New Device for Controlling the Evolution of Materials Under Microwave Field Using Doppler Effect

T-H. Vuong[1*], J. David[1], J.W. Tao[1], M. Boussalem[2], F. Choubani[2]

[1]Laplace UMR5213, 2 rue C. Camichel, Toulouse 31071, France
[2]Sup'Com de Tunis,-Rte de Raoued Km 3,5, Ariana – 2083, Tunis, Tunisia
*E-mail: Tan-Hoa.Vuong@enseeiht.fr

Introduction

The use of microwaves as a source of energy in material-processing procedures has brought advantages and disadvantages, in particular difficulties in measuring the physical quantities of the material (e.g. temperature). Indeed, the usual sensors (apart from those using an optical fiber) cause disturbances and create microwave leaks during the emission phase of the microwave-power source. For example, a problem often encountered concerns the measurement by metal thermocouples of the temperature of the product to be treated during the microwave heating. In addition, when chemicals (e.g. acids) are to be treated, measurements at the core of the product by contact are virtually impossible.

In this paper, we present the development of a system for controlling the evolution of a material under microwave field, without sensors in contact with the material. The system we developed using the Doppler effect led to a patent filed at the National Institute of Industrial Property (INPI). Our objective was to obtain a compact and cheap system, and the first application concerned is a mineralization system for chemical analyses.

Operating principle

By causing an electromagnetic wave to propagate in the material to be heated, the appearance of gas bubbles due to heating will result in a Doppler signal due to the high rate of expansion of its bubbles. By comparing the spectrum of the Doppler signal with a template, it should be possible to control the heating process[1-5].

In the case of microwave heating, we do not need an additional microwave source because the electromagnetic wave used to carry the energy will also serve as a signal reference to create the Doppler echo. The use of the same electromagnetic heating signal to transport information to control the microwave processing is one of the original aspects of the principle.

The Doppler principle is illustrated in Fig. 1. The frequency shift of the signal reflected by the moving target is given by

$$f_d = 2V\frac{f_0}{c}\cos\phi \,,$$

where f_0 is the transmitter's frequency, c is the speed of light, V is the speed of the target, ϕ is the angle between the microwave (plane-wave) propagation and the target directions. For $\phi = 0$, the Doppler shift is

$$f_d = 2V/\lambda \,.$$

where λ is the wavelength. Figure 2 shows the basic diagram of the device for controlling the evolution of the material under microwave field, using the Doppler effect[1].

Diode detector-mixer

We refer to this device as a detector-mixer because of the mixing effect that takes place between the echo signal received from the loaded applicator and the reference signal which leaks to the device due to the non-ideal coupler. In order to further reduce the cost, we have chosen to realize this detector-mixer with common diodes, as illustrated in Figs. 3 and 4.

Moreover, we can determine the load impedance by placing several detectors at a distance equal to λ/8 from one another as shown in Fig. 5 for a 6-port assembly.

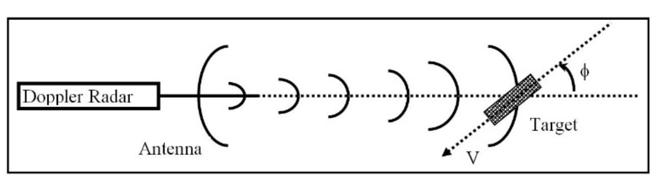


Figure 1: Doppler effect created by a moving target.

