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# Spatiotemporal Wave Front Shaping using Spatial-Microwave-Modulators: a possible Alternative to Time Reversal

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## 1. Extended Abstract

The control of wave propagation in complex media has become an important area of research, notably through the powerful tools of time reversal and wave front shaping. A common ground of both approaches is that they make use of the secondary sources offered by scatterers and reflectors, which provide additional degrees of freedom (DoF). While time reversal is naturally a broadband approach that yields spatiotemporal focusing of waves, wave front shaping acts only in the spatial domain and is therefore originally a monochromatic concept yielding maxima of deposited energy at desired foci. Nonetheless, complex media mix spatial and temporal DoF which enabled the recently reported counterintuitive focusing, both in space and time, of optical pulses after propagation through a complex medium [1-2]. Here we transpose this idea to a microwave experiment using a reverberating cavity (complex medium) and flat arrays of electronically tunable resonators (wave front shaper) [3].

Firstly, we demonstrate that maximizing the Green's function between two antennas at a chosen time yields diffraction limited spatiotemporal focusing. Secondly, we modify the cavity's quality factor $Q$, thereby altering the relative distribution of the spatial and temporal DoF, and prove that it has no impact on the field enhancement: wave front shaping uses all available DoF, irrespective of their spatial or temporal nature. Analyzing the enhancement of deposited energy for different quality factors points out an important difference to time reversal focusing: while longer photon dwell times permit time reversal to deposit more energy, this is not the case in wave front shaping as in any case the same pulse is emitted before and after wave front shaping.

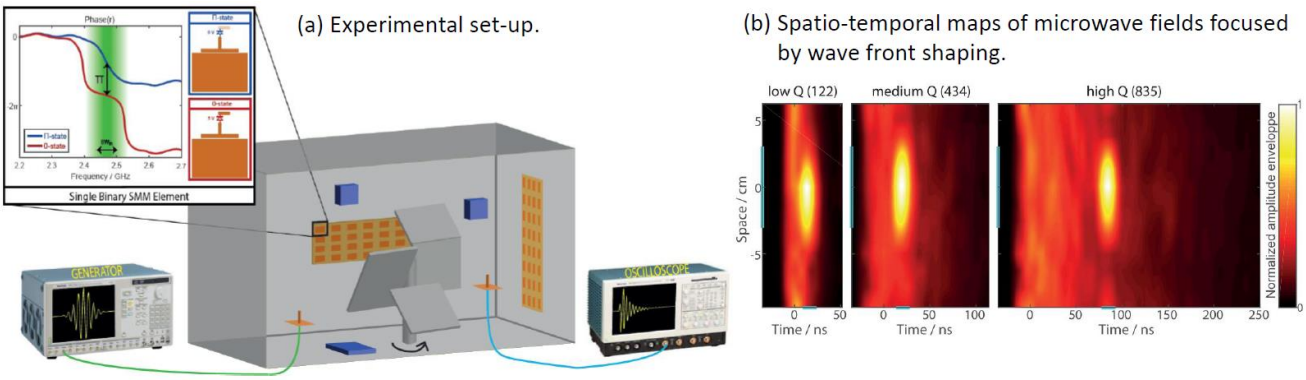


**Figure 1.** (a) Set-up containing a metallic cavity, electromagnetic absorbers to modify its quality factor, two Spatial-Microwave-Modulators whose working principle is illustrated on the inset, an antenna emitting a pulse generated by a wave generator, a receiving antenna whose output is monitored on an oscilloscope (triggered by the wave generator) and a mode-stirrer to realize disorder. (b) Examples of spatiotemporal foci obtained by wave front shaping, for three different cavity quality factors, averaged over 60 realizations.

Our results show that wave front shaping using simple electronically reconfigurable arrays of reflectors is a viable approach to the spatiotemporal control of microwaves, with potential applications in medical imaging, therapy, telecommunications, radar, or sensing. Our approach is novel and different from time reversal, in particular it is considerably simpler and cheaper. We also provide new fundamental insights regarding the coupling of spatial and temporal DoF in complex media.

## 2. References

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