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Analysis and Modelling of the Optimal Command for an Ultrasound Pulse Inversion Imaging System

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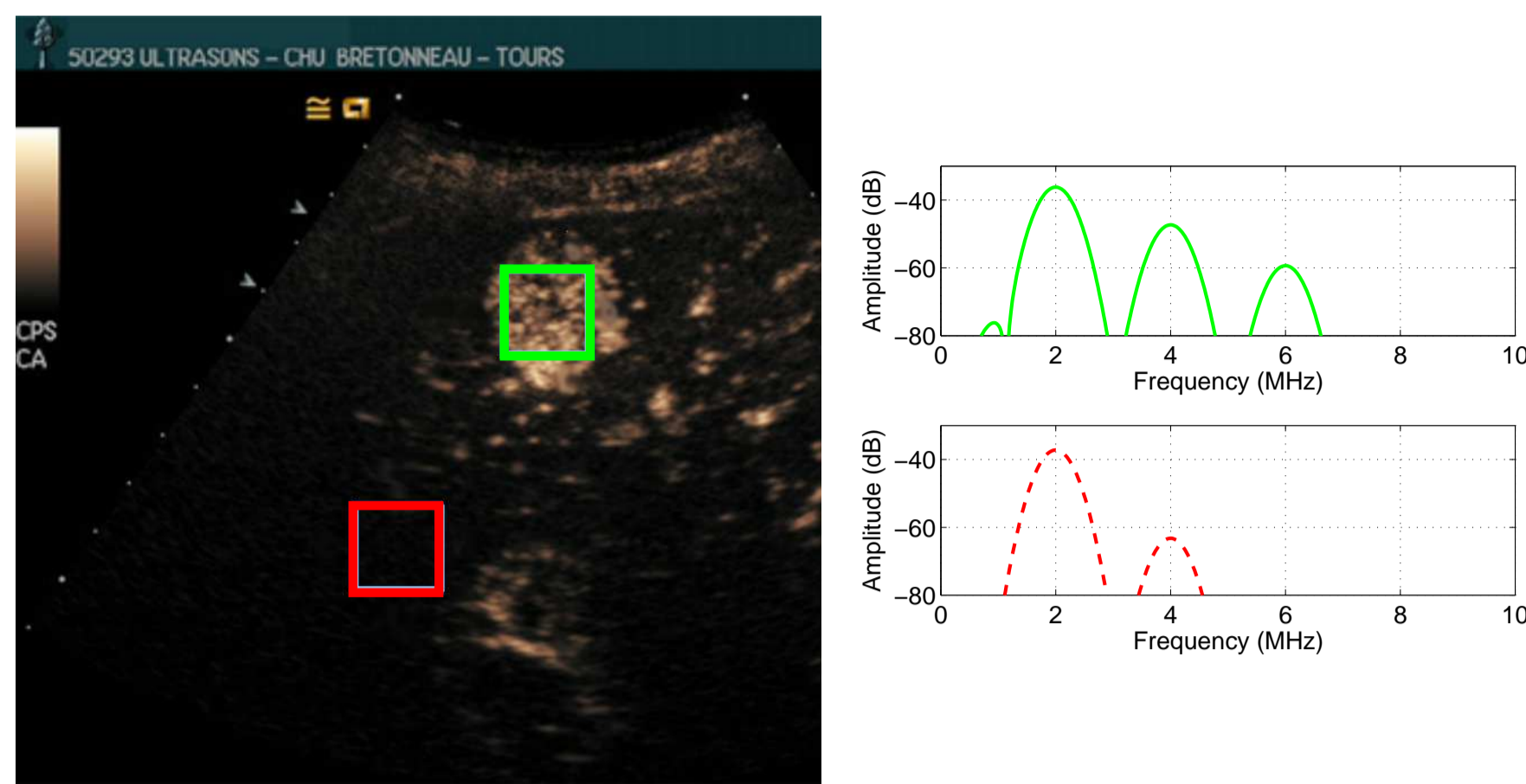
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1. Introduction & Background

