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Experimental Characterization of the Traveling Wave Strength in Modulated Microstrip-Line-Based High Impedance Surface through Infrared Thermography

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Abstract—**Preliminary experimental results on the measurements of the electric field strength dissipation in a width-modulated microstrip line based periodic structure are presented and discussed. The measurements are carried out using infrared sensors, and allow instantaneous visualization of the temperature with a high spatial and temporal resolution. The non-invasive technique is useful, for example in evaluating surface impedance, special features included in the sample or even defects and imperfections occurring during manufacturing, that can change the electromagnetic performances of devices, based on manipulation of surface current density, as in cloaking or other critical applications.**

Index Terms—**Caloric dissipation, High Impedance Surface, Experimental characterization, Periodic structure.**

I. INTRODUCTION

METAMATERIALS have been widely studied in the last years. Commonly they are based on periodic or quasi-periodic structures. Their 2D appearances, known as metasurfaces, are versatile structures that can also be used on conformal shells. Wave propagation along the surface, described in terms of surface waves, or across the surface, as in the case of Frequency Selective Surfaces, are their two main working scenarios. Such configurations present a large variety of uses in different applications as wavefront manipulation, realization of leaky wave antennas (LWA) [1], polarizer, cloaking [2], electromagnetic coupling reduction between devices sharing the same ground plane [3], or through free space interaction [4], etc. More recently tunable versions are largely studied, and the ability of such structures to perform mathematical computations are explored [5]. Incorporation of innovative materials in their structure is also a hot topic. Use of such complex materials, e.g., exhibiting phase change features, is exploited for example in [6] for image processing.

Their design has received a substantial attention including numerical optimizations to achieve specific performances, which in turn requires heavy computational effort. In some cases, analytic design has been reported [7]. However, the numerical analysis of their dispersive behavior is also very computational demanding [8]. Experimental verification in wide frequency bands is also very time consuming. This is even more significant when observation of the field strength in the largely extended structure is targeted. Depending on the application, bounded waves and/or leaking energy can be present; their observation is important to get insight of the propagation/radiation mechanism. High precision movement of the field sensors requires accurate control, and acquisition of large amount of data is also an issue.

To overcome some of the above mentioned difficulties, in the present work an infrared (IR) measurement technique is proposed for the quantification of the electric field strength effects of traveling waves. The considered support of the propagation is a widely extended periodic structure based on width-modulated microstrip line [7].

The work is structured as follows: After the general introduction in the present section, Sec. II presents a short description of the structure under investigation. The considered analysis technique for the investigations is briefly discussed in Sec. III. Performed measurements are described and the obtained experimental results are interpreted in Sec. IV. Finally some conclusions are drawn in Sec. V.

II. WIDTH-MODULATED LINE

The structure under investigation has been previously introduced in [7] and was already subjected to various studies in terms of design, numerical analysis, and practical applications as radial LWA [9] or coating of circular transverse section cylinders for cloaking purpose [10].

In the present study, a more detailed investigation is carried out targeting the understanding of the propagation mechanism of the surface current; the power dissipation is metered using IR measurements on a planar Cartesian appearance, allowing to see the field effect and the material behavior when the signal is applied along one of the lines with transverse periodic loading of similar conductors. The line is fed by an SMA connector that connects the structure to a radiofrequency power amplifier connected to the signal generator, while the second connector is left open. A vector network analyzer was also used, allowing measurement of the S21 transmission coefficient. The other lines of the periodic structure are in open circuit at both ends. To break the symmetry, the number of parallel lines around the fed one are intentionally different, as it can be observed in Fig. 1 that reports the photograph of the structure under test.

