POLITECNICO DI TORINO
Repository ISTITUZIONALE

LP-WAN Nodes with Integrated Leaf Wetness Sensors

Original
LP-WAN Nodes with Integrated Leaf Wetness Sensors / Filipescu, E., Colucci, G.P., Mora Zoppi, J.C., Trinchero, D.. - ELETTRONICO. - (2024), pp. 135-139. (IEEE Conference on AgriFood Electronics (CAFE 2024) Xanthi (Gre) 26-28 September 2024) [10.1109/CAFE63183.2024.11069334].

Availability:
This version is available at: 11583/2991095 since: 2025-07-11T09:01:24Z

Publisher:
IEEE

Published
DOI:10.1109/CAFE63183.2024.11069334

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright
IEEE postprint/Author's Accepted Manuscript

©2024 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collecting works, for resale or lists, or reuse of any copyrighted component of this work in other works.

(Article begins on next page)

15 October 2026

LP-WAN nodes with integrated leaf wetness sensors

Elena Filipescu
iXem Labs - DET
Politecnico di Torino
Turin, Italy
elena.filipescu@polito.it

Giovanni Paolo Colucci
iXem Labs - DET
Politecnico di Torino
Turin, Italy
giovanni.colucci@polito.it

Juan Camilo Mora Zoppi
iXem Labs - DET
Politecnico di Torino
Turin, Italy
juan.morazoppi@polito.it

Daniele Trinchero
iXem Labs - DET
Politecnico di Torino
Turin, Italy
daniele.trinchero@polito.it

***Abstract*—This paper introduces an innovative Low-Power Wide-Area Network (LP-WAN) node, which integrates in a unique board a leaf wetness sensor (LWS), a microcontroller, a LoRa radio and a Planar Inverted-F Antenna (PIFA). Unlike the majority of traditional setups, where the node is an entity independent from the sensing unit (or units), connected to the node by external cables, our solution is more compact and highly resistant to possible damages. Moreover, it redefines the concept of weather station by using solely a capacitive leaf wetness sensor, which allows the leaf wetness duration (LWD) computation, pivotal for predicting and preventing several diseases like powdery mildew and downy mildew. The whole board was optimized by means of CST Studio simulations, including antenna simulations. After board realization, tests were done in anechoic chamber to prove the RF performance. The node configuration allows deployments within the crops, in any operational conditions, enhancing its portability, reducing its footprint, and simplifying installation. Initial results demonstrate adequate radio-frequency performance, compared to nodes with external antennas. Future works will explore energy consumption patterns over time and validate long-term packaging durability.**

***Index Terms*—Leaf wetness sensor, wireless sensor network, IoT, printed antennas, smart farming.**

I. Introduction

Traditional weather stations consist of multiple sensing units that measure several environmental parameters; the sensors are connected to a central node, usually a data logger or a wireless sensor network node. Among measured parameters, the most important one is the leaf wetness duration (LWD) [1], which is sufficient to model fungal infections, permitting the introduction of decision support systems (DSS) to predict and prevent diseases [2, 3], such as powdery mildew and downy mildew.

In recent years, advancements in sensor technology have led to the development of innovative leaf wetness sensors capable to provide precise and real-time data about wetness duration within crops. This allows for timely prevention and optimized irrigation practices. Additionally, they contribute to the implementation of sustainable agricultural practices by minimizing the use of water and pesticides, reducing the environmental impact.

This work was partially supported by PSR 2014-2020, Regione Piemonte, Operazione 16.1.1, "Integrated Tools for the Environmental Sustainability of the Vineyard" (SISAV) Project (CUP J66B20006500002); the European Union under the Italian National Recovery and Resilience Plan (PNRR) of Next-GenerationEU, partnership on "Telecommunications of the Future" (PE00000001 - program "RESTART") and the Agritech National Research Center (PNRR – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Fig. 1. Previous configuration for the WSN and LWS

Our research group [4] has been active for several years in the design and development of leaf wetness sensors and has proposed different solutions. Formerly, we proposed a microwave-based method [5], which was very precise but not suitable for Internet-of-Things (IoT) applications. More recently, we introduced a novel configuration applicable to low-power and low-cost leaf wetness sensors [6].

