Single-antenna microwave imaging and wireless-link control with a reconfigurable intelligent surface

Paul Garnier, Matthieu Davy
Univ Rennes, CNRS, IETR – UMR 6164, Rennes, France

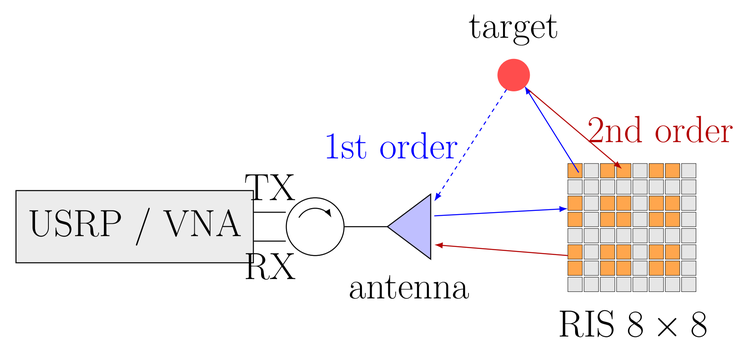
Animated figures and poster online
paul-garnier.fr/p/gdr26

One antenna + one RIS = a programmable synthetic array

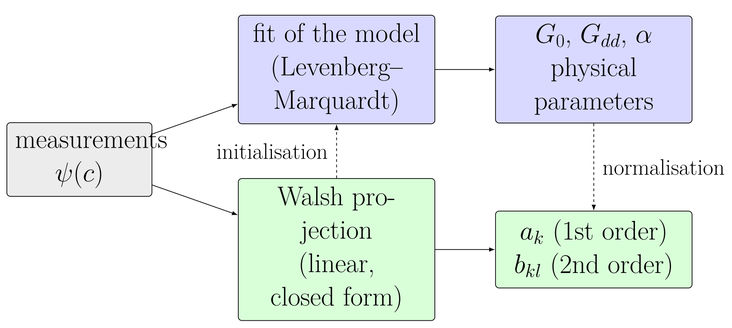
A reconfigurable intelligent surface (RIS) of 8×8 elements, each switched between two states, is placed in front of a single transmitting–receiving antenna (circulator). For each configuration $c \in \{0,1\}^{64}$ the antenna measures one complex number $\psi(c)$. Cycling the configurations turns the RIS into a 64-element synthetic array that probes the scene [1].

- VNA: 3–4.5 GHz, 101 frequencies (wideband).
- Software-defined radio (USRP N210): ≈ 2 ms per configuration (fast).

[1] A. Goïcoechea, F. Sarrazin, T. Karamanos, M. Fink, F. Lemoult, M. Davy, *Single-Antenna Non-Line-of-Sight Matrix Imaging via Reconfigurable Intelligent Surfaces*, arXiv:2512.12359 (2025).



1. Two complementary readings of the measurements



Model: $\psi(c) = E_0 + G_0^T\,\Gamma(c)\,G_0$, $\Gamma(c) = \left[\mathrm{diag}(1/\alpha(c)) - G_{dd}\right]^{-1}$, fitted at each frequency; predicts unseen configurations with $R^2 \approx 0.99$.
Walsh: with $\xi_k = 2c_k - 1 = \pm 1$, $\psi = a_0 + \Sigma_k\, a_k\xi_k + \Sigma_{k<l}\, b_{kl}\,\xi_k\xi_l + \ldots$; each degree is one family of paths, no model needed.

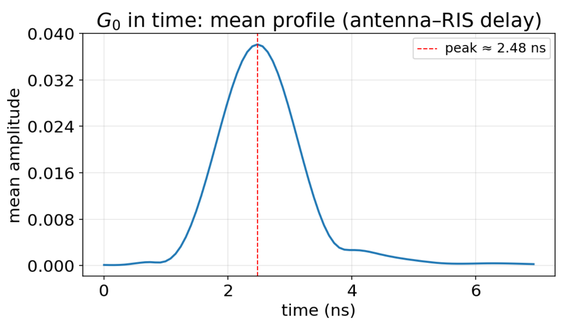
2D or 3D is set by the bandwidth, not by the degree. The degree sets the speed and what the antenna must see:

