Gabor nonstationary deconvolution for attenuation compensation in highly lossy dispersive media

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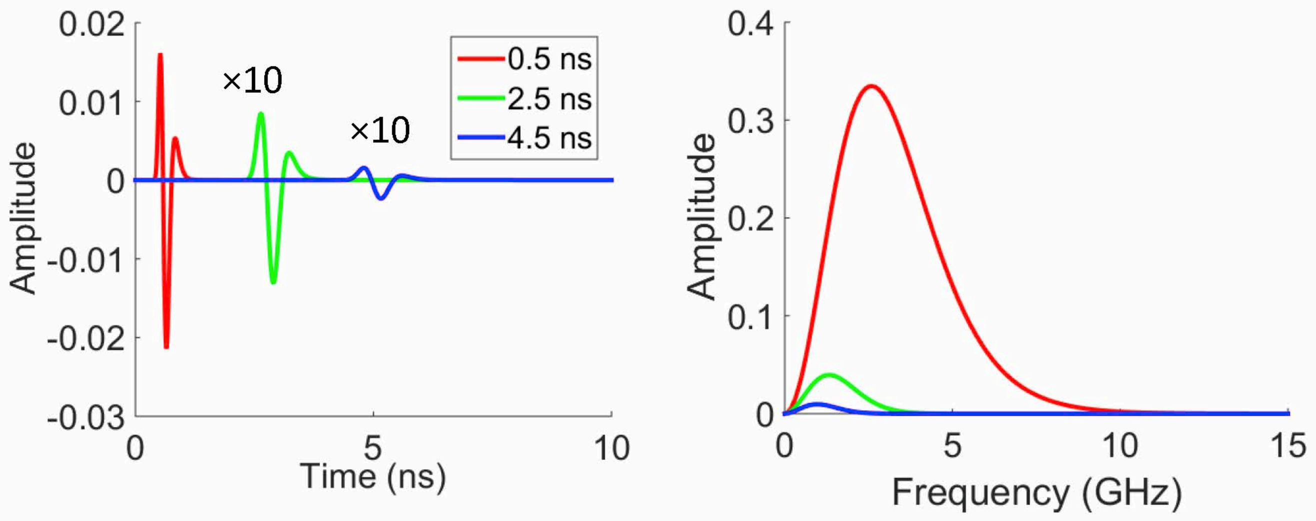
Motivation

- ***Problem:*** Signals that form microwave (MW) image exhibit **severe frequency-dependent attenuation** →
  - ✗ Wavelet distortion → **Nonstationarity**
  - ✗ **Lack of resolution** in image



A example of wavelet distortion at different travel times

- ***Method:*** Gabor Nonstationary Deconvolution (GND)

$$\hat{S}(f,\tau) \approx W(f)B(f,\tau)R(f,\tau) \qquad |B(f,\tau)| = e^{\left(-\frac{\pi|f|\tau}{Q}\right)}$$

  - A **local analysis** scheme based on time-frequency decomposition
  - Constant Q theory → Hyperbolic smoothing