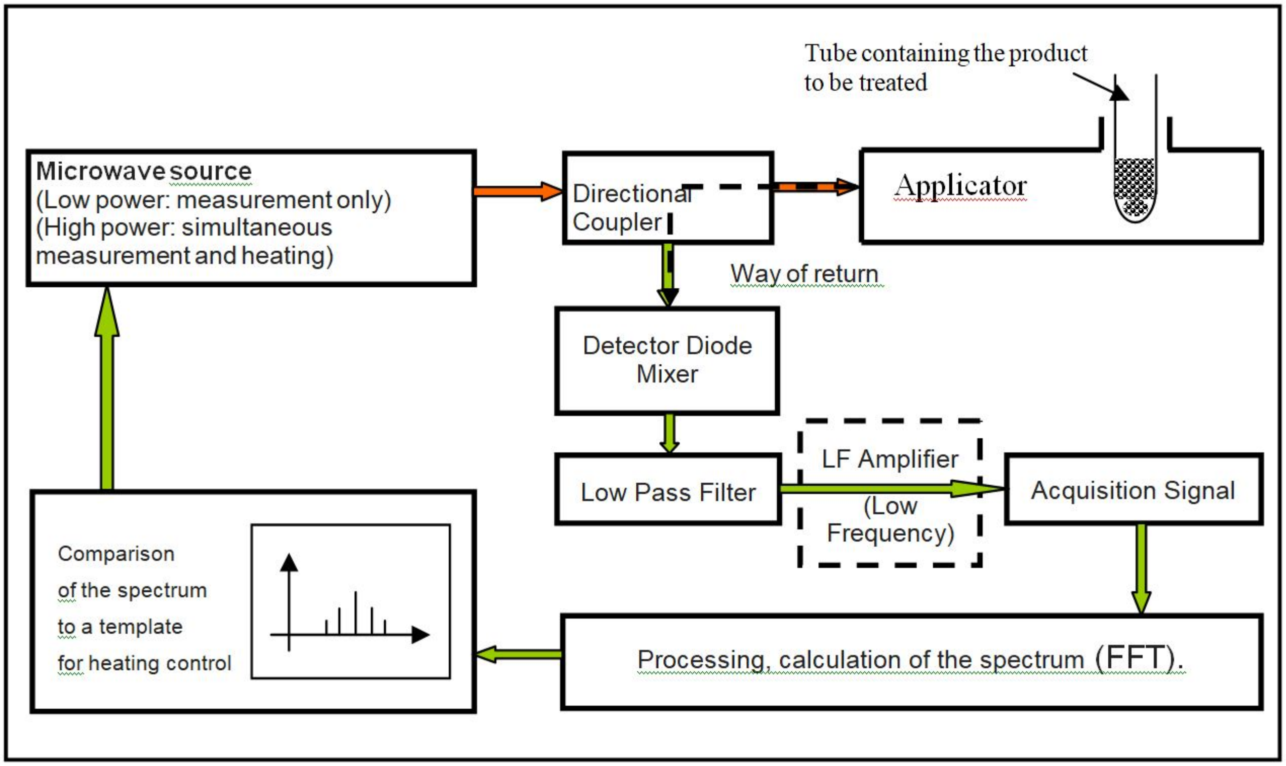


Figure 2: Diagram of the device.

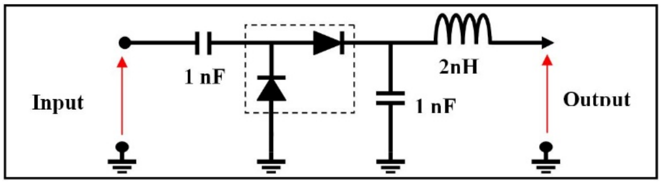


Figure 3: The diode detector-mixer scheme.

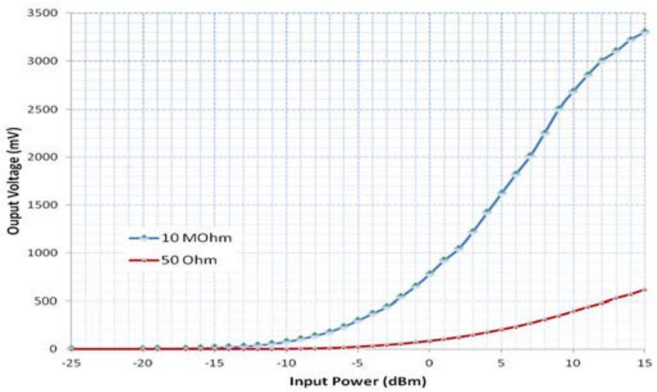


Figure 4: The detector response for 50-Ω and 10-MΩ gauges in parallel to a 30-pF capacitor.

