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Automatic Approach Seeking Optimal Frequency Modulation Parameters In Chirp Inversion and Chirp Reversal Ultrasound Contrast Imaging

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I – Introduction

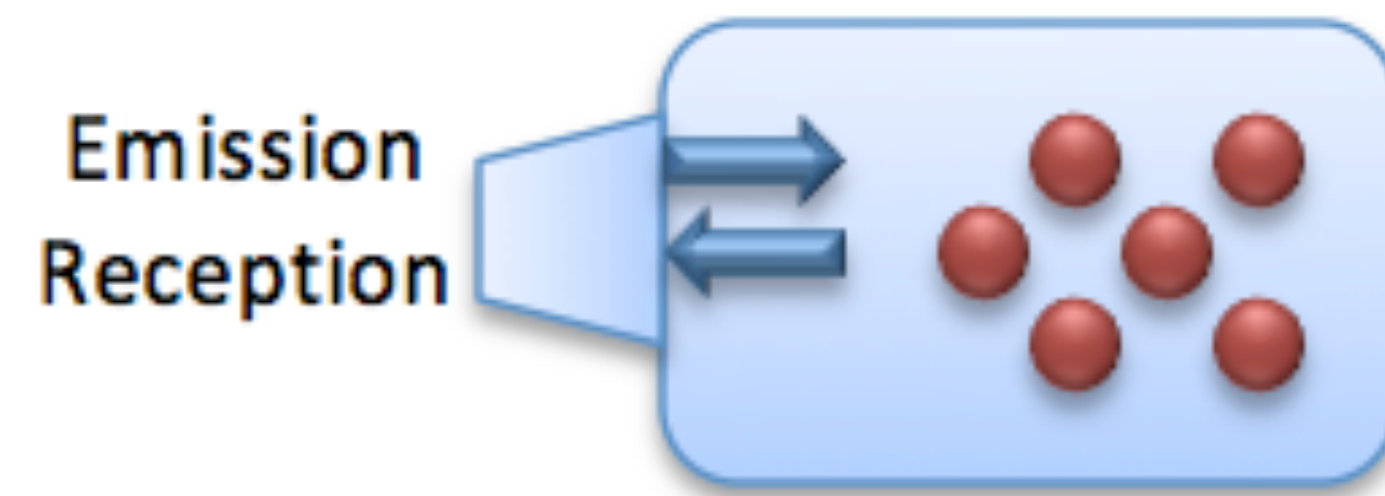
State-of-the art applications involving frequency coded excitations known as chirp excitations, are cutting edge in contrast ultrasound imaging. A question may arise: How does the manufacturer select the frequency modulation parameters of chirp excitations in clinical practice? The present study aims to select, automatically, the optimal frequency modulation parameters of chirp excitations by maximizing the backscattered power using two post-processing techniques: chirp inversion and chirp reversal imaging. Why the power? As the contrast-to-tissue ratio \nearrow the power backscattered by microbubbles \nearrow

$$CTR = \frac{P_{microbubbles}}{P_{tissues}}$$

II – Materials and Methods

Simulated Microbubbles with Matlab

- \nearrow Air-filled of diameter 5 μm
- \nearrow Immersed in blood mimicking fluid
- \nearrow Motion described by Modified Plesset-Rayleigh Differential Equation