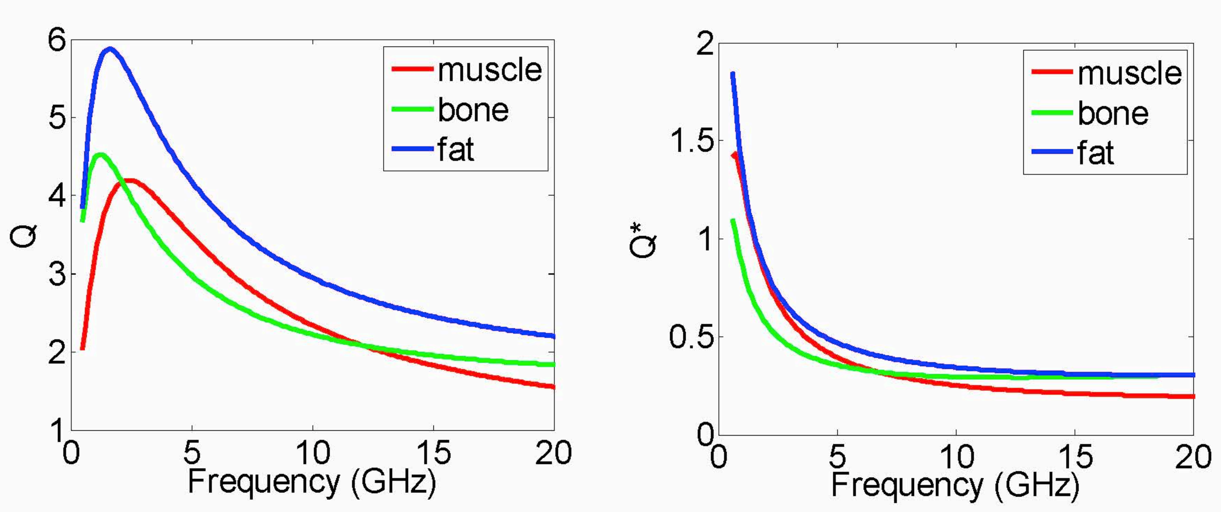
- ***Objective:*** Determine effectiveness of GND for MW signals propagating through biological tissues regarding
  - ? Q characterization appropriate for MW signals
  - ? High attenuation and dispersion
  - ? Impact of frequency-dependent Q

