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Passive and chipless packaged sensor for the wireless pressure monitoring in harsh environment

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Summary

A new millimetre-wave passive and chipless packaged sensor for wireless pressure monitoring in harsh environment is proposed. This sensor uses a planar microstrip resonator coupled with a high resistivity silicon membrane. The remote interrogation of this sensor is performed from a Frequency-Modulated Continuous-Wave (FMCW) radar. Prototypes have been designed and fabricated using photoresist intermediate layer for the silicon membrane bonding. Radar measurements on two sensors validate a 6dB full-scale response for 1.4 bar overpressure. Depression measurements demonstrate the transducer hermeticity and a measured sensitivity of 1.6% per bar on the millimetre-wave resonant frequency.

Motivation and results

Wireless, batteryless and chipless (without electronic circuit) sensors are a promising solution for the remote measurement of physical quantities in high radiation or extreme temperature environment or/and when the battery replacement is difficult or induces high costs. Electromagnetic sensors at millimetre-wave frequency are good candidates and the authors have demonstrated the proof-of-concept from several transducers [1] using Frequency-Modulated Continuous-Wave (FMCW) radar interrogation up to 58 meters [2-3].

In this communication, the authors focus on a practical application case in which pressure is monitored in nuclear plant building. The objective is to validate a packaged transducer that fits the pressure specification ($\cong 1.4$ bar of overpressure) and operates in the frequency band of our radar (22.8GHz/24.8GHz). In our previous studies, we used a coplanar waveguide (CPW) microwave resonator whose resonant frequency was modified by the displacement of a silicon membrane. However, this configuration required a CPW-to-microstrip line transition (Figure 1) which creates undesirable spurious modes. By removing this transition we show here the possibility to reach a full-scale radar response up to 10dB (Figure 2).

The new design of the transducer with microstrip resonator is shown in Figure 3 and Figure 4. A 0.5 μm thick aluminium layer is used to fabricate a half-wavelength coupled line resonator on a 500 μm thick borosilicate glass wafer. A 100 μm thick high resistivity silicon membrane is then bonded over the resonator using low-loss photoresist ($\cong 10\mu\text{m}$ thick). This bonding solution allows a quite simple process providing a sufficient hermeticity for experimentally validating the prototype performances.

The simulated transducer response is given in Figure 5 where the resonant frequency shift is plotted versus the distance between the silicon membrane and the resonator. The electromagnetic simulation was performed assuming a planar silicon membrane deflection. For the full-scale pressure, a 9 μm membrane deflection is expected leading to a resonant frequency shift of 9%. Transducers were fabricated using two different photoresist thicknesses (12 μm and 3 μm) and allow validating a 6dB full-scale radar measurement range (Table 1).

Figure 6 shows the fabricated transducer inside its packaging. The reflection coefficient parameter S_{11} is measured in a controlled vacuum chamber in order to check the hermeticity of the transducer (Figure 7). Figure 8 shows that the resonant frequency shift depends quasi-linearly on the depression with a sensitivity of 1.6%/bar up to 1 bar. The next steps will be the radar measurements under overpressure indoor and then outdoor.

Word count: 488

References

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- [3] D. Henry and al.: Long Range Wireless Interrogation of Passive Humidity Sensors using Van-Atta Cross-Polarization Effect and 3D Beam Scanning Analysis, *IEEE International Microwave Symposium, June 2017, Honolulu, Hawaii*.

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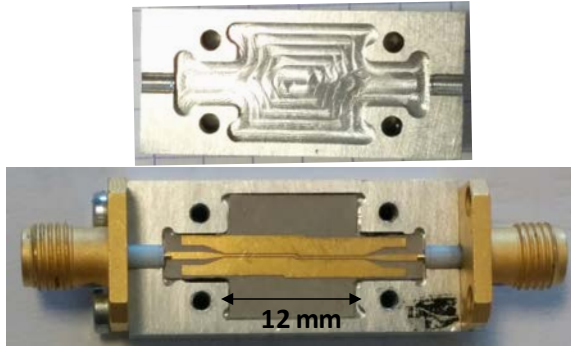


Figure 1: View of microstrip/CPW line inside the packaging (bottom) and packaging cover (top)

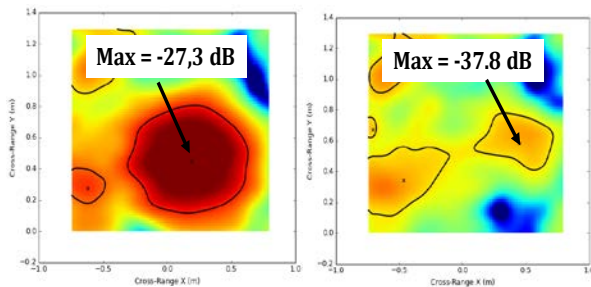


Figure 2: Cut-planes of a 3D millimeter-wave radar image obtained from a packaged 50Ω microstrip line loaded by a short-circuit (left) and by the 50Ω matched impedance (right)