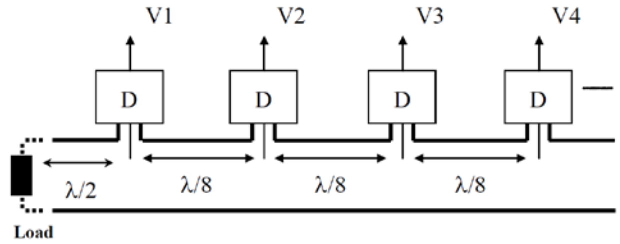


Figure 5: A 4-detector cascade to set the load impedance.

Doppler acquisition and signal processing

The Doppler signal acquisition can be done using specified data acquisition cards. In our device, we use the PC sound card (personal computer) as a Doppler-signal acquisition card, because these sound cards are very inexpensive and very common. In addition, we employ inexpensive software codes for recording and Fast Fourier Transform (FFT) processing (such as Speclab, Winspec32, and Analyzer2000). By comparing the spectrum of the received signal with a pre-recorded template, we can generate a control signal for the microwave-generator power.

Example of industrial application – Mineralization for EUROPSOL

Chemical analyses often need to resort to the mineralization of a product in order to separate the various components. The mineralization process is usually carried out in a hot acid medium. This imposes several difficulties for their automation. To raise the temperature of the medium, conventional heaters are slow and it is very difficult to control thermal runaway. Moreover, these heating modes have a very high thermal inertia. For example, the electric hot plate needs a few minutes for its temperature drop. Microwave heating seems more appropriate because of its faster rate, better volumetric uniformity, and lack of thermal inertia constraint (which enables the product's core heating). The microwave applicator is presented in Fig. 6.

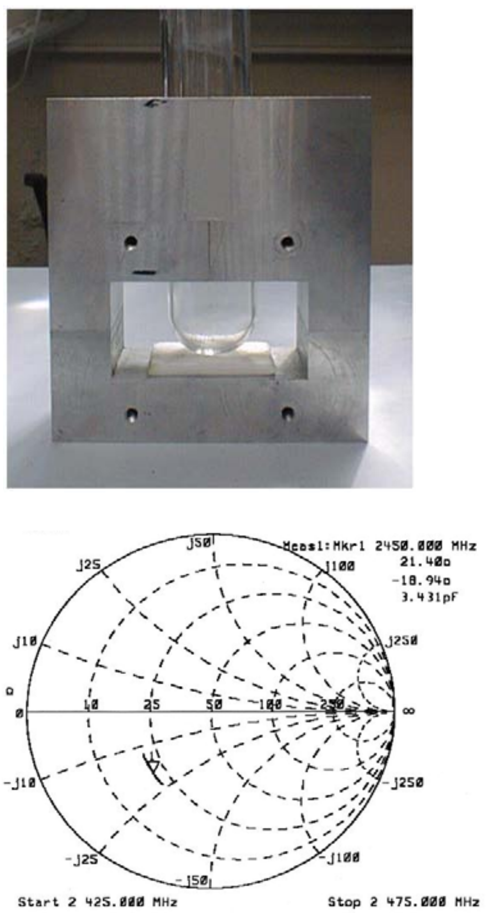
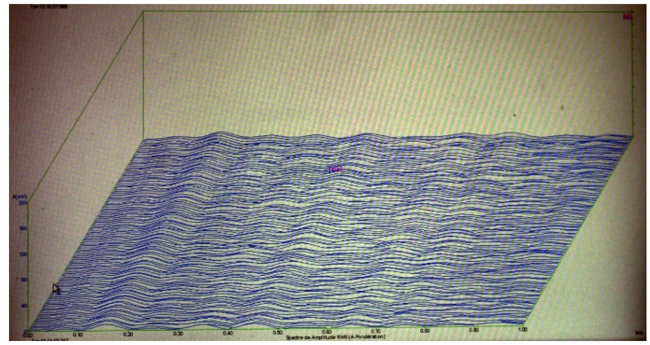
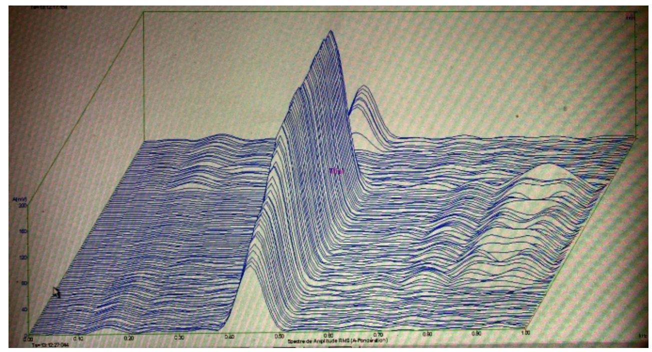