Q for EM Wave

$$Q = 2\pi \frac{Average\ energy\ stored\ per\ half\ cycle}{Energy\ dissipated\ per\ half\ cycle}$$

⇩

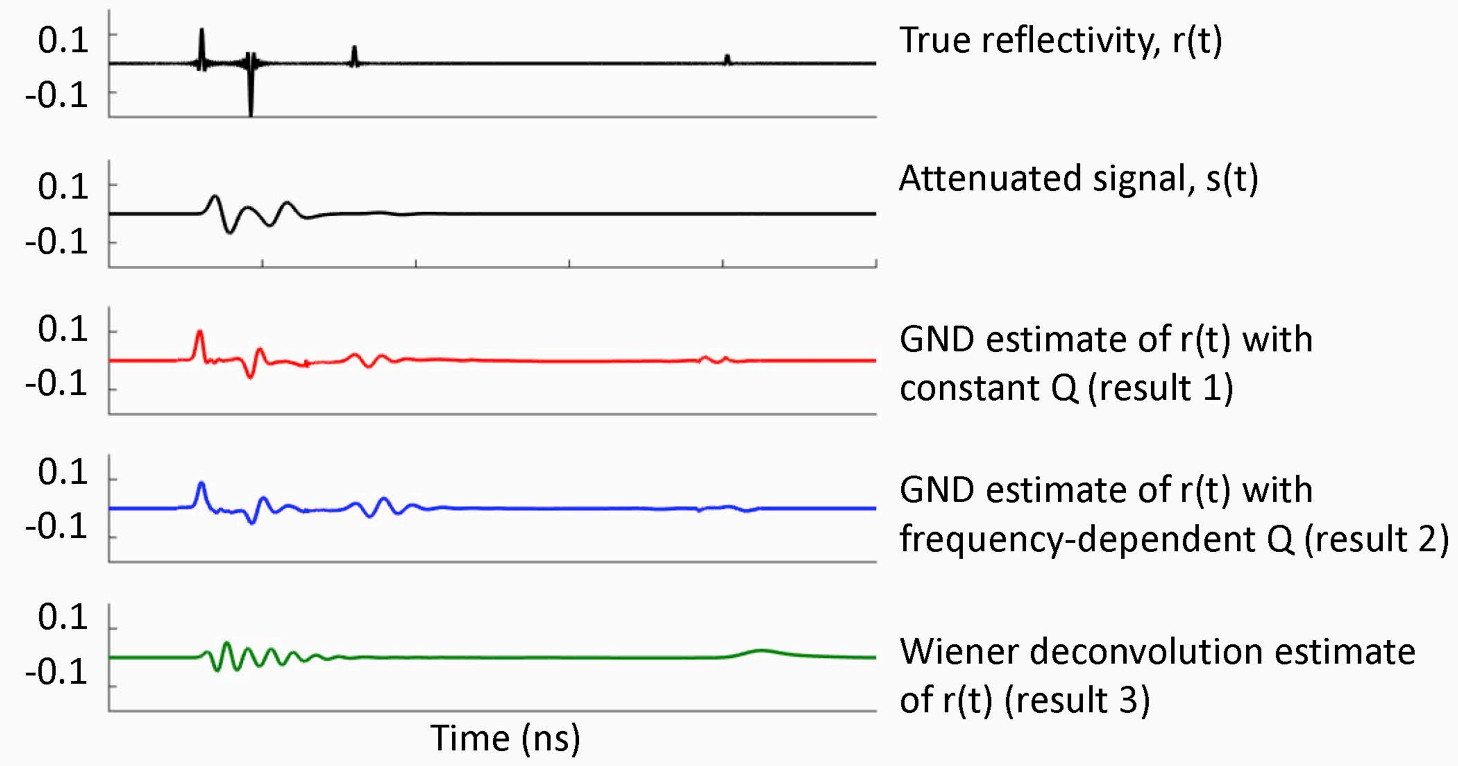
$$Q = \omega/(2v\alpha) \quad \Rightarrow \quad Q^* = \frac{1}{2v}\left(\frac{d\alpha}{d\omega}\right)^{-1}$$