Very recently [7] we presented a complete design solution for an innovative capacitive leaf wetness sensor, which can be used as sensing unit by any wireless node, as shown in Fig. 1. In particular, a reading method based on a capacitance-to-digital converter (CDC), i.e. FDC2112 [8], allows to lower both production costs and power consumption. Tests over

months in the fields have demonstrated adequate and reliable performance, being able to detect wetness in several conditions, even when traditional indirect methods fail, i.e. the one based on the dew point calculation [9], especially in case of rainfalls or significant evapotranspiration.

Periodic calibrations in laboratory demonstrated the absence of significant drift in the measurements over time. The LWS was connected to a custom wireless sensor node (WSN) based on a microcontroller unit and a LoRa radio in the 868 MHz frequency band, exploiting its long-range capabilities, suitable in rural environments where the LTE coverage is limited.

Despite the several advantages, some unresolved issues remained:

- the sensing subsystem, containing the sensor and its reading circuit, is a separate entity from the node and requires a wired connection;
- the wire connecting the LWS and the node can be damaged by animals, accidental human intervention or weather events;
- the majority of commercial nodes implement an external antenna that can be damaged during maintenance operations, i.e. the battery replacement.

To face these drawbacks, we designed a simpler structure capable to integrate all components in a single board: the LWS, the microcontroller, the radio, the antenna and the power management, without the need of any external wires. To this purpose, the sensor and the antenna were designed together on the same board, that hosts also the microcontroller, the radio and the battery. This approach enhances portability, reduces footprint, and eliminates the requirement for an additional commercial external antenna.

II. Sensor Design

The capacitive leaf wetness sensor was designed according to the method published in [7], as a two-sided, four-layer printed circuit board (PCB), where both the upper and lower layers feature a quasi-circular pattern of alternate strips, as shown in Fig. 2, while the two intermediate layers have floating ground planes for separation. This setup forms two distributed capacitances, one on the top and one on the bottom layer, which vary depending on the surrounding medium's dielectric constant ϵ_r.

Through an analytical formulation fully described in [7], the sensor capacitance is predicted as a function of all the different physical parameters of the grounded coplanar waveguides (Fig. 3), such as the thickness of the electrodes (w), the distance between two adjacent electrodes (s), the number of electrodes, the type of dielectric medium and the PCB manufacturing parameters.

The simulation results were considered to dimension the conditioning circuit of the LC resonator of the FDC2112, that is in parallel with the sensor capacitance. In order to optimize the sensor excitation frequency range (10 kHz - 10 MHz), we computed the capacitance obtained for the case of wet surface, corresponding to the minimum frequency, and the dry case, corresponding to the maximum frequency. In

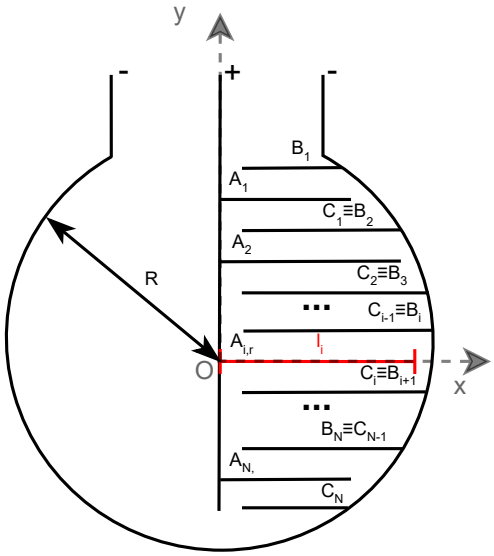

Fig. 2. Strips pattern [6]

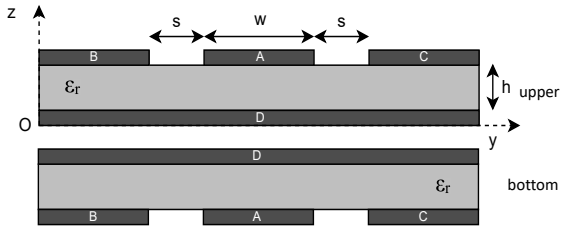

Fig. 3. Coplanar waveguide model for both leaf sides (modified from [7])

these conditions, we chose $L_c = 10mH$ and $C_c = 15pF$ for the conditioning circuit, which ensured to always get a read capacitance value within the FDC2112 sensing range. The output of the CDC is, therefore, $C_{tot} = C_c + C_{sens}$, where C_c is the capacitance value of the LC conditioning circuit and C_{sens} is the sensor capacitance. This final value was then converted into a leaf surface wetness (in percentage), through a calibration procedure, realized by measuring the sensor capacitance at known values of leaf wetness percentage.