Figure 6: Applicator without load

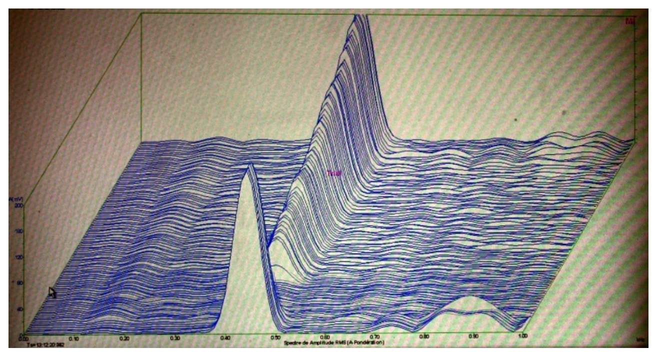
The signal evolution during the mineralization process is presented by spectrograms in Figs. 7a-d.



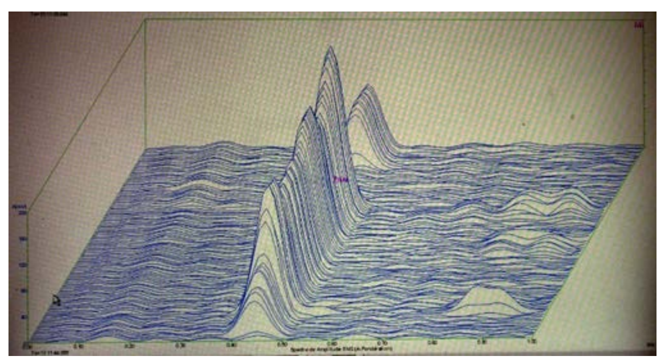
(a) Before the reaction



(b) Early reaction



(c) Start of runaway



(d) The controlled chemical reaction

Figure 7: Typical spectrograms of the different phases of mineralization process.

Conclusion

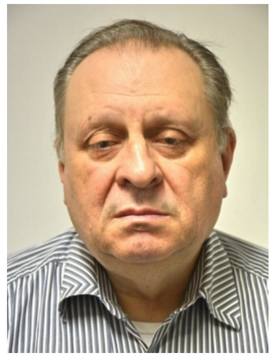
This original device is simple, efficient and perfectly adapted to the process of microwave heating. In particular, it is of great interest with respect to chemical processes under microwaves. A fine FFT analysis of the Doppler signal by an FPGA (Xilink) substitute for the computer allows us to propose a system to embark for the control of industrial chemical processes.

For further reading:

1. T-H. Vuong, Thèse Institut National Polytechnique de Toulouse, 2000, pp. 60–84.
2. T-H. Vuong, J. David, Procédé de contrôle à distance du chauffage d'un produit liquide ou solide et dispositif associé – Réf. 02803658A1, INPI
3. C. P. Bodenstein, W. C. Venter, "A Doppler radar for multiple targets ", IEEE Trans. Instrum. Meas., Vol 43, N° 5, pp. 706-710, 1994.
4. L. Landau, E. Lifchitz, "Physique théorique, mécanique des fluides ", Ellipses Edition, 1998.
5. C. M. Howell, R. Hubert, "Fundamentals of commercial Doppler systems and speed, motion an distance measurement," M/A-COM, Inc, AG320.