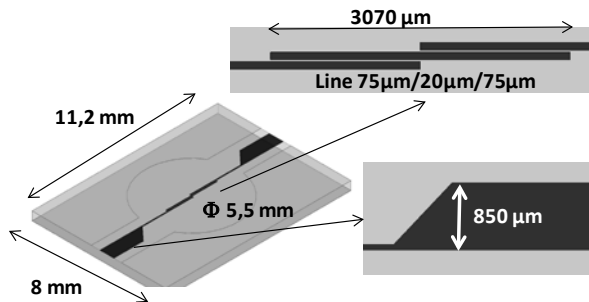


Figure 3: Dimensions of the microstrip planar resonator

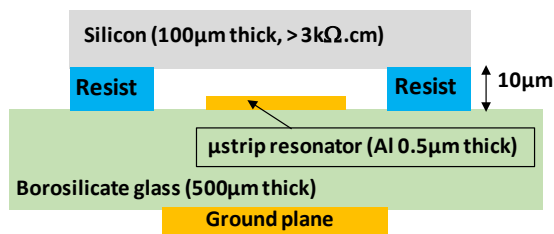


Figure 4: View of sensor layers

Table 1: Shift of the reflection coefficient S_{11} at the input of the planar resonator and radar echo amplitude between two [silicon membrane / resonator] distances (12μm and 3μm)

Shift of S_{11} @ 23.8 GHz	4.8 dB
Shift of S_{11} in [22.8GHz/24.8GHz] band	5.9 dB
Shift of radar echo	6.1 dB

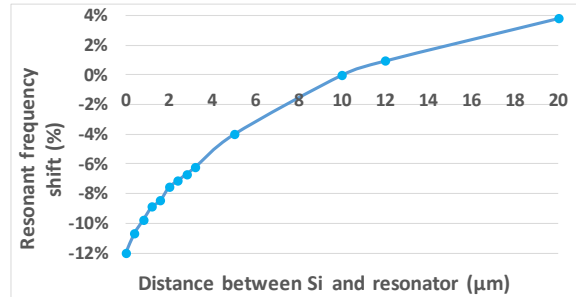


Figure 5: Simulated resonant frequency shift versus the distance between the Si membrane and the planar resonator

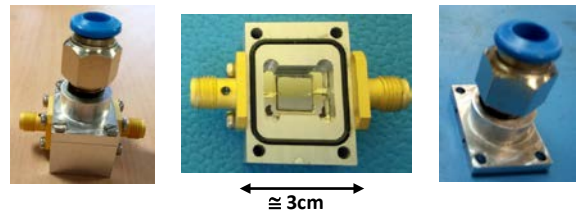


Figure 6: View of the packaged sensor

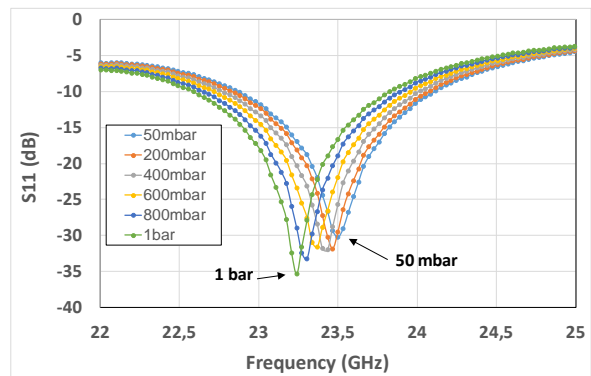


Figure 7: Measured S_{11} parameter versus frequency for various depressions from 50mbar to 1 bar

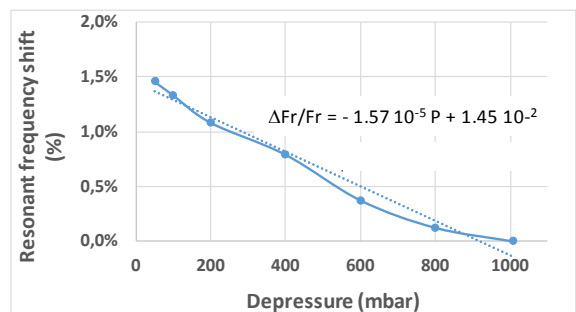


Figure 8: Measured resonant frequency shift versus depression

Topic : Sensors for factory of the future