III. Antenna Design

To maximize the compactness and ergonomics of the device, a planar antenna was designed on the very same board hosting the sensing units and the active components. For an effective choice, a planar inverted-F antenna (PIFA) was selected.

Various authors have investigated antenna integration in wireless sensor networks for diverse purposes, in particular microstrip patch antennas [10] for short-range applications or chip antennas [11] with insufficient operational coverage. For instance, in [12], an integrated antenna solution within an agricultural WSN was proposed. This demonstrated improved WSN performance through an ad-hoc integrated antenna,

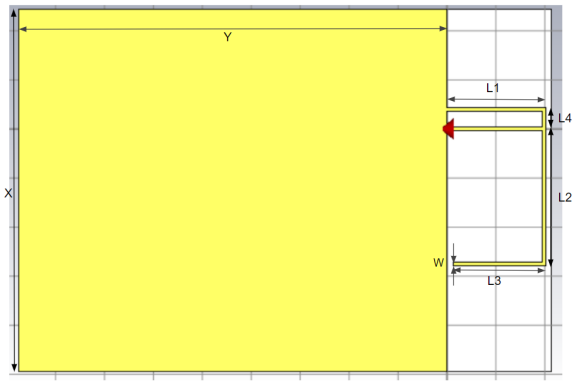

Fig. 4. Planar inverted-F antenna

TABLE I
DIMENSIONS OF PCB INVERTED-F ANTENNA

Parameter	Dimension (mm)
X	74
Y	87.5
L1	20.25
L2	28.34
L3	18.90
L4	3.97
W	0.8

TABLE II
COMPARISON BETWEEN SIMULATIONS RESULTS AND TESTS IN ANECHOIC CHAMBER FOR THE INVERTED-F ANTENNA

Test	Freq (MHz)	$S11_{min}$ (dB)	BW_{-10dB} (MHz)	Zin (Ω)	GMax (dBi)
Simul	867.6	-45.3	844-893	50.2	-
Chamber	869.5	-18.0	839-914	-	-1.02

based on a bowtie-shaped folded dipole (BSFD). Another work [13] detailed the development of a fully autonomous LoRa WSN with antennas in substrate integrated waveguides, specifically designed for human wearable applications, which differ from the rural context we are addressing. Despite the proposed solution is very effective for the specific application, it cannot work for an integration with a capacitive leaf wetness sensor board. Other authors explored research on integrating antennas with solar panels [14], or for RFID-enabled sensors [15].

PCB antennas were considered also by authors in [16], to provide an integrated wireless sensor node equipped with a Sigfox chip. A planar inverted-F antenna was used to enable RF energy harvesting of a wireless powered sensor node [17]. A flexible wireless sensor node was integrated with a meandered antenna for body area networks at 2.4 GHz [18].

Chip antennas available off the shelf, like the Linx ANT-868-uSP410, were discarded due to poor radiative capabilities, at least 7 dB less than the printed alternatives.

The methodology we have adopted to design the antenna consists in designing and simulating a PIFA with CST Studio, inserting in the model all PCB components, together with the sensing unit; after, the device was tested in an anechoic chamber for radiation pattern, resonant frequency, gain, and radiated power.

Design and dimensions for the selected antenna are presented in Fig. 4 and TABLE I. TABLE II compares the simulations results and tests in anechoic chamber (Fig. 5) for the selected topology of our PCB, proving the consistency of the antenna's behavior. The resulting radiation pattern is shown in Fig. 6, with a resonant frequency of $865\,\mathrm{mH}$ and maximum gain of $-1.02\,\mathrm{dBi}$. The ability to easily tune the antenna's input impedance by simply modifying the geometry of the short circuit stub, the relatively good omnidirectional radiation pattern and the opportunity to deploy components below the ground plane, confirm the antenna suitability for the desired application.