- **Small** Q between **1.5** and **8.**
- **Q*** approximated as **constant**

Preliminary Testing

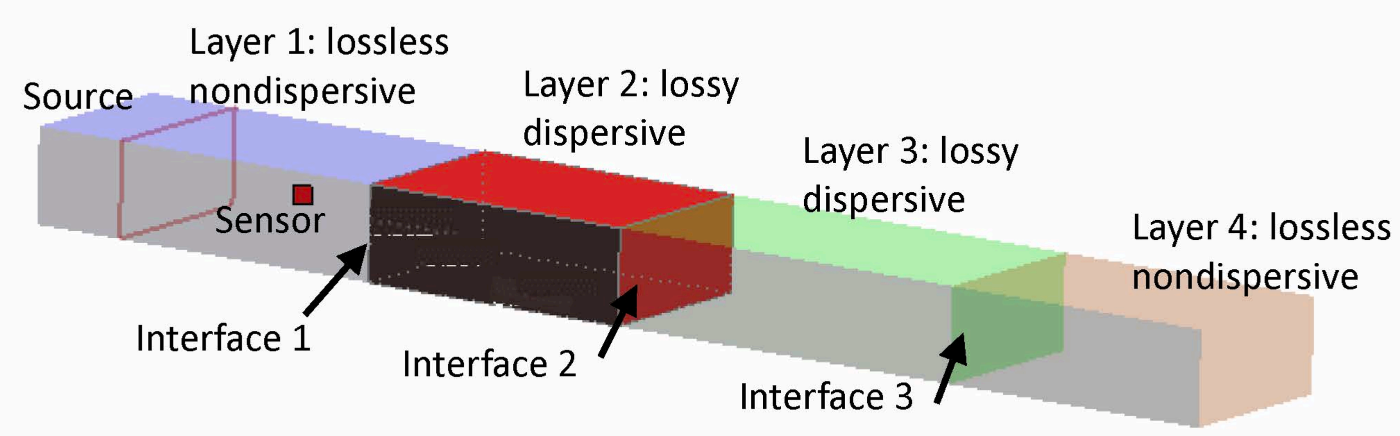
Synthetic Data

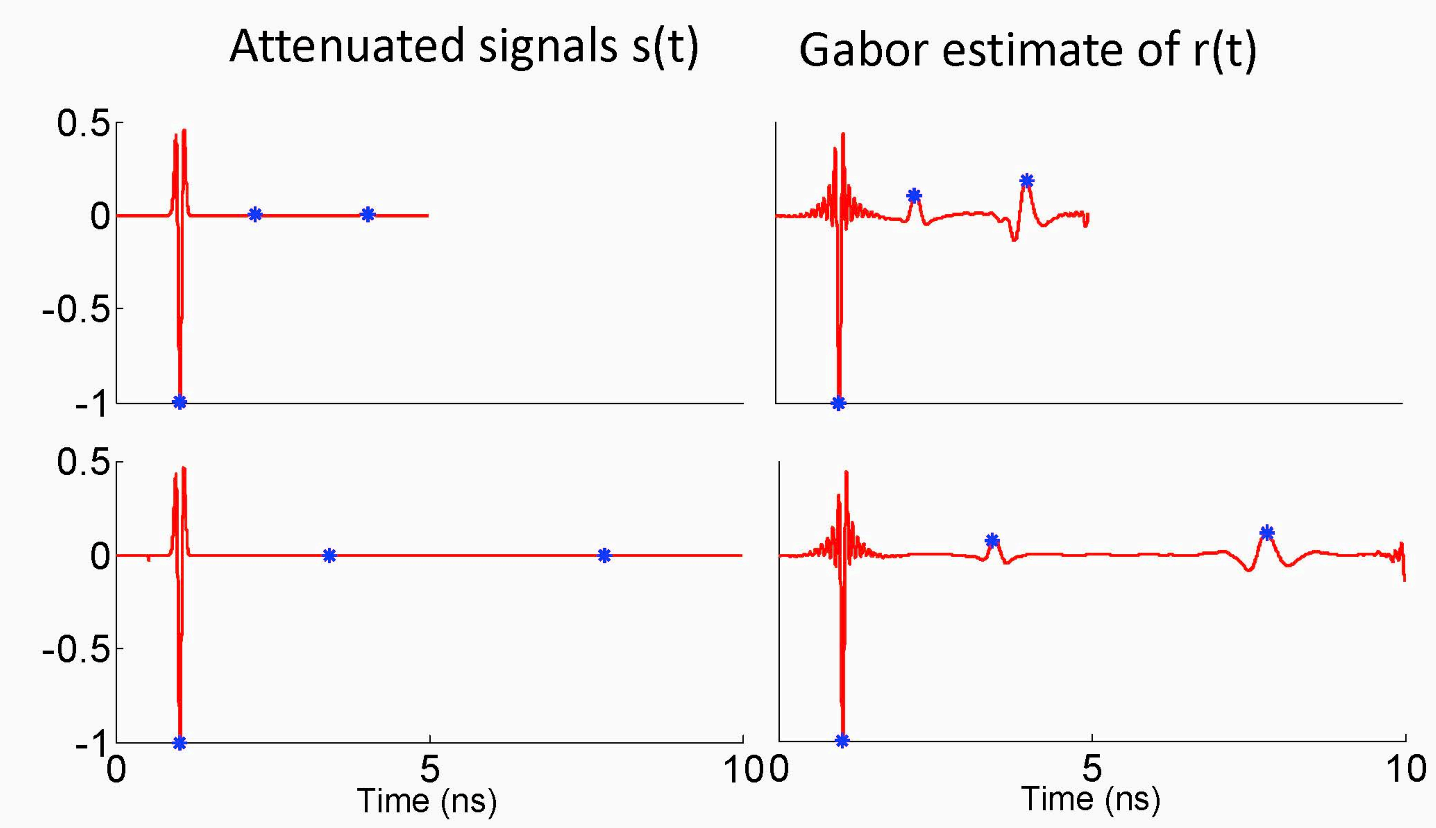


- Nonstationary example of GND
  - ✓ **Result 1,2,3 → more effective** than Wiener deconvolution.
  - ✓ **Result 1,2 → insensitive** to frequency-dependent Q.