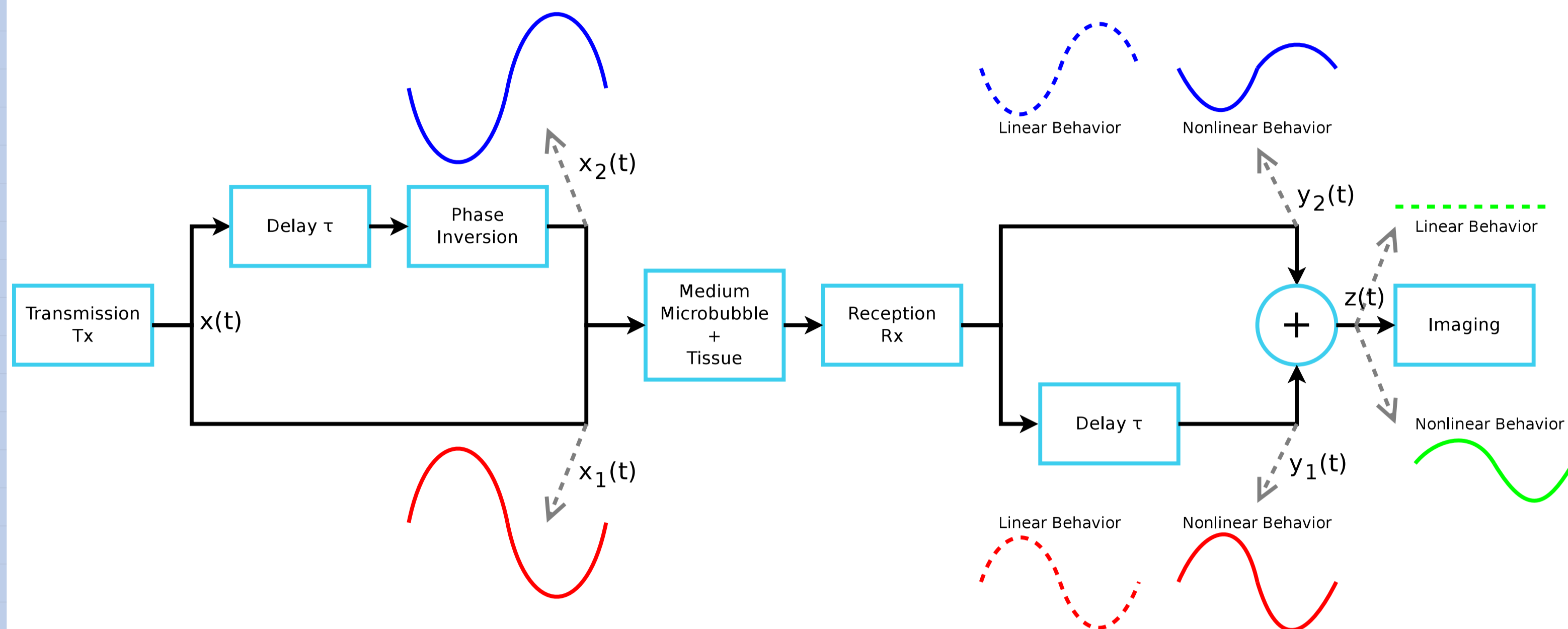
A. Ultrasound Contrast Imaging

- Injection of encapsulated microbubbles
- High nonlinear behavior
- Contrast-to-Tissue Ratio

$$CTR = \frac{E_{microbulles}}{E_{tissu}}$$



B. Pulse Inversion Ultrasound Imaging



Increasing CTR by odd harmonic extraction with the sum [Simpson, 1999]