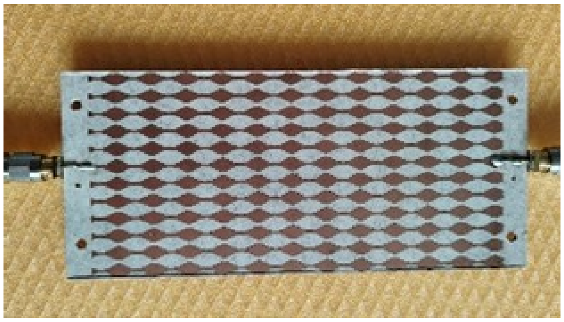

Fig. 1. Photograph of the analyzed structure with the soldered connectors.

III. Infrared Thermography Analysis

The electromagnetic loss may be quantified by means of IR spectrum emission captured by the camera's detector. However, without the complete knowledge of the emissivity of the structure under test, the limits of the thermal transformation quantification remain unknown [11]. From this perspective, at this point, the complete ability of the structure to emit energy by thermal radiation is not yet established.

IR thermography was successfully used for electromagnetic field effects identification and quantification starting from the end of 1980's [12]-[17]. Based on IR thermography, here we describe the surface heating map at the surface-air interface or close to it, without emissivity corrections applied. An IR camera - model Teledyn FLIR A700 with a thermal sensitivity of 40 mK - was used for the thermal analysis of the surface [18]. The IR detection range covers the range 7.5 to 14 µm wavelength. The camera was used in two configurations: with a macrolens (far field view) and with a microlens (allowing spatial resolutions as low as 8 μm). Recordings of the surface temperature increase when the line was excited with a continuous wave (CW) at 2.29 GHz with an input power of 8 W, were captured during a few tens of seconds. The FLIR Research Studio R&D Software allowed recordings at a rate of 30 frames/sec. Regions of interest (ROI) can be defined by the user (either surfaces or lines) and matrix data of each pixels' temperature dynamics may be recorded. Therefore, the position-time-temperature information may further provide a refined analysis of the caloric map, describing these "transducer" behavior of the investigated structure.

IV. Results and discussions

As a first assessment, the transmission coefficient S_{21} of the single line has been measured. In the Fig. 2 the sequence of pass-band (from 0 to 7 GHz), stop–band ($7 \approx 9.8$ GHz) and the following pass-band with leakage of the energy (decreasing amount of power arriving to port 2) can be identified.

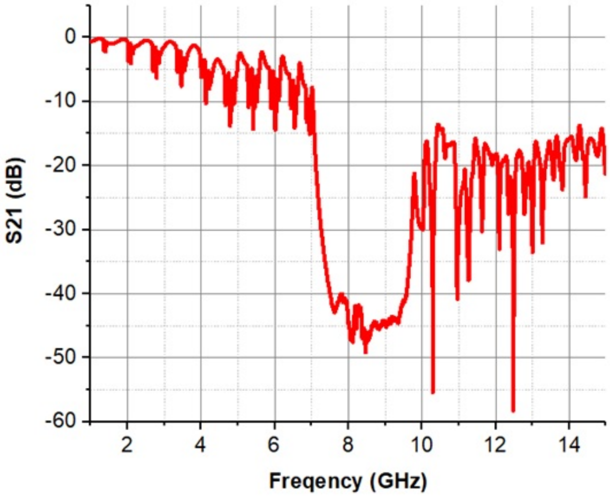

Fig. 2. Measured transmission scattering parameter of the structure

In the present investigation, aiming to get confidence with the measurements set-up and identify possible issues, the attention is focused on the behavior of the circuit in the first pass-band. Figure 3 reports a snapshot of the field distribution after 16 sec. of switch on the input signal at the frequency of 2.29 GHz. The shape of the guiding structure can be clearly identified. Moreover, the input signal is concentrated along the driven line since it represents a guiding structure for bounded waves from the input to the output.