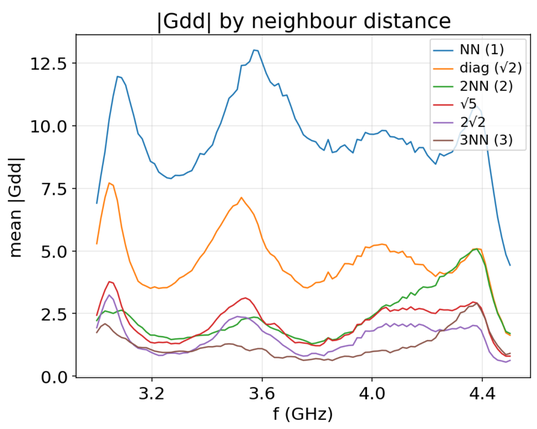
	degree 1 (a_k)	degree 2 (b_{kl})
paths	antenna → element → antenna (RIS alone) + antenna → element → object → antenna	antenna → element → element → antenna (coupling) + antenna → element → object → element → antenna
unknowns / configs	64 / ∼128	2016 / ∼7000
requires	antenna sees the object	only the RIS sees it (NLOS)
use	fast imaging (2D, one frequency)	NLOS imaging (3D, wide band)

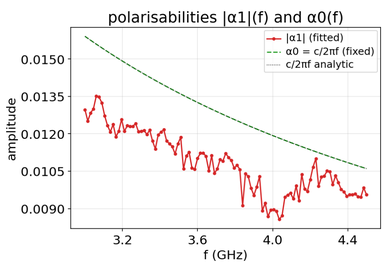
2. Wideband calibration of the RIS

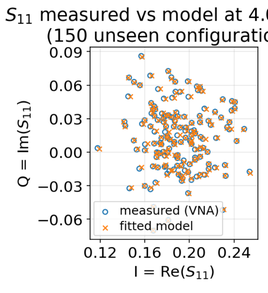
Procedure. Empty scene, 15000 random configurations × 101 frequencies (3–4.5 GHz, VNA). At each frequency, independently: closed-form Walsh initialisation (degree 1 → G_0, degree 2 → G_{dd}), then Levenberg–Marquardt on 5000 configurations; validation on unseen ones. The fitted parameters are physical (internship data):

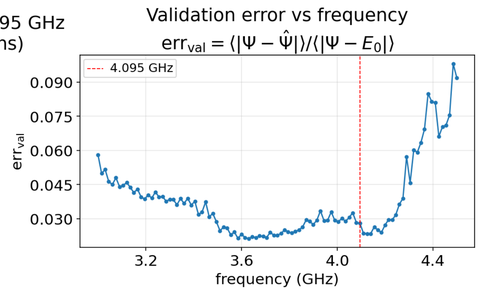
- G_0 in time (inverse FFT over the band): a single peak at 2.48 ns, the antenna–RIS delay (cables included), and no multipath.
- G_{dd}: strongest between nearest neighbours, with coupling resonances in f.
- α_1: fitted, close to and below $\alpha_0 = c/2\pi f$.







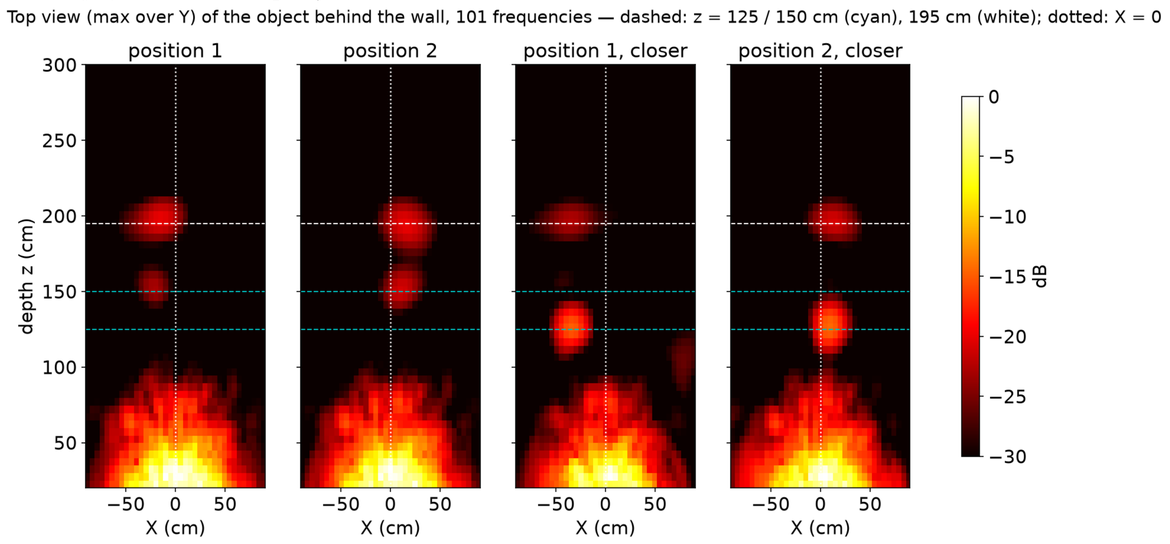




Validation (bottom right): S_{11} of configurations never used in the fit is predicted within 2–6 % below 4.3 GHz; the error rises at the top of the band, where the RIS barely modulates.