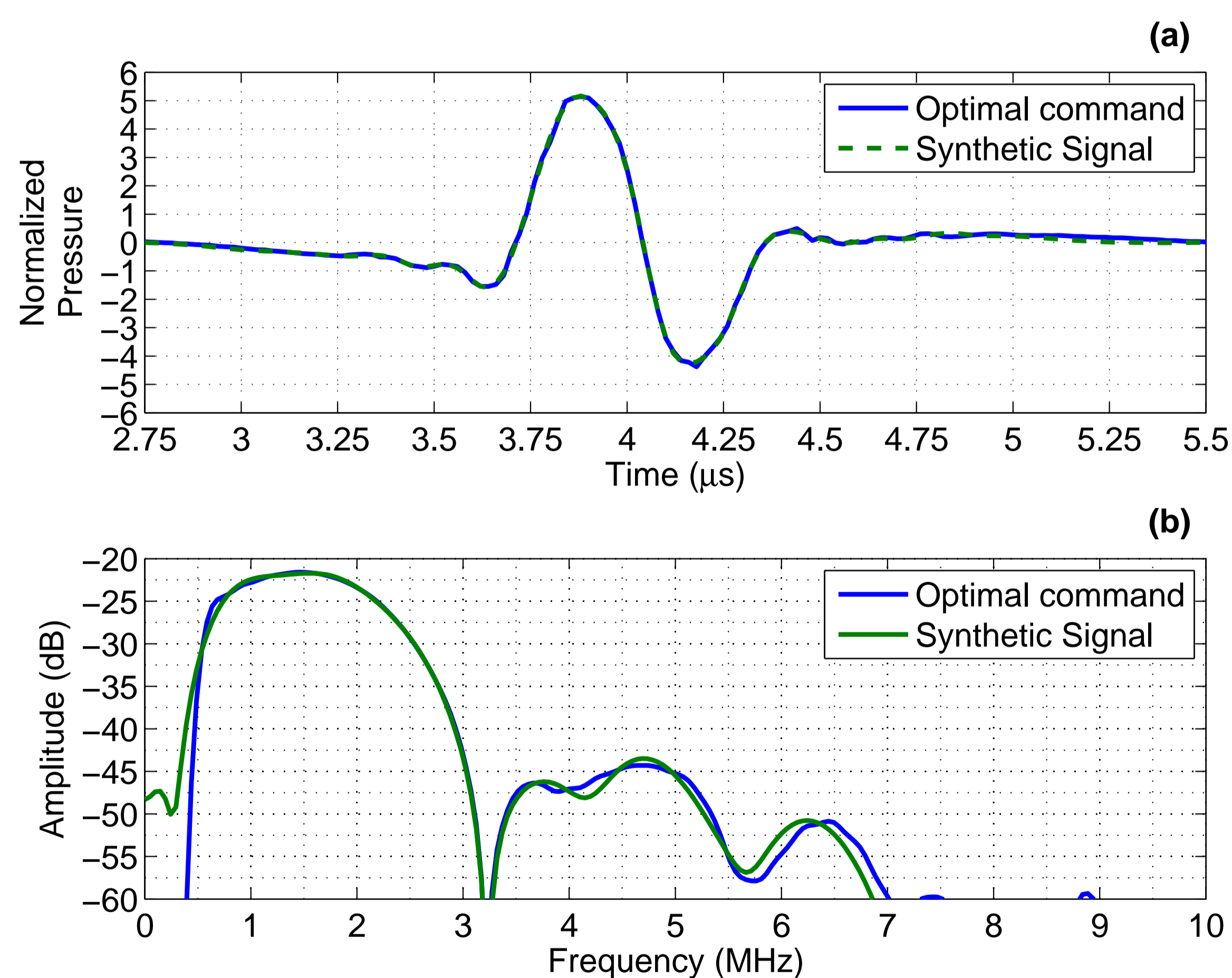
C. Simulation

BUBBLESIM [Hoff, 2001] for a 2.5 μm microbubble; tissue ≈ fat globules; transducer: 3 MHz - 90%

2. Analysis of Optimal Command for Pulse Inversion Imaging System

In a previous work [1], CTR was optimized by a Monte-Carlo method:

