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***Abstract*—The paper provides a first theoretical study on the effect of rotational Doppler on circularly polarized pulsed communication. Despite the circularly polarized communication being considered immune to signal fading due to rotary misalignment, such misalignment will cause a frequency-invariant phase-shift. This phase shift will significantly distort the shape of the time-domain pulse. The property can be used for integration of orientation sensing into well establish pulse-based localization. However, it has also the potential to distort communication for some pulse-modulated UWB systems.**

Keywords*—*Ultra-Wideband; UWB; Pulse modulation; Circular Polarization; Localization; Wireless sensing

I. INTRODUCTION

Circularly Polarized (CP) antennas have been long used for communication between rotating objects (e.g. satellite communication, RFID) as they are immune to polarization losses due to misalignment [1]. In the presence of a rotation between transmitter and receiver antennas, the amplitude of the CP signal is not affected; however its phase will change proportionally to the rotation angle – a phenomena known as the rotational Doppler Effect [2]. A recent study demonstrated that the phenomena can be used to accurately measure rotational speeds of various devices, with very high dynamic range [3]. For instance: a rotating speed of 600M RPM (which was reported in [4] as the fastest man-made rotating object) would produce a frequency shift of 10 MHz, which falls well within measurement capabilities of state-of-the-art RF measurement equipment.

While the single-frequency signal allows measurement of rotating objects at a fixed-distance, it fails for more dynamic cases since the system cannot distinguish whether the phase shift originated from rotational or linear movement. However, contrary to the translational Doppler effect, the rotational case is frequency invariant, i.e. rotation by an angle α will produce a frequency shift of α at all frequencies (assuming the conditions for CP are satisfied) [5]. This property was used for dual-frequency implementation that allows simultaneous measurement of rotation and distance change [6]. However due to the lack of redundancy the technique was prone to errors.

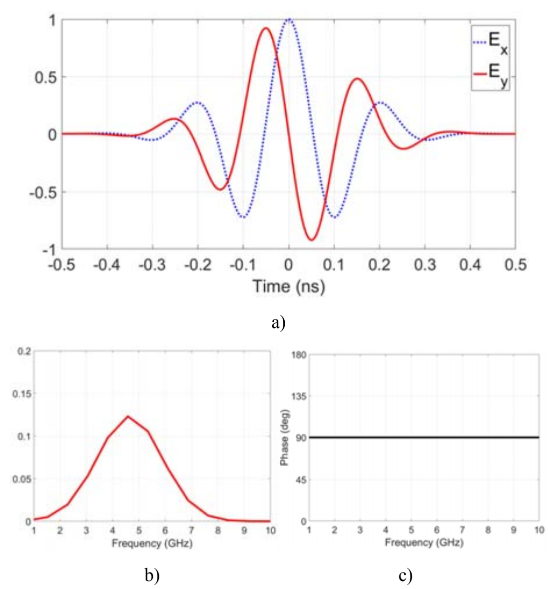

Fig. 1: E_x and E_y components of the CP Gaussian pulse: a) time-domain; b) amplitude of the spectrum; c) phase difference between E_x and E_y spectrum

This paper investigates for the first time the use of Ultra-Wide Band (UWB) time-domain CP pulses [7] for measurement of the rotation. It provides a first theoretical study on how rotation influences the shape of UWB pulses and – most importantly – that such influence is significantly different from the one experienced by distance change. Since UWB pulses have been extensively used for accurate localization with <20 cm resolution [8], the implementation of rotation sensing based on the same technology is very attractive, due to easy integration capabilities.

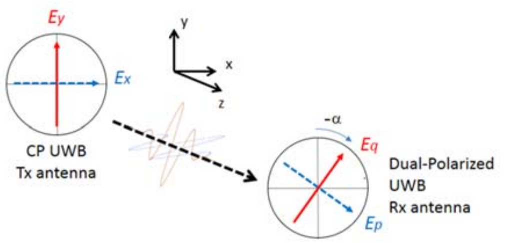

Fig. 2: Investigated scenario

II. Mathematical model

Fig. 1 demonstrates the two orthogonal components of a CP Gaussian pulse, representing frequencies from 3.2 to 6.2 GHz. This corresponds to the 3dB Axial Ratio (AR) band of the antenna proposed in [9]. It was ensured that the spectrum of E_x and E_y components have the same amplitudes and are shifted in phase by 90°, thus providing an AR = 0 at all investigated frequencies.

Fig. 2 depicts the investigated scenario. The transmit antenna is an UWB CP antenna, transmitting the pulse with component E_x and E_y. The receive antenna is dual linearly-polarized, measuring independently two orthogonal components E_p and E_q, which lie in the plane orthogonal to the propagation direction of the pulse. The measured components E_p and E_q are rotated with respect to E_x and E_y by angle α. This can be described as:

$$\begin{bmatrix} E_p \\ E_q \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} E_x \\ E_y \end{bmatrix} \quad (1)$$

III. Pulse distortion

Based on (1) the shape of the pulse was calculated for various rotations α in negative direction from -60° to -360° in 60° steps. Fig. 3a shows the shape of the pulses received by the detector measuring the E_p component, while Fig 3b – E_q component. It can be seen, that the rotational Doppler Effect causes modulation which significantly changes pulse's shape. This distortion is unique to rotary movement and is significantly different from time-delay caused by distance travelled (used in localization applications) and from shortened/prolonged pulse due to the translational Doppler Effect. While facilitating simultaneous measurement of orientation and localization

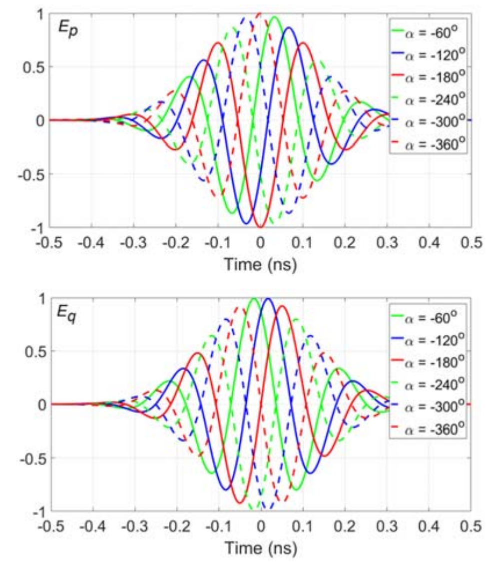

Fig. 3: E_p and E_q components of received pulses as a function of α

integrated into a single UWB tag, the demonstrated pulse distortion may also impede communication when certain pulse-modulation techniques are used on rotating platforms (e.g. pulsed satellite communication).

IV. Conclusions

The paper demonstrates theoretically the impact of rotary movement on UWB CP pulse. It shows a significant distortion of such pulse, which is caused by a frequency-invariant phase shift due to rotational Doppler Effect.

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