IV. BOARD INTEGRATION

The PCB for the proposed sensor node was drawn using Altium Designer and manufactured by Eurocircuits. The final PCB stack-up includes 4 conductive layers with board thickness $1.536\,\mathrm{mm}$ with a separation of $0.36\,\mathrm{mm}$ in prepreg between outermost layers and $0.71\,\mathrm{mm}$ in FR-4 between innermost layers. Fig. 7 shows the bottom layer of the final PCB.

The design features a single System on a Chip (SoC), i.e. the Murata Module 1SJ [19], which embeds both MCU (STM32L0 by STMicroelectronics) and LoRa radio (SX1262 by Semtech [20]).

The current solution involves power supply via a coin battery CR2450, which has a capacity of 540 mAh and a maximum continuous discharge current of 3 mA. Preliminary analyses indicate an operational lifespan of approximately three months. While this duration is sufficient to accommodate a broad spectrum of agricultural applications, our objective is to extend the battery life to five months. We are working towards this goal, possibly by reducing the measurement frequency or by using different measurement times throughout the day. This battery can be easily changed thanks to a new

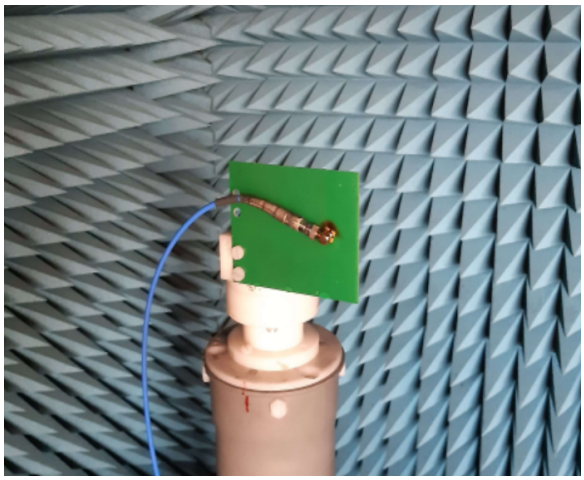

Fig. 5. Inverted F antenna tested in anechoic chamber

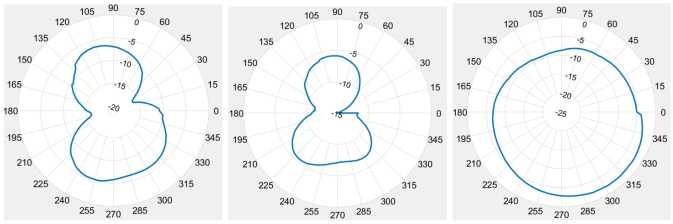

Fig. 6. Radiation pattern cuts: a) $\phi = 0$, b) $\phi = 90$, and c) $\theta = 90$

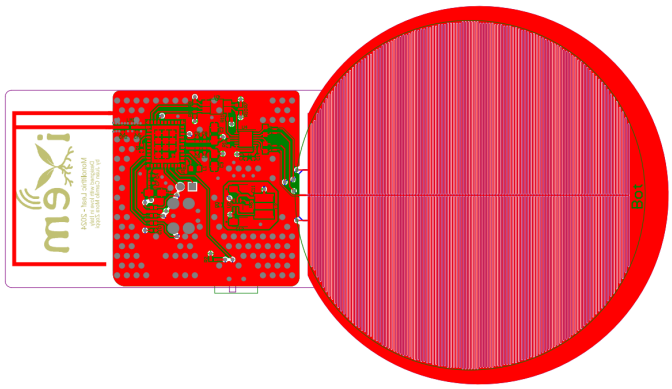

Fig. 7. Monolithic leaf PCB

3D printed box for the packaging, which can be opened when needed, while formerly, the PCB of the LWS was encapsulated into the box through resin to protect the circuit inside.

The PCB was also coated to protect the strips from atmospheric events or mechanical damages and inserted in a protective box, as shown in Fig. 8. As detailed in [7], the protective conformal coating has a negligible impact on sensor sensitivity, since its dielectric constant is comparable to that of the solder mask.

