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Dual-Polarized Through-Wall Repeater for the Wireless Reading of Millimeter-wave Passive Sensors

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Abstract— This paper reports the reading of passive and chipless millimeter-wave sensors using a dual-polarized through-wall repeater. The reader is here a millimeter-wave Frequency-Modulated Continuous-Wave Radar, and the batteryless sensor corresponds to a chipless sensing device whose cross-polarized electromagnetic reflectivity depends on the applied pressure. The proposed dual-polarized repeater allows transmitting two different electric field polarizations, depending on the direction of the transmission. The feasibility of through-wall reading of sensors is demonstrated here at 24GHz from a passive pressure sensing device.

Keywords— *passive repeater, dual polarization, millimeter-wave, wireless and passive sensors, pressure sensors*

I. INTRODUCTION

Millimeter-wave (mm-wave) Frequency-Modulated Continuous-Wave (FMCW) radar can be advantageously used for the detection and the reading of batteryless (passive), chipless and wireless sensors [1]. From three-dimensional radar imaging techniques, mm-wave FMCW radar allows wirelessly interrogating these sensors, even in highly reflective environments [2]. Mitigation of electromagnetic (EM) clutter in multipath environments can be efficiently achieved from using depolarizing mm-wave passive sensors (see, e.g., [3] for the remote measurement of humidity up to 50 m). The cross-polarized EM reflectivity of these sensors – or equivalently, the magnitude of the cross-polarized electric field backscattered by the sensors– depends on the physical (or chemical) quantity of interest and consequently, this quantity may be remotely derived from the direct measurement of the cross-polarized backscattered electric field.

Many Structure Health Monitoring (SHM) applications require short-range (i.e., few meters) interrogation of sensors placed inside metallic cavities or pipes. For such closed and confined environments, passive repeaters could be used for transmitting the mm-wave EM field through the wall of cavities and interrogate sensors. Such well-known repeaters have been applied to improve the indoor coverage of wireless networks [4], ensure through-wall digital communications [5], or else, enhance the Tx-to-Rx antenna isolation [6]. Up to now, through-wall repeaters are mono-polarized, that is, the polarization of the transmitted electric field is identical when crossing the wall from one side to the other side of the wall, regardless of transmission direction. For through-wall interrogation of depolarizing mm-wave sensors, dual-

polarized repeaters are needed. For the repeaters proposed here, the polarization of the transmitted electric field depends on the transmission direction. In this paper, the feasibility of through-wall reading of sensors is demonstrated at 24GHz from a passive pressure sensing device and a dual-polarized passive repeater using orthogonal polarization.

II. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental setup is illustrated in Fig. 1. All antennas are here horn antennas of gain 20 dBi and operating at 24 GHz. The incident vertical-polarized (V-polarized) electric field is radiated by the Tx-antenna of the 24GHz FMCW Radar (bandwidth = 2GHz and repetition time = 50ms). The passive repeater transmits this V-polarized field from one side of the metallic plate to the other side. The passive pressure sensor receives the transmitted field, and reradiates an horizontal-polarized (H-polarized) electric field whose magnitude depends on the pressure at the sensor location. Next, this field is received by the H-polarized Rx-antenna of the repeater, passes through the metallic plate, is reradiated and finally received by the H-polarized Rx-antenna of the mm-wave Radar (this set up can also use only the V-polarized EM field from rotating all H-polarized horn antennas by 90°). The transmission lines between the repeater antennas are short coaxial cables.

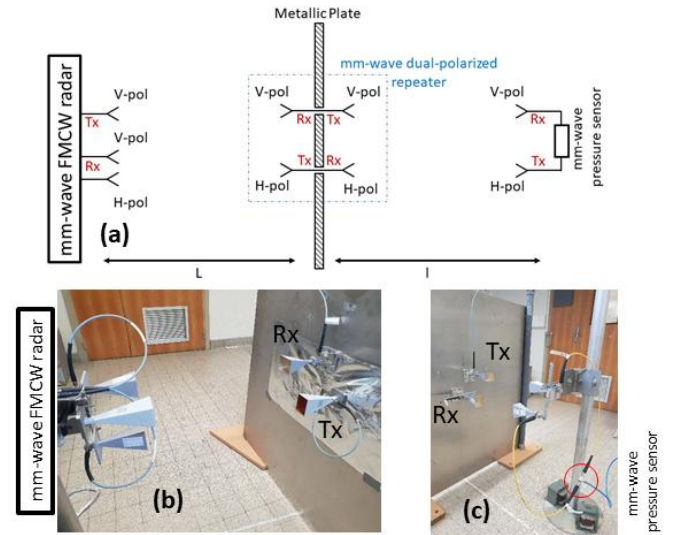


Fig. 1. (a) Experimental setup schematic with the 24GHz FMCW Radar, the dual-polarized passive repeater, the metallic plate (thickness = 2 mm) and the mm-wave passive and wireless pressure sensor ($L = 0.5$ m and $l = 0.45$ m); (b)

picture of the side containing the radar reader and (c) picture of the side containing the passive pressure sensor

The pressure sensor is a two-port network (see [2] for details on this sensor). It consists of a silicon membrane and a half-wavelength parallel-edge coupled-line microstrip resonator operating in the radar band and placed inside a cavity. When a pressure is applied on the membrane, a deformation occurs and causes a variation of the transmission coefficient of the two-port resonator (Fig. 2(b) gives the measured attenuation on the field propagating through the two-port sensor at 23.8 GHz as a function of the applied pressure). As a consequence, the magnitude of the cross-polarized reradiated EM field through the sensor depends also on the applied pressure in the radar frequency band.