As a further step, considering the higher resolution of the thermal camera (microlens mounted) the 2D thermal map in Fig. 4 has been recorded. It allows pixel-widely identifying of the temperature values on the surface of the geometry. The recorded temperature maps closely follow the geometry: the narrower line width, corresponding to a higher local impedance, will make the current path through a narrower metallization, giving rise to a higher current distribution. In turn this will determine higher local temperature, as it results form the longitudinal distribution in the top of the figure. One measurement is along the symmetry axis of the line, hence higher values of the currents are present. The second measurement have been performed considering a small lateral shift. Lower values but similar behavior can be observed. Along the transverse direction, the measurements put in evidence the high current in correspondence to the narrow line (single green peak on the right plot), and the divergent field behavior near the edges, represented by the two local maxima along a transverse section in correspondence of the wide width.

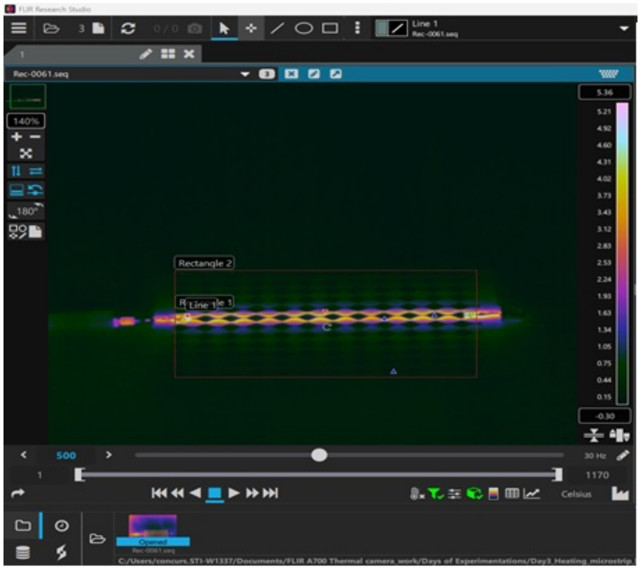

Fig. 3. Frame of the recorded time variation of the power dissipation / field strength at 16 sec. from the start of the feeding

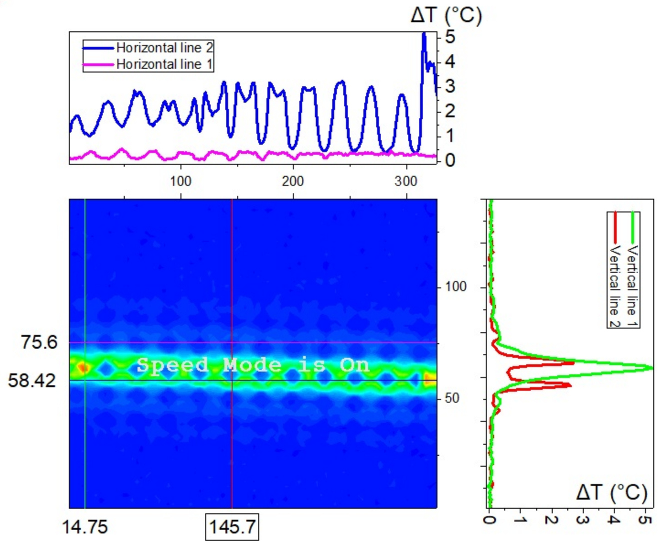

Fig. 4. 2D thermal map (bottom left), with longitudinal (top) and transverse (right) directions of represented distributions of the thermal drift along the structure.

Figure 5 exemplifies the determination of the curves of the temperature increase evolution in time for the desired user-defined ROI. In this example we showed the mean and the maximum value of the temperature increase each second, ΔT, the ROI being in this case the entire surface of the structure under test. The time period of tracing temperature change was of 35 sec. Different local slopes between the maximum and average temperature increase curves reveal distinct thermal behaviors: a steeper maximum slope indicates rapid, localized heating, while a gentler average slope suggests more uniform heat distribution or higher thermal capacity. A significant difference between slopes implies heat concentration in a limited area, whereas similar slopes would suggest even heat spreading. Analyzing these slope variations provides insights into heat generation, distribution, and dissipation within the structure.