Additionally, including the MCU in the same PCB as the FDC2112 allows for further low-power optimizations through firmware.

V. Results

The sensor node with integrated antenna was installed in the field along with a legacy station using a separate capacitive leaf wetness sensor and an external antenna, with the purpose to test the performance of the integrated solution.

In Fig. 9 a comparison for the signal-noise-ratio (SNR) and received signal strength indicator (RSSI) is reported. The resulting average SNR and RSSI are shown in TABLE III. The higher value of SNR proves the better performance of our PCB antenna with respect to the commercial dipole.

TABLE III
AVERAGE SIGNAL CHARACTERISTICS COMPARISON BETWEEN INTEGRATED AND EXTERNAL ANTENNA

Antenna	Avg. SNR (dB)	Avg. RSSI (dBm)
Integrated	10.20	-90.7
External	5.33	-93.6

Fig. 8. Prototype of LWS

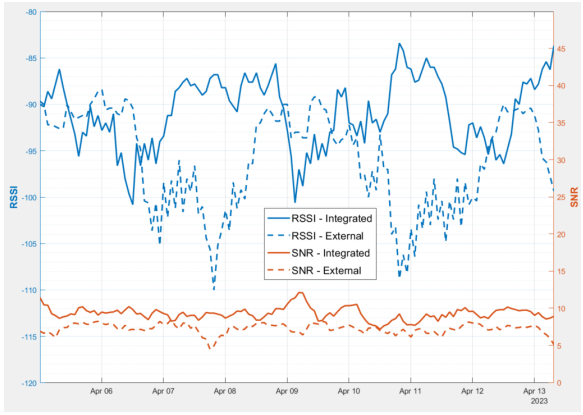

Fig. 9. RSSI and SNR comparison between integrated and external antenna

VI. Conclusion

An LP-WAN node featuring an integrated leaf wetness sensing unit has been proposed for an extremely compact, movable, ergonomic solution. Results demonstrated a better performance and space minimization.

This allowed to eliminate any external wire avoiding possible breaks and random damages. The integration of the node antenna on board has improved the robustness of the device.

Future steps to validate our solution include a long-term test on the field to prove the weatherproofness over time of the new package and energy consumption.

References

[1] Tracy Rowlandson et al. “Reconsidering Leaf Wetness Duration Determination for Plant Disease Management”. In: *Plant Disease* 99 (Mar. 2015), pp. 310–319. DOI: 10.1094/PDIS-05-14-0529-FE.

[2] D. Hoppmann and K.-P. Wittich. “Epidemiology-related modelling of the leaf-wetness duration as an alternative to measurements, taking Plasmopara viticola as an example / Epidemiologie-bezogene Modellierung der Blattnässedauer als Alternative zur Messung, gezeigt am Beispiel von Plasmopara viticola”. In: *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz / Journal of Plant Diseases and Protection* 104.6 (1997), pp. 533–

544. ISSN: 03408159, 23649968. URL: http://www.jstor.org/stable/43386523 (visited on 05/10/2024).

[3] Mark L. Gleason et al. "Obtaining weather data for input to crop disease-warning systems: leaf wetness duration as a case study". In: *Scientia Agricola* 65.spe (Dec. 2008), pp. 76–87. ISSN: 0103-9016. DOI: 10.1590/S0103-90162008000700013. URL: https://doi.org/10.1590/S0103-90162008000700013.

[4] URL: https://www.ixem.polito.it/.

[5] Elisa Pievanelli, Riccardo Stefanelli, and Daniele Trinchero. "Microwave-based leaf wetness detection in agricultural wireless sensor networks". In: *2016 IEEE Sensors Applications Symposium (SAS)*. 2016, pp. 1–4. DOI: 10.1109/SAS.2016.7479881.

[6] Elena Filipescu, Giovanni Paolo Colucci, and Daniele Trinchero. "Advances in Design and Construction of Leaf Wetness Sensors". In: *2023 IEEE Conference on AgriFood Electronics (CAFE)*. 2023, pp. 128–131. DOI: 10.1109/CAFE58535.2023.10291759.

