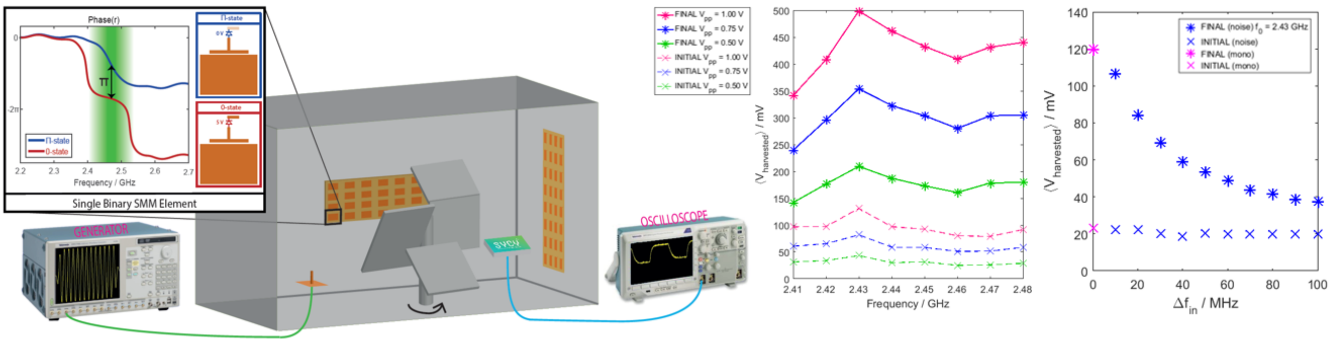
Shaping Microwave Fields using non-linear unsolicited Feedback: Application to Energy Harvesting

Philipp del Hougne*, Mathias Fink, Fabrice Lemoult and Geoffroy Lerosey
Institut Langevin, ESPCI Paris and CNRS UMR 7587, 1 rue Jussieu, Paris 75005, France

1. Extended Abstract

Harvesting the energy contained in radiofrequency (RF) wave fields is a promising approach in the advent of concepts as *Smart Home* and *Internet of Things*, to enable for instance remote sensors to run without batteries. Moreover, by paving the way to a better use of the omnipresent RF fields in our urban environments, it can constitute a step towards a greener future. A key problem so far is that the field incident on the harvester is usually too weak to generate the voltages required for real-life applications [1]. Here, we propose to address this challenge in an indoor environment with simple electronically reconfigurable reflector arrays. By creating constructive interferences of reflected waves, these so-called Spatial-Microwave-Modulators (SMMs) [2] can focus the wave field on the harvester, thereby enhancing the harvested energy.

Firstly, we demonstrate in the controlled environment of a disordered microwave cavity the ability to significantly enhance the voltage output of a harvester by optimizing the incident wave front. To this end, we cover 7% of the cavity walls with a SMM consisting of 102 elements of electronically reconfigurable reflection coefficient. With an iterative optimization scheme using the harvester's voltage output as feedback, we identify step by step the optimum SMM configuration. We demonstrate the feasibility of this procedure for a variety of monochromatic and broadband signals, as shown in Figure 1.



(a) Schematic of experimental set-up. (b) Monochromatic excitation. (c) Noise excitation.

Figure 1. (a) Set-up containing a metallic cavity, two Spatial-Microwave-Modulators whose working principle is illustrated on the inset, an antenna emitting a 30 µs excitation signal generated by a wave generator, the harvester prototype from SYCY whose output is monitored on an oscilloscope (triggered by the wave generator) and a mode-stirrer to realize disorder. (b) Final and initial harvested voltages, averaged over 300 realizations, for monochromatic excitations of different frequency and power. (c) Final and initial harvested voltages, averaged over 150 realizations, for noise excitations of different bandwidth but same power, centred on 2.43 GHz.

Secondly, we explore the possibility to carry out this iterative optimization without access to the harvester's output. The harvester, intrinsically being a non-linear device, generates non-linear responses that can be detected on spectra recorded at other positions inside the cavity [3]. Both the strength of the non-linear signatures in the spectrum and the harvested voltage increase monotonously as the field intensity incident on the harvester rises. We demonstrate that detected non-linear responses can be successfully used as feedback for wave front shaping, enabling a substantial enhancement of the harvested RF energy.

We gratefully acknowledge the start-up SYCY (http://www.sycy.fr) for providing us with a prototype of their RF harvester.

2. References

1. V. Talla, B. Kellogg, B. Ransford, S. Naderiparizi, S. Gollakota, and J. R. Smith, "Powering the next billion devices with Wi-Fi," *arXiv preprint* arXiv:1505.06815, May 2015.

2. N. Kaina, M. Dupré, M. Fink, and G. Lerosey, "Hybridized resonances to design tunable binary phase metasurface unit cells," *Optics Express*, **22**, 16, July 2014, 18881–18888, doi: 10.1364/OE.22.018881.

3. M. Frazier, B. Taddese, B. Xiao, T. Antonsen, E. Ott, and S. M. Anlage, "Nonlinear time reversal of classical waves: Experiment and model," *Physical Review E*, **88**, 6, December 2013, 062910, doi: 10.1103/PhysRevE.88.062910.