurement setup can be seen in Fig. 2. The tag is placed on foam support. The tag is positioned in a different  $x$  position for each measurement, and the backscatter complex signal for each tag position is enrolled. The tag has been moved with the help of a micrometer with a step of 30  $\mu\text{m}$  along a constant  $h$  position. The distance between the antennas  $L = 8.5$  cm and the distance to tag plan  $h = 13.3$  cm are established. Contrary to [2], the bistatic configuration in co-polarization is utilized without any calibration or post-processing to improve the tag response.

#### A. Experimental results

The frequency response of the magnitude  $|S_{21}|$  parameter is shown in Fig. 3(a) where the same resonance frequency is depicted for each position. For each phase measurement shown in Fig. 3(b), different phase shifts are noted.

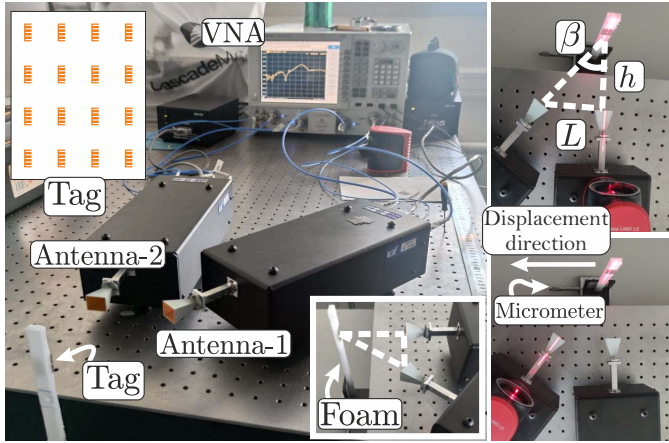
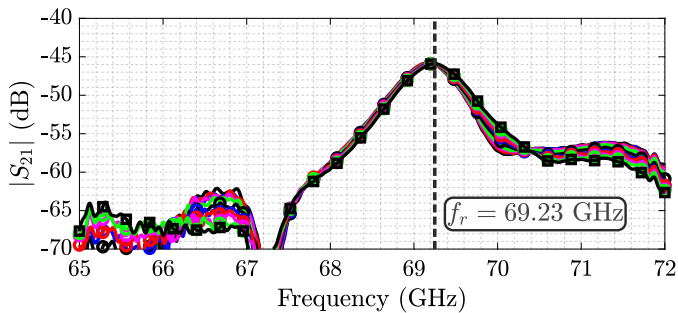
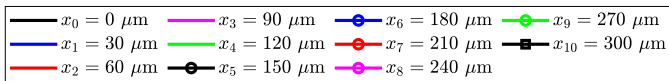
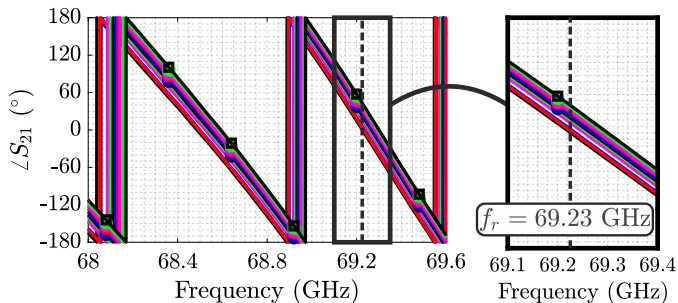


Fig. 2. Setup for V-band measurements in an office environment. Bistatic configuration is used, and both antennas have co-polarization orientation.



(a)



(b)

Fig. 3. Frequency domain response raw measurements for bistatic configuration  $|S_{21}|$  in (a) magnitude and (b) phase. A step of  $30 \mu\text{m}$  were adopted.

### B. Error estimation

The results of the extracted displacements with (3) and the results shown in Fig. 3(b) are given in Fig. 4. The extracted tag positions are close to the actual positions. However, some deviations appear when the positions are evaluated from  $30 \mu\text{m}$  to  $150 \mu\text{m}$ . Some misalignment can introduce these errors in the setup measurement. From  $180 \mu\text{m}$  to  $300 \mu\text{m}$ , the measured results agree well with the extracted results. The deviation between measured and calculated results depends

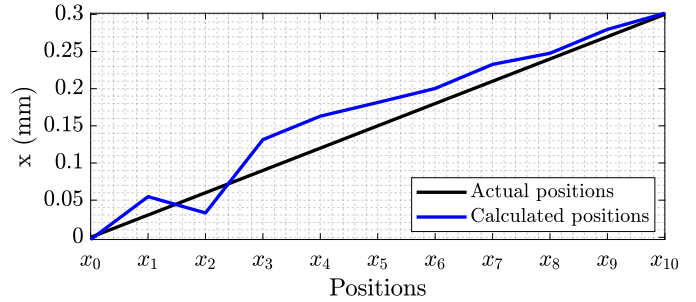


Fig. 4. The comparison between extracted displacement with (3) and actual positions.

TABLE I  
COMPARISON BETWEEN CHIPLESS DISPLACEMENT SENSOR APPLICATIONS.

Reference	Configuration	Step	Mean error
[2]	Monostatic	0.5 mm	0.045 mm
[3]	Monostatic	10 mm	4 mm
[4]	Multistatic	10 cm	2 cm
[5]	Monostatic	10 cm	0.2 cm
<b>This work</b>	Bistatic	$30 \mu\text{m}$	$5 \mu\text{m}$

on the distance between the antennas and the tag. In the calculation model, the distance between the antennas and tag plan is defined as the length  $h$ . Thus, when the distance  $h$  increases, the measured results match the calculation for values below  $150 \mu\text{m}$ . However, the supposed position relations to the calculation model between the distances cannot be held, which yields geometrical value deviations.

The proposed method is compared with different sensor application techniques in terms of configuration, resolution, and displacement error in Table I. Considering all the points over the calculated displacement, an error around  $5 \mu\text{m}$  is highlighted. It is a promising result when the results are compared to other chipless tag sensor applications.

### IV. CONCLUSION

A technique based on phase measurement considering bistatic configuration is proposed to accurately identify and locate mmWave chipless RFID tags. A bistatic configuration that enables the tag signal extraction is implemented from a hardware point of view; thus, no calibration is needed. A frequency mmWave chipless RFID tag is designed and fabricated with potential low-cost printing techniques. The distance between the tag and antennas is calculated by two-phase measurements and *a priori* known measurement geometry. Thus, a simple analytical expression can obtain the tag's position. An error around  $5 \mu\text{m}$  is found when displacements of  $30 \mu\text{m}$  are applied.

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