[7] Elena Filipescu, Giovanni Paolo Colucci, and Daniele Trinchero. "Design and Implementation of a Capacitive Leaf Wetness Sensor Based on Capacitance-to-Digital Conversion". In: *IEEE Transactions on AgriFood Electronics* (2024), pp. 1–8. DOI: 10.1109/TAFE.2024.3401252.

[8] *FDC2x1x EMI-Resistant 28-Bit,12-Bit Capacitance-to-Digital Converter for Proximity and Level Sensing Applications*. SNOSCZ5A. Rev. A. Texas Instruments. June 2015.

[9] JULIUS F. BOSEN. "AN APPROXIMATION FORMULA TO COMPUTE RELATIVE HUMIDITY FROM DRY BULB AND DEW POINT TEMPERATURES". In: *Monthly Weather Review* 86.12 (1958), pp. 486–486. DOI: https://doi.org/10.1175/1520-0493(1958)086⟨0486:AAFTCR⟩2.0.CO;2. URL: https://journals.ametsoc.org/view/journals/mwre/86/12/1520-0493_1958_086_0486_aaftcr_2_0_co_2.xml.

[10] Abhinav Mishra, Azharuddin Khan, and S.K. Dubey. "Design of Compact Circular Shaped Slot Antenna for Wireless Sensor Networks". In: *2023 First International Conference on Microwave, Antenna and Communication (MAC)*. 2023, pp. 1–4. DOI: 10.1109/MAC58191.2023.10177115.

[11] Yuxiang Sun and Aydin Babakhani. "Wirelessly-Powered Dielectric Sensor With On-Chip Antennas in 180 nm SOI CMOS Process". In: *IEEE Sensors Journal* 19.7 (2019), pp. 2613–2620. DOI: 10.1109/JSEN.2018.2888620.

[12] Nuno Pires et al. "Design and Measurement of a Differential Printed Antenna for a Wireless Sensor Network Node". In: *IEEE Antennas and Wireless Propagation Letters* 16 (2017), pp. 2228–2231. DOI: 10.1109/LAWP.2017.2708742.

[13] Patrick Van Torre, Thomas Ameloot, and Hendrik Rogier. "Wearable 868 MHz LoRa Wireless Sensor Node on a Substrate-Integrated-Waveguide Antenna Platform". In: *2019 49th European Microwave Conference (EuMC)*. 2019, pp. 496–499. DOI: 10.23919/EuMC.2019.8910705.

[14] Terence Wu, Ronglin Li, and Manos. M. Tentzeris. "A Scalable Solar Antenna for Autonomous Integrated Wireless Sensor Nodes". In: *IEEE Antennas and Wireless Propagation Letters* 10 (2011), pp. 510–513. DOI: 10.1109/LAWP.2011.2152357.

[15] Amal Harrabi, Ali Gharsallah, and Manos M. Tentzeris. "Design of a miniaturized RFID antenna integrated with sensor for wireless agricultural applications". In: *2012 6th European Conference on Antennas and Propagation (EUCAP)*. 2012, pp. 3483–3486. DOI: 10.1109/EuCAP.2012.6206699.

[16] Laura Joris et al. "An Autonomous Sigfox Wireless Sensor Node for Environmental Monitoring". In: *IEEE Sensors Letters* 3.7 (2019), pp. 01–04. DOI: 10.1109/LSENS.2019.2924058.

[17] Salahuddin Raju et al. "A Self-Sustained Sensor Node through Far-Field Wireless Powering". In: *2019 IEEE Asia-Pacific Microwave Conference (APMC)*. 2019, pp. 1604–1606. DOI: 10.1109/APMC46564.2019.9038467.

[18] Mahmoud Wagih, Yang Wei, and Steve Beeby. "Flexible 2.4 GHz Node for Body Area Networks With a Compact High-Gain Planar Antenna". In: *IEEE Antennas and Wireless Propagation Letters* 18.1 (2019), pp. 49–53. DOI: 10.1109/LAWP.2018.2880490.

[19] URL: https://www.murata.com/en-eu/products/connectivitymodule/lpwa/overview/lineup/type-1sj.

[20] URL: https://semtech.my.salesforce.com/sfc/p/#E0000000JelG/a/2R000000Un7F/yT.fKdAr9ZAo3cJLc4F2cBdUsMftpT2vsOICP7NmvMo.