$$x^*(t) = \arg \max_{x(t)} (CTR(x(t))) \Rightarrow CTR = 31.62 \text{ dB}$$

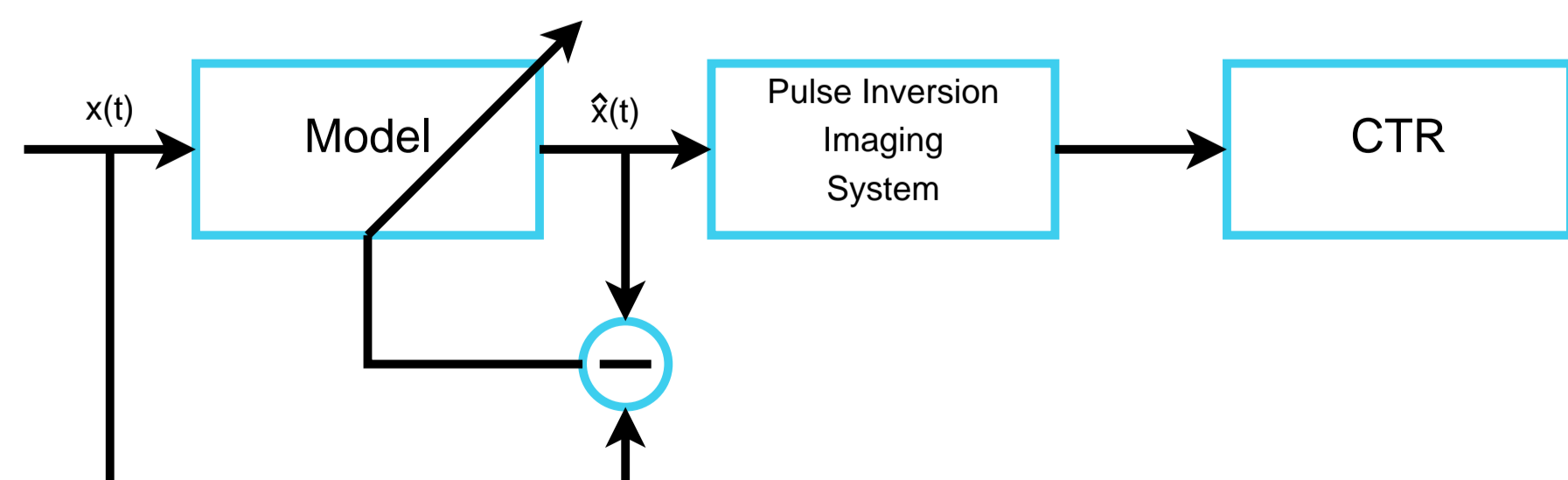


What are the properties of this optimal command? → Nonlinear signal

[1] S. Ménigot and J.-M. Girault, "Random excitation by optimized pulse inversion in contrast harmonic imaging", in *Acoustics 2012*, pp. 2895–2900, April 2012.

3. Objectives of Modelling

- Modelling the optimal command $x^*(t)$ including nonlinear components



- Finding model parameters Ξ by minimizing Mean Square Error

$$\Xi^* = \arg \min_{\Xi} (MSE) = \arg \min_{\Xi} \left(\sum_{t=0}^T [x(t) - \hat{x}(t)]^2 \right)$$

- Building a synthetic signal $\hat{x}(t)$

- Checking CTR performances for the synthetic input signal $\hat{x}(t)$

4. Optimal Command Modelling

$$\hat{x}(t) = G(t) \cdot \left[\sum_{k=1}^M \alpha_{1,k} \cos(2\pi k f t + \theta_{1,k}) + \sum_{k=1}^N \alpha_{2,k} \cos\left(2\pi \left(k - \frac{1}{2}\right) f t + \theta_{2,k}\right) \right]$$

Whole harmonic components and Half-whole harmonic components

$G(t)$ → Gaussian apodization; $\Xi = [\alpha^T, \theta^T, f]^T$

A. Frequency optimization: Newton-Raphson method

$$f_{i+1} = f_i - \frac{MSE(f_i)(f_i - f_{i-1})}{MSE(f_i) - MSE(f_{i-1})}$$

B. Amplitude and phase optimization for each iteration i

- Algebraic expression

$$\mathbf{x} = \Psi \vartheta,$$

$$\vartheta^T = [\alpha_{1,1} \cos \theta_{1,1}, -\alpha_{1,1} \sin \theta_{1,1}, \dots, \alpha_{1,M} \cos \theta_{1,M}, -\alpha_{1,M} \sin \theta_{1,M}, \alpha_{2,1} \cos \theta_{2,1}, -\alpha_{2,1} \sin \theta_{2,1}, \dots, \alpha_{2,N} \cos \theta_{2,N}, -\alpha_{2,N} \sin \theta_{2,N}].$$