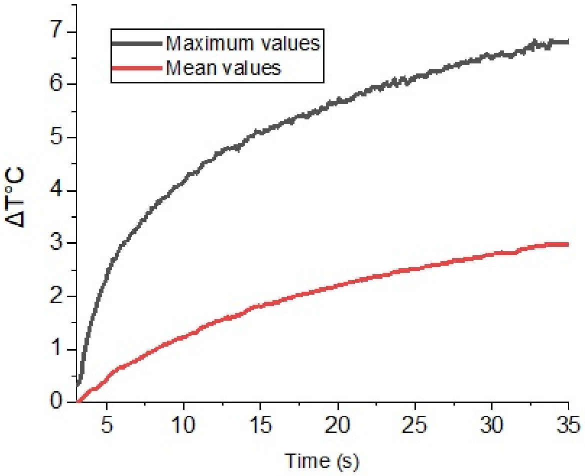

Fig. 5. Variation of the temperature contrast over ROI equal to the entire surface (maximum and mean values) in time.

Using the microlens of the FLIR A700 instrument, we aimed to describe with an increased resolution, local dissipation effects. These may be observed in Fig. 6 where the frame no. 500 of the recording was analyzed. In the left side of Fig. 6 the IR image of the fed line is presented, where the edges of the variable width profiles are prove to be the most radiant and slight differences of temperature are revealed at pixel level in similar positions of the periodicity. Parallel and transversal ROI traces reveal the exact temperature increase distributions, and they are observed in the right side graphs. In this way, frequency- and location-specific losses quantification can be performed with high accuracy anywhere on the area of the high impedance surface.

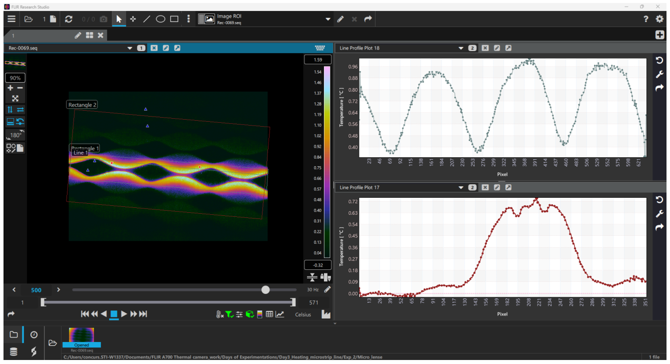

Fig. 6. Detailed IR analysis of the heating using micrometric lens and two lines as ROIs for the description of pixels temperature variation.

V. CONCLUSIONS

A non-invasive thermographic technique based on IR emissions detection and analysis has been applied for fast and dynamic thermal maps generation at the surface of a planar periodic structure fed by a CW microwave signal in the pass-band region. It allows identifying the shape of the metallic periodicity against dielectric bed, the surface current density and local impedance changes, and allows monitoring the energy losses flow along the guiding structure and its dynamic distribution. These promising preliminary results open the way to a more detailed and wide-band characterization of similar structures in a timely manner.

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REFERENCES

[1] M. Faenzi, G. Minatti, D. González-Ovejero, et al. "Metasurface Antennas: New Models, Applications and Realizations", *Sci Rep* 9, 10178 (2019).

[2] A. Alú, "Mantle cloak: Invisibility induced by a surface," *Phys. Rev. B*, 80, 245115, 2009.

[3] D. Lee and A. B. Yakovlev, "Metasurface Cloaks to Decouple Closely Spaced Printed Dipole Antenna Arrays Fed by a Microstrip-to-Balanced Transmission-Line Transition," *IEEE Access*, vol. 9, pp. 128209-128219, 2021.

[4] J. Soric, Y. Ra'di, D. Farfan and A. Alú, "Radio-transparent dipole antenna based on a metasurface cloak," *Nat Commun.* 13, 1114 (2022).