Simulation of Plane Wave Propagation

- Challenging features of model:
  - Layers 2&3 high attenuation and dispersion
  - Low contrast at interfaces 2&3

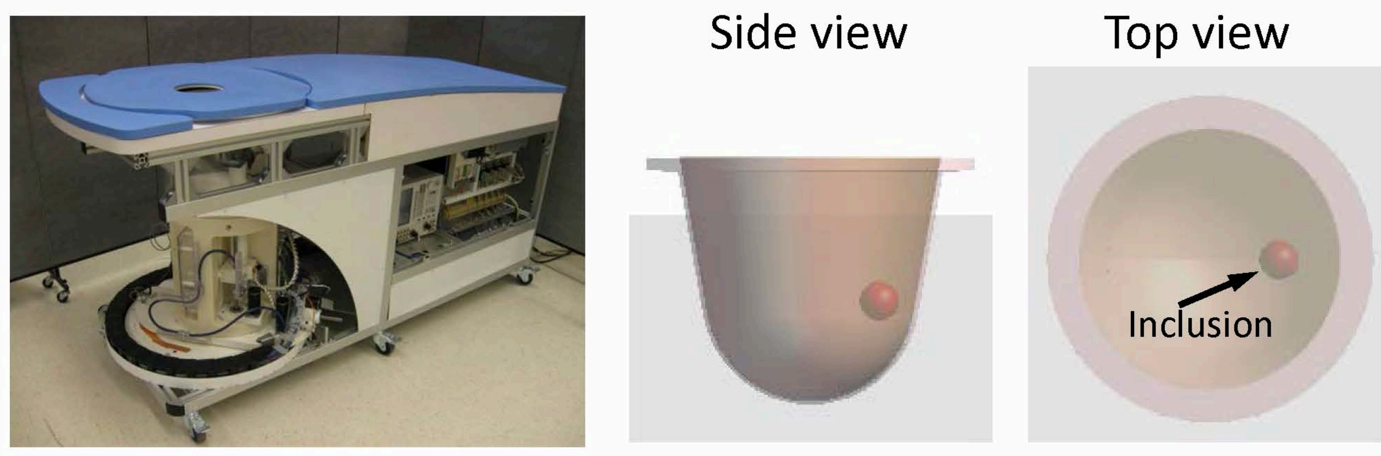




Case 1 (top): Mild loss and dispersion. Case 2 (bottom): High loss and dispersion. Blue '*' represents interfaces 1 to 3.