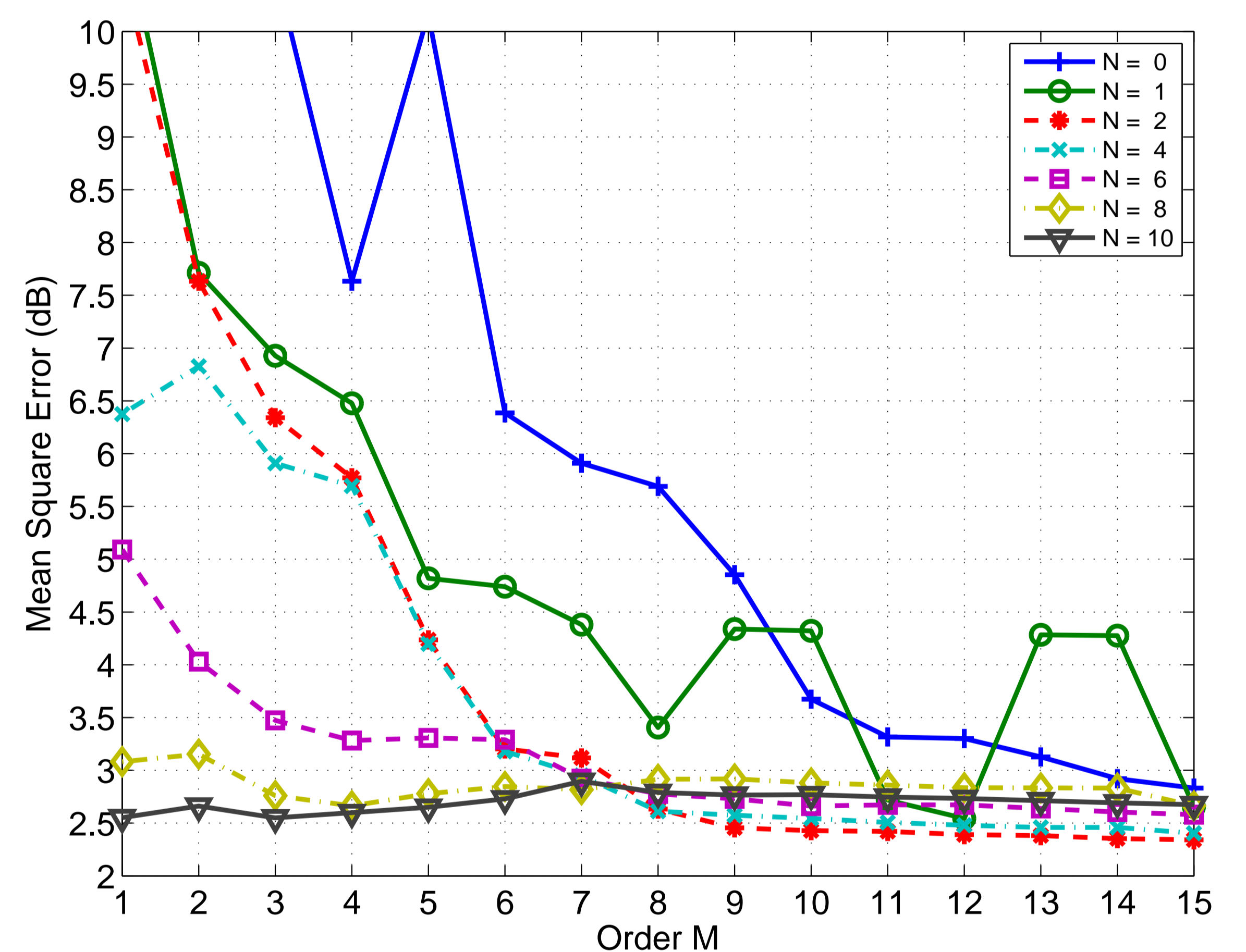
$$\Psi^T = (\Psi_1, \Psi_2, \dots, \Psi_T),$$

$$\Psi_t = [G(t) \cos(2\pi f t), G(t) \sin(2\pi f t), \dots, G(t) \cos(2\pi M f t), G(t) \sin(2\pi M f t), G(t) \cos(\pi f t), G(t) \sin(\pi f t), \dots, G(t) \cos(2\pi(N-1/2) f t), G(t) \sin(2\pi(N-1/2) f t)]$$