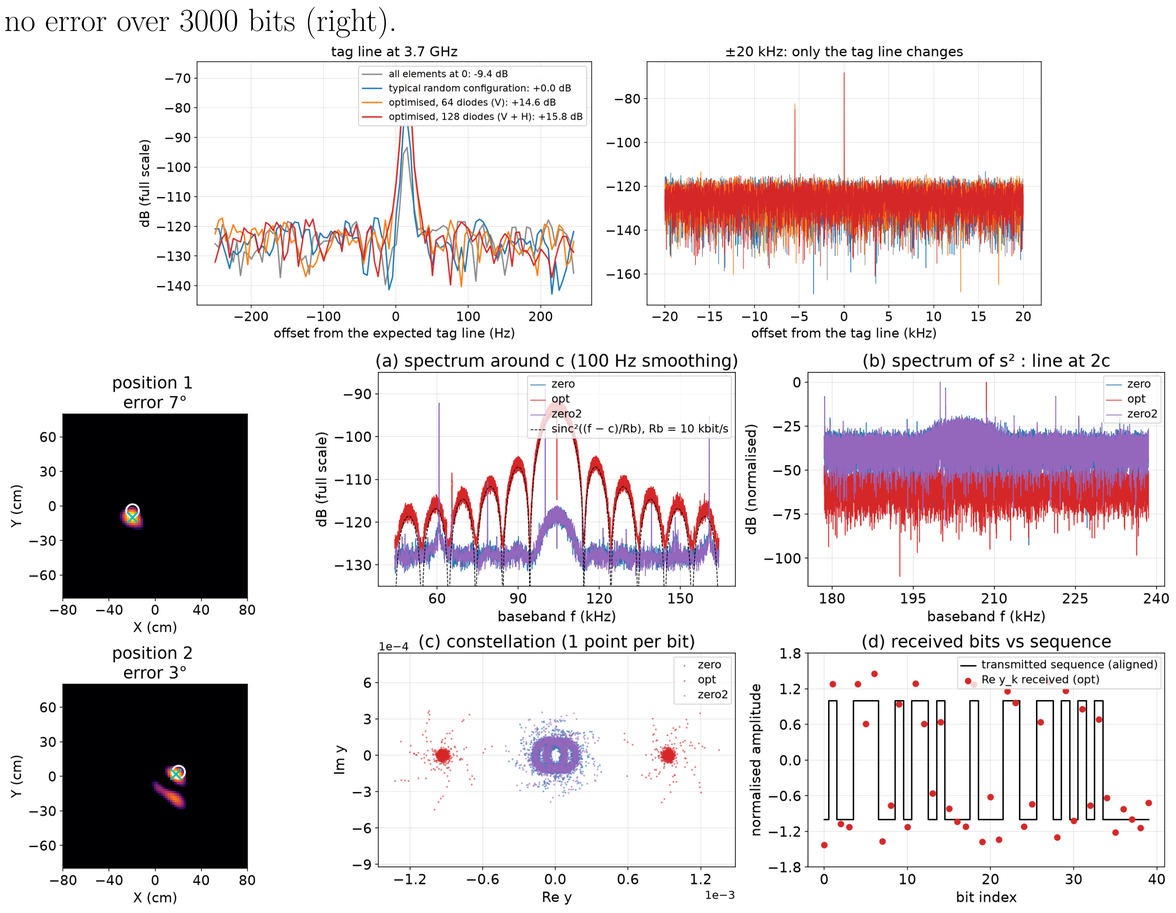
3. Wideband 3D imaging through a wall

The object changes the element–element coupling of the fitted model (2nd order): $\Delta G_{dd} = G_{dd}^{\text{object}} - G_{dd}^{\text{reference}}$, at identical geometry. Coherent back-propagation over 101 frequencies (3–4.5 GHz), after a 2 ns time gate that removes the direct RIS coupling: $I(\mathbf{r}) = \left|\Sigma_f\, w_f\, \mathbf{g}_f(\mathbf{r})^H\, \Delta G_{dd}(f)\, \overline{\mathbf{g}_f(\mathbf{r})}\right|^2$. The object behind the wall follows its displacements (30 cm sideways, 25 cm in depth).



4. Locating and enhancing a frequency-shifting tag

A tag re-emits the illumination at a shifted frequency, free of static clutter. With the RIS: **link boost** up to +17.8 dB by flipping elements one by one (top), **direction** of the tag seen only through the RIS within 3–7° (left), **BPSK** pseudo-random sequence decoded with no error over 3000 bits (right).



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