[5] D.C. Tzarouchis, B. Edwards and N. Engheta, "Programmable wave-based analog computing machine: a metastructure that designs metastructures," *Nat Commun.* 16, 908 (2025).

[6] M. Cotrufo, S.B. Sulejman, L. Wesemann, et al. , "Reconfigurable image processing metasurfaces with phase-change materials," *Nat Commun.* 15, 4483 (2024).

[7] L. Matekovits, G. C. Vietti Colomé and M. Orefice, "Propagation of electromagnetic waves in a sinusoidally modulated dielectric substrate," *IEEE Antennas and Wireless Propagat. Letters*, Vol. 6, pp. 207 - 210, 2007.

[8] L. Matekovits, G. Vecchi, M. Bercigli and M. Bandinelli, "Efficient Numerical Analysis of Large Planar High Impedance Surface by the Synthetic Function eXpansion (SFX) technique," *Microwave and Optical Technology Letters* (MOTL), Vol. 51, No. 11, pp. 2763 - 2769, Nov., 2009.

[9] S. K. Podilchak, L. Matekovits, Al. P. Freundorfer, Y. M. M. Antar and M. Orefice, "Controlled Leaky Wave Radiation from a Planar Configuration of Width-Modulated Microstrip Lines," *IEEE Trans. Antennas and Propagat.*, Vol. 61, No. 10, pp. 4957 - 4972, Oct. 2013.

[10] L. Matekovits and T. S. Bird, "Width-modulated Microstrip-line based Mantle Cloaks for Thin Single- and Multiple Cylinders," *IEEE Trans. Antennas and Propagat.*, Vol. 62, No. 5, pp. 2606 - 2615, May 2014.

[11] U. Kayikci, O. Arslan, E. Oduncu, M. Sivasligil, and K. Uluca, "Infrared emissivity measurement approach for solid and opaque materials," *Appl. Opt.* 64, 2525-2533 (2025)

[12] J. E. Will, J. D. Norgard , R. M. Sega , M. Seifert , A. Pesta and J. Cleary "Determining Antenna Near Field Magnitude Data Using Infrared Thermographic Measurements," *Proc. of the 18*th *Annual Symp. of the Antenna Measurement Techniques Association*, pp.193 -197 1996.

[13] J. D. Norgard, "Electromagnetic magnitude and phase measurements from infrared thermograms," *Proc. of 1997 IEEE Aerospace Conference*, vol.2, pp.145-157 vol.2, 1-8 Fe. 1997, Snowmass, CO, USA.

[14] J. D. Norgard; J. Will; C. F. Stubenrauch, "Quantitative images of antenna patterns using infrared thermography and microwave holography," *Int. J. Imag. Syst. Tech.*, vol. 11, n. 4, Special issue on "Advances in quantitative image analysis," pp. 210-218, Jul.- Aug. 2000.

[15] J. Nogard and Musselman, "CEM code validation using infrared thermograms," *Proc. International symposium on electromagnetic compatibility*, pp. 637-640 9-13 Aug. 2004, Silicon Valley, CA, USA.

[16] N. Chiyo, M. Arai, Y. Tanaka, A. Nishikata, T. Hirano, T. Maeno, "Measurement technique for electromagnetic field intensity distribution using infrared 2-D lock-in amplifier," *2010 Annual Report Conference on Electrical Insulation and dielectric*, 17-20 Oct. 2010.

[17] K. Muzaffar, S. Tuli and S. Koul, "Infrared thermography for electromagnetic field pattern recognition," *Proc. IEEE MTT-S International Microwave and RF Conference*, pag. 1-4, New Delhi, India, 14-16 December 2013.

[18] FLIR A-Series Model: A400 Science Kit, https://www.flir.eu/products/a400-a700-science-kits/?vertical=rd+science & segment=solutions