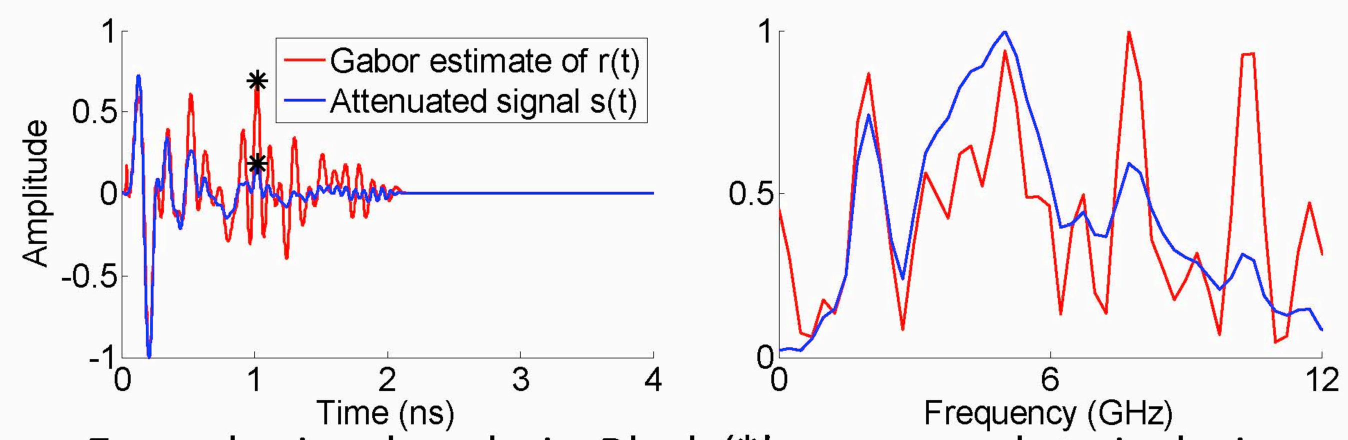
Application: MW Imaging

- Gabor deconvolution as preconditioning for imaging

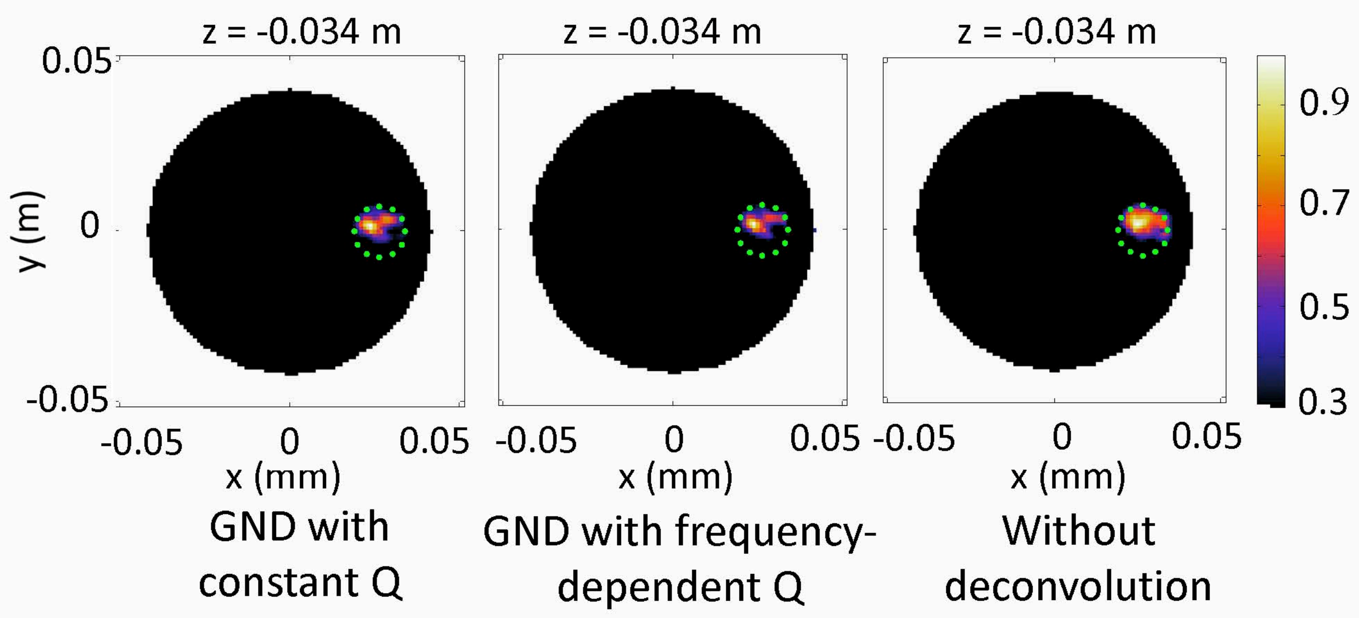


TSAR MW imaging system for breast tumor detection

Structure of lossy dispersive phantom



Example signal analysis. Black '*' corresponds to inclusion centre location in signal.



- ✓ GND → **Better localization** of scattering object, **reduced smearing** of the reconstructed response

Conclusions

- Hyperbolic smoothing is **insensitive** to Q frequency-dependency.
- EM wave attenuation can be characterized by a **constant Q*** model.
- Results demonstrate GND is **effective** for media with high loss and high dispersion.

References

Fear, et. al., 2013, IEEE Trans. Microw. Theory Techn., 61, 2119-2128.

Margrave, et. al., 2011, Geophysics, 76, W15-W30.

Turner and Siggins, 1994, Geophysics, 59, 1192-1200.