About the Authors:

Tan-Hoa VUONG obtained the PhD degree of electronics from the National Polytechnic Institute of Toulouse (INPT), Toulouse, France, in 2000 with the very honourable mention. The thesis rewarded the prize Léopold ESCANDE (INPT) and the prize for thesis for the doctoral school for Toulouse. Then, it decreed the title of enabling with written research (HDR) by the chancellor of the Universities in 2014. Currently, he is the head of the electronic department of IPST-CNAM - Occitanie - Midi-Pyrenees center and professor of engineering in electronics and automation with the IPST, where he teaches analogue and numerical electronics. He also teaches "the techniques of the communication of proximity" to the MSc students, and the formation training: electronics, embarked system, telecommunication. He works at the LAPLACE - UMR 5213 (Laboratoire Plasma et Conversion d'Energie – Unité Mixte de Recherche 5213: CNRS Joint Research Unit - ENSEEIHT-INPT-UPS 5213) of ENSEEIHT, the National Polytechnic Institute of Toulouse, since 1997 on the measurement techniques of HF and microwaves at low and high power, wave-matter interaction, dielectrics characterization, mobile communication, electromagnetic compatibility, antennas, and microwaves sensors. He is interested in electromagnetics applied to medical and military environments.



Jacques David was born in France in 1946. He received the PhD degree in electronic from the Federal University of Toulouse, France, in 1974, and the Doctorate in Science degree in 1984, from the National Polytechnic Institute of Toulouse. He is currently a professor of electrical engineering at ENSEEIHT (National Polytechnic Institute of Toulouse), where he has been teaching electromagnetism, microwave techniques, radar, instrumentation and measurements, since 1973. He has been working at the Electronic Laboratory of ENSEEIHT since 1971, and his primary interest is in the field of electromagnetic wave propagation with applications in the electromagnetic compatibility domain, antennas, wave-matter interaction, and in dielectrics characterization.

Junwu Tao was born in Hubei, China, in 1962. He received the B.Sc. degree in electronics from the Huazhong (Central China) University of Science and Technology, Wuhan, China, in 1982, the Ph.D. degree (with honor) from the Institut National Polytechnique of Toulouse, ENSEEIHT Toulouse, France, in 1988, and the Habilitation degree from the Université de Savoie, Savoie, France, in 1999. From 1983 to 1991, he was with the Electronics Laboratory, ENSEEIHT, where he was involved with the application of various numerical methods to two- and three-dimensional problems in electromagnetics, and the design of microwave Laboratory (LAHC), University of Savoie, where he was an Associate Professor of electrical engineering and involved in the full-wave characterization of the discontinuity in various planar waveguides and the nonlinear transmission-line design. Since September 2001, he has been a Full Professor in LAPLACE (Laboratoire Plasma et Conversion d'Energie) at ENSEEIHT where he is involved in the numerical methods for electromagnetic, microwave and RF energy applications, and millimeter-wave measurements.

Mohamed Boussalem was born in 1979 in Tunis. He obtained the master's degree in microwaves and optical telecommunications from ENSEEIHT in 2003, and obtained the PHD in electromagnetism and hyper frequency in 2007 from ENSEEIHT in collaboration with the high school of communication of Tunis. In 2008 Mohamed Boussalem obtained the Young Researcher Award from the Toulouse Academy of Sciences. Since 2008, he has worked on design and conception of microwave circuits and systems, and their applications in the field of telecom, space and aerospace technology.

Fethi Choubani was born in Mahdia (Tunisia) in 1961. He received the electrical engineering diploma from Ecole Nationale d'Ingenieurs de Tunis, Tunisia in 1987, and the M. Eng and PhD degrees from ENSEEIHT, Institut National Polytechnique de Toulouse, Toulouse, France in 1988 and 1993 respectively. Since 1993, he has been with Sup'Com, Ecole Supérieure des Communications de Tunis, as an Assistant, Associate and Full Professor of Radio frequency components and devices, and Electromagnetic Compatibility. His main interests are focused on oscillators and their applications to electromagnetic sensors, EMC, nonlinear devices, modelling of passive, active components and RF techniques and measurements. He has been offered a position of visiting Research Professor in the Department of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign in 1999 during 3 months, and in Laplace laboratory in ENSEEIHT for one month. He was Head of the Telecommunications Department, ESPTT (Tunisia) from 1995 to 1996, and Director of Strategic studies, Tunisia Telecom (Tunisian operator in Telecommunications) during 1999-2001. From 2012 to 2014, he served as an Advisor for the ICT Minister. He has published more than 100 journal and international conference papers