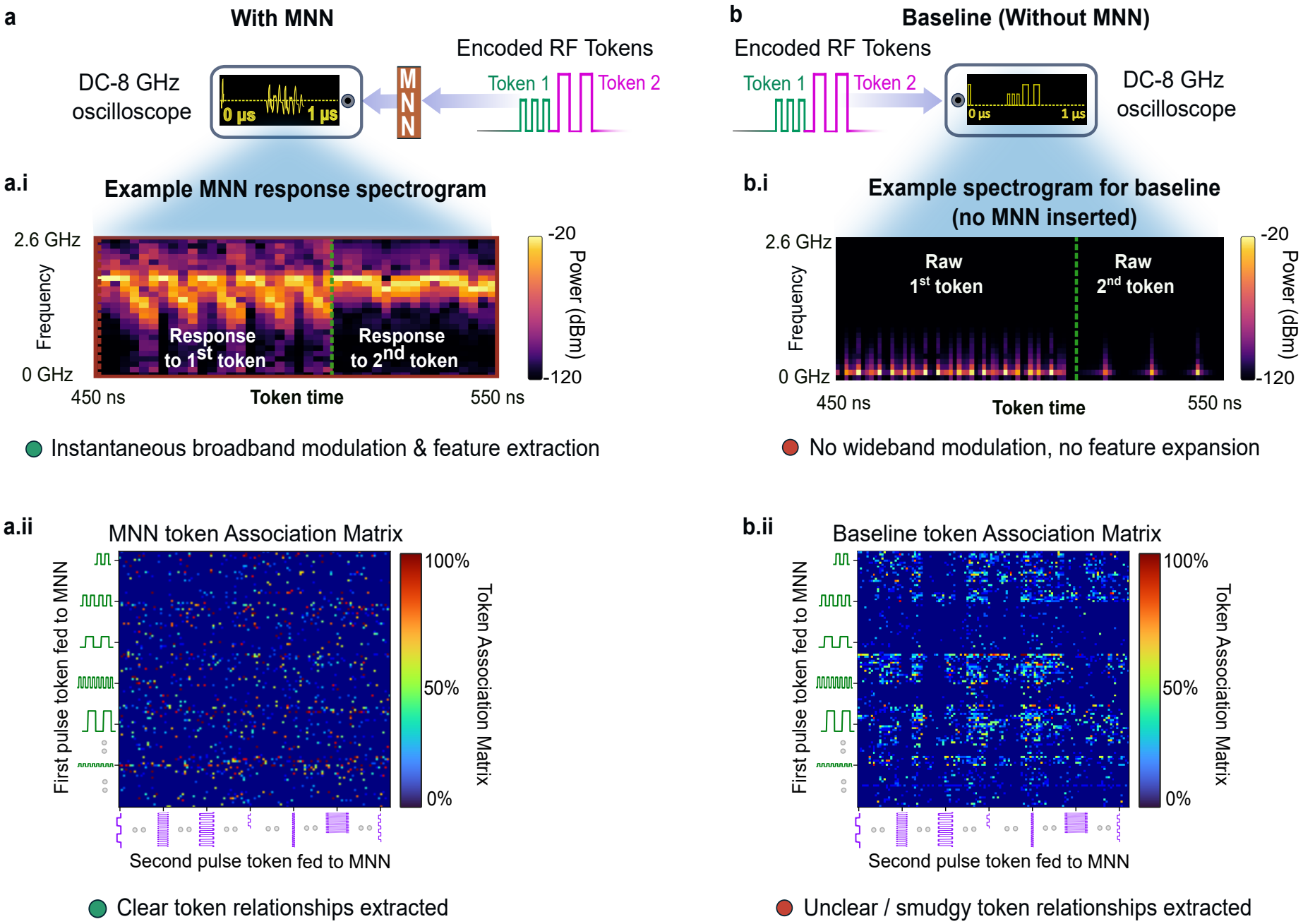

Extended Data Figure 3. Effect of MNN-based feature expansion on token relationships. a, RF pulse-train tokens are injected into the MNN, whose nonlinear dynamics expand each token's spectrum over several gigahertz (followed by mixer-based downconversion to baseband for measurement; circuitry not shown). **a.i,** Example spectrogram showing that different tokens generate distinct broadband signatures within a ~100 ns window. **a.ii,** Token Association Matrix derived from a linear classifier applied to these spectrograms, revealing clear and separable token-to-token relationships. **b,**The same tokens are directly observed using identical measurement bandwidth, without feature expansion. **b.i,** Raw spectrograms remain narrowband and visually similar across different tokens. **b.ii,** The resulting association matrix shows weak, blurred structure, indicating that tokens lack discriminable spectral features without MNN processing.