AN ICE DETECTION SYSTEM BASED ON A GRAPHENE PLANAR CAPACITIVE SENSOR

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Accurate ice detection is critical in many contexts, such as roads, infrastructure, aerospace, photovoltaic systems, and weathered surfaces. Early detection helps prevent damage or dangerous situations. In this context, an innovative capacitive sensor based on a composite material, a strip of graphene (95 %) and polyurethane (5 %) nanopatterns, is proposed with a compact, inexpensive and easily scalable monitoring system [1].

The sensor is built according to a multi-gap architecture: three strips, acting as armatures, form two planar capacitors with different gaps (0.4 mm for GAP-1 and 1.6 mm for GAP-2), as shown in Fig.1. Each gap generates a capacitance composed of two components: an internal one, which is independent of the external environment, and an external one, which is sensitive to the change in the dielectric constant of the overlying materials. Since ice has a much higher dielectric constant than air, its presence causes an increase in fringe capacitance, which can be exploited for detection.

For signal readout, a noise-resistant conditioning circuit was developed based on the classical NE555 oscillator, as shown in Fig. 2a, which can convert the change in capacitance into a change in oscillation frequency. Each sensor capacitor (C_S) is flanked by a fixed ballast capacitance (C_B = 330 pF) and an R_2 resistor (different for each gap: 820 kΩ and 680 kΩ), forming an RC circuit whose charge/discharge time determines the frequency of the output square wave, following the equation :

$$f = \frac{1}{0{,}693(2R_2)C_T} \; where \; C_T = C_S + C_B \qquad (1)$$

This solution is a robust transmission ideal for distributed systems.

Tests showed a clear correlation between ice thickness and output frequency measured with the system shown in Fig. 2b: as thickness increases, capacitance increases and frequency decreases. This behavior confirms the sensitivity of the system to permittivity variation in the fringe electric field region. The measurements obtained, reported in Fig. 3, show a stable and consistent response between the two gaps, validating the operating principle.

The proposed sensor combines simplicity of construction, sensitivity, low cost and possibility of integration into distributed measurement networks. Using innovative materials and established circuits, it is a viable solution for environmental ice monitoring in various fields. Future developments will focus on optimizing sensitivity to detect different types of ice, extending the operating range, and integrating the system into smart infrastructures, with attention to resistance to electromagnetic disturbances.

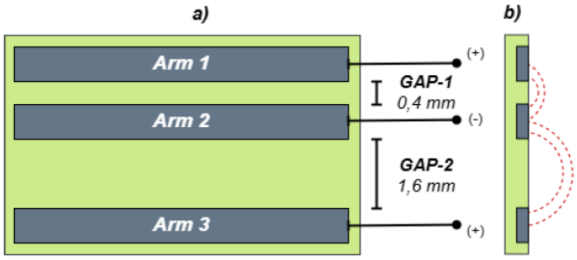
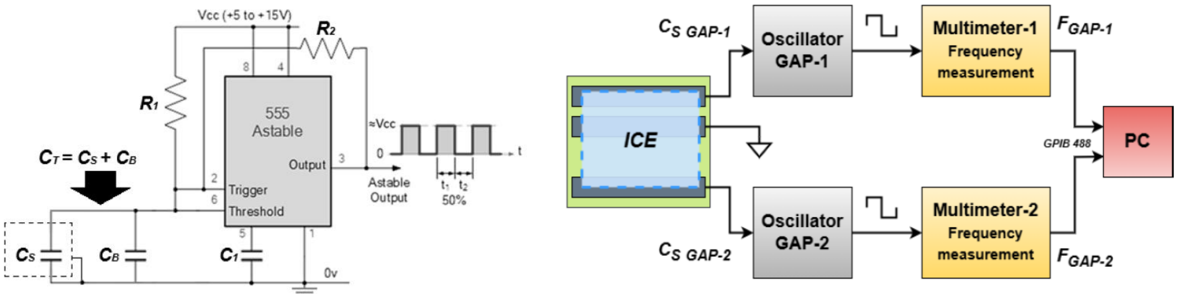
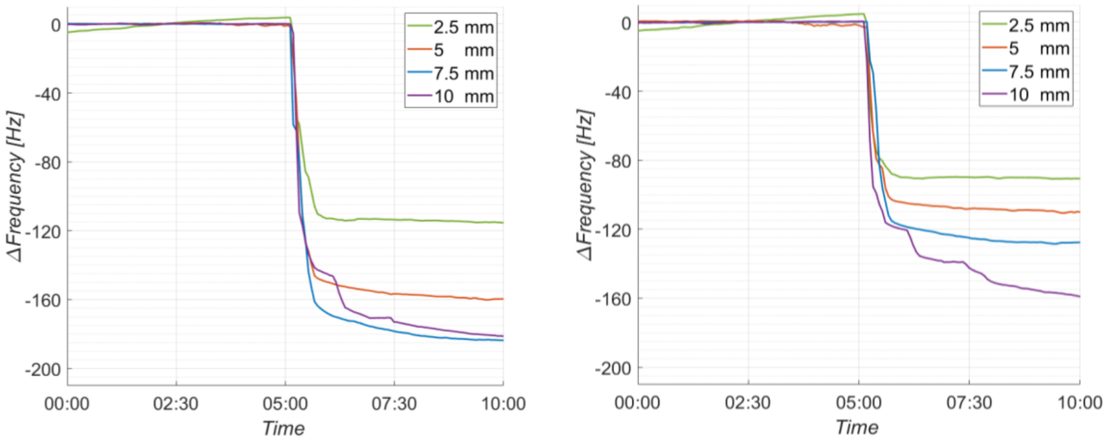


Fig.1 Top view (a) and side view (b) of the conceptual schematic of the planar capacitor. The side view qualitatively shows the lines of the fringe electric field between the capacitor arms (edge effect).



(a) (b)

Fig.2 Conditioning circuit used based on NE555 oscillator (a). In detail: C_S represents the capacitive sensor, and C_B is the ballast capacity for operating point selection. The dotted line around C_S represents the shielding. Block diagram of the implemented measurement setup (b). The system inputs the GAP capacitances and outputs the related oscillation frequency.



(a) (b)

Fig.3 Trend of the oscillation frequency output from the GAP-1 oscillator (a) and from the GAP-2 oscillator (b), for each thickness tested. Responses are reported in terms of frequency change relative to the corresponding baseline, i.e. subtracting the average response relative to the first 5 minutes.

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