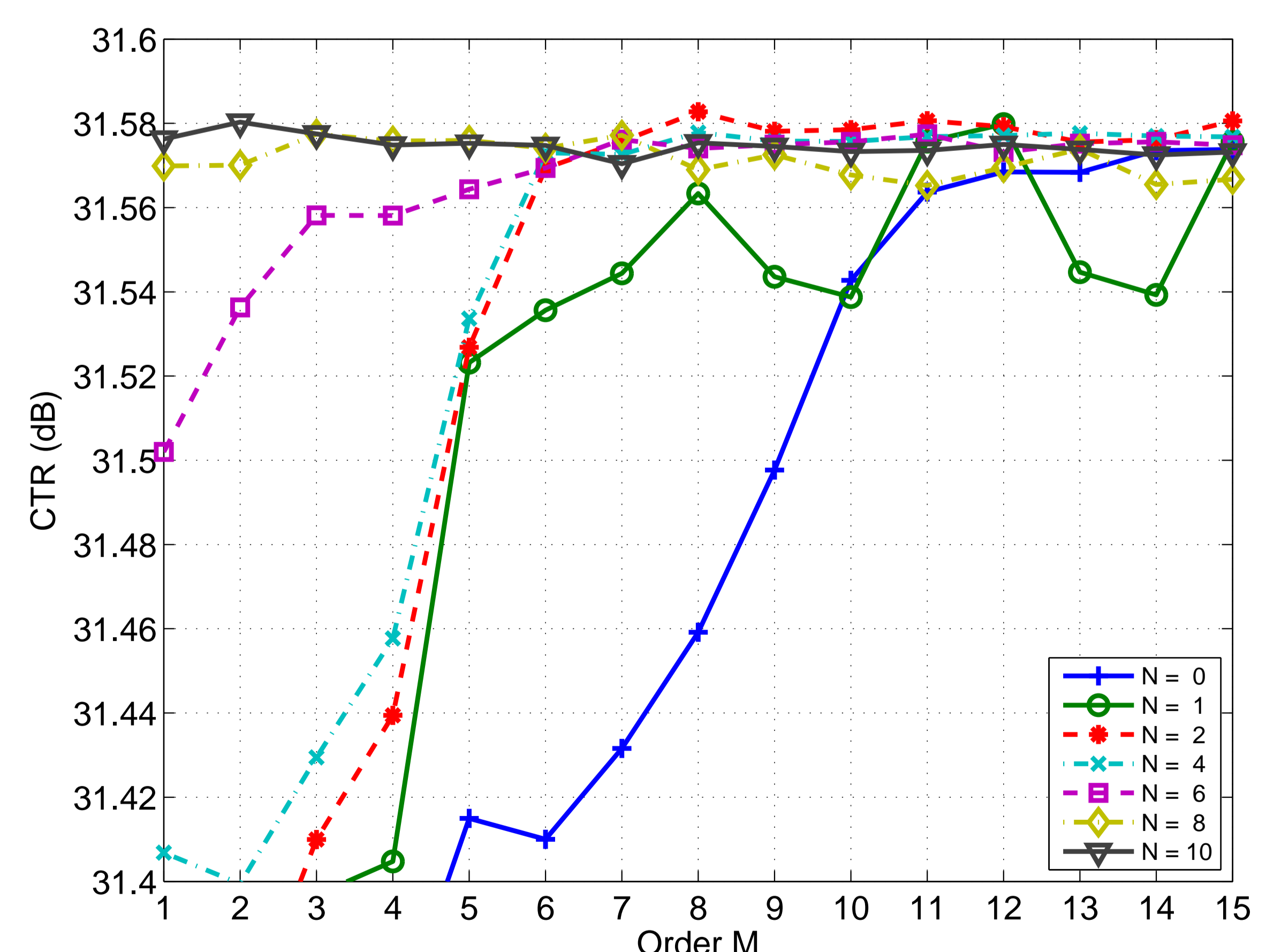
- Least squares method

$$\vartheta = (\Psi^T \Psi)^{-1} \Psi^T \mathbf{x}$$

5. Mean Square Error



6. CTR Performances Checking with the Synthetic Signals $\hat{x}(t)$



If $N = 1$ and $M = 0$, $x(t)$ is a Gaussian-modulated sinusoidal pulse where optimal frequency $f_0^* = 1.5 \text{ MHz}$, $\Rightarrow CTR = 30.3 \text{ dB}$

[2] S. Ménigot, J.-M. Girault, I. Voicu and A. Novell, "Optimization of Contrast to Tissue Ratio by Frequency Adaptation in Pulse Inversion Imaging", *IEEE Trans. Ultrason., Ferroelectr., Freq. Control*, in press, 2012.

7. Conclusions & Prospect

- Description of the optimal command
- Optimal command has harmonic and subharmonic components
- Prospect : transforming shape optimization in parameter optimization