As a first experiment, the sensing device is replaced by an adjustable attenuator in order to determine the maximal achievable full-scale measurement range. For a given attenuation, the mean value of the echo level (that is, the magnitude of the beat frequency of the sensor) is computed from 100 measured echoes. As shown in Fig. 2 (a), for attenuation between 0dB and 17.5dB, the echo level depends linearly on the attenuation (the coefficient of determination R^2 of the linear regression is of 0.99). For comparison purposes, it may allow the measurement of an applied pressure from 0 to 2.5 bars in a range of attenuation $\Delta=5$ dB (see the two-port sensor characteristics in Fig. 2(b)).

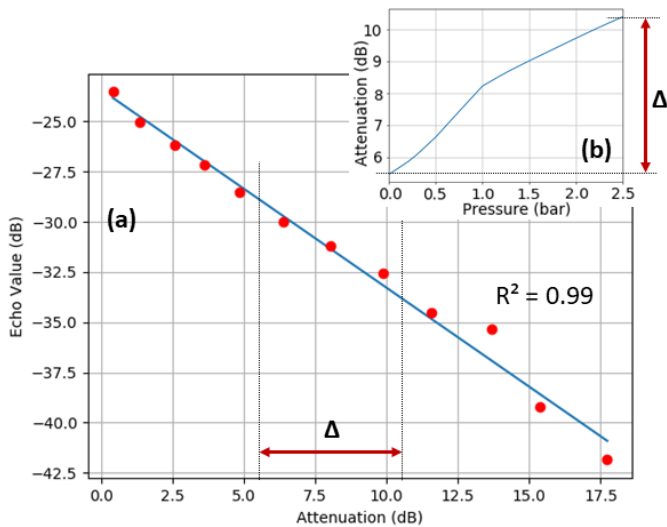


Fig. 2. (a) Measured amplitude of the beat frequency (echo level) as a function of the attenuation when using the dual-polarized repeater shown in Fig.1 and a variable attenuator; (b) measured attenuation on the field propagating through the two-port sensor at 23.8 GHz for applied pressure ranging from 0 to 2.5 bar.

Fig. 3 reports the variation of the echo level (or amplitude of the beat frequency) as a function of the pressure at the location of the sensor. As expected, this level depends linearly on the applied pressure (the coefficient of determination R^2 of the linear regression is of 0.95). The full-scale measurement range (or dynamics) is of 4dB for an applied pressure ranging from 0 to 2.5 bars. Measurement uncertainty on the echo level is of 0.4dB and corresponds to an uncertainty of 0.25 bar on

the pressure and consequently a precision of 10%. These experimental results demonstrate the feasibility of through-wall reading of passive depolarizing sensors at 24GHz.

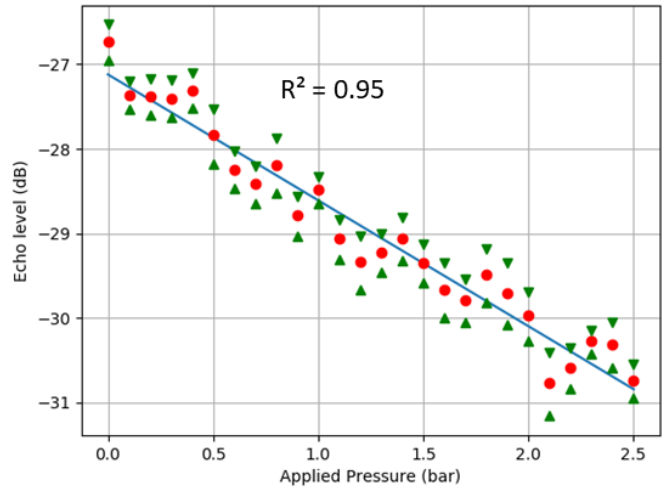


Fig.3. Measured amplitude of the beat frequency (echo level) as a function of the pressure at the location of the pressure sensor (red points). The coefficient of determination R^2 of the linear regression is of 0.95 (in blue). Standard deviations are sketched in green

III. CONCLUSION

This paper has reported the reading feasibility of passive and chipless millimeter-wave sensors using a dual-polarized through-wall repeater. These repeaters allows transmitting two orthogonal electric field polarizations, depending on the transmission direction. Further work will be focused on the miniaturization of this new class of repeater, and their use in the through-wall interrogation of passive millimeter-wave sensors in highly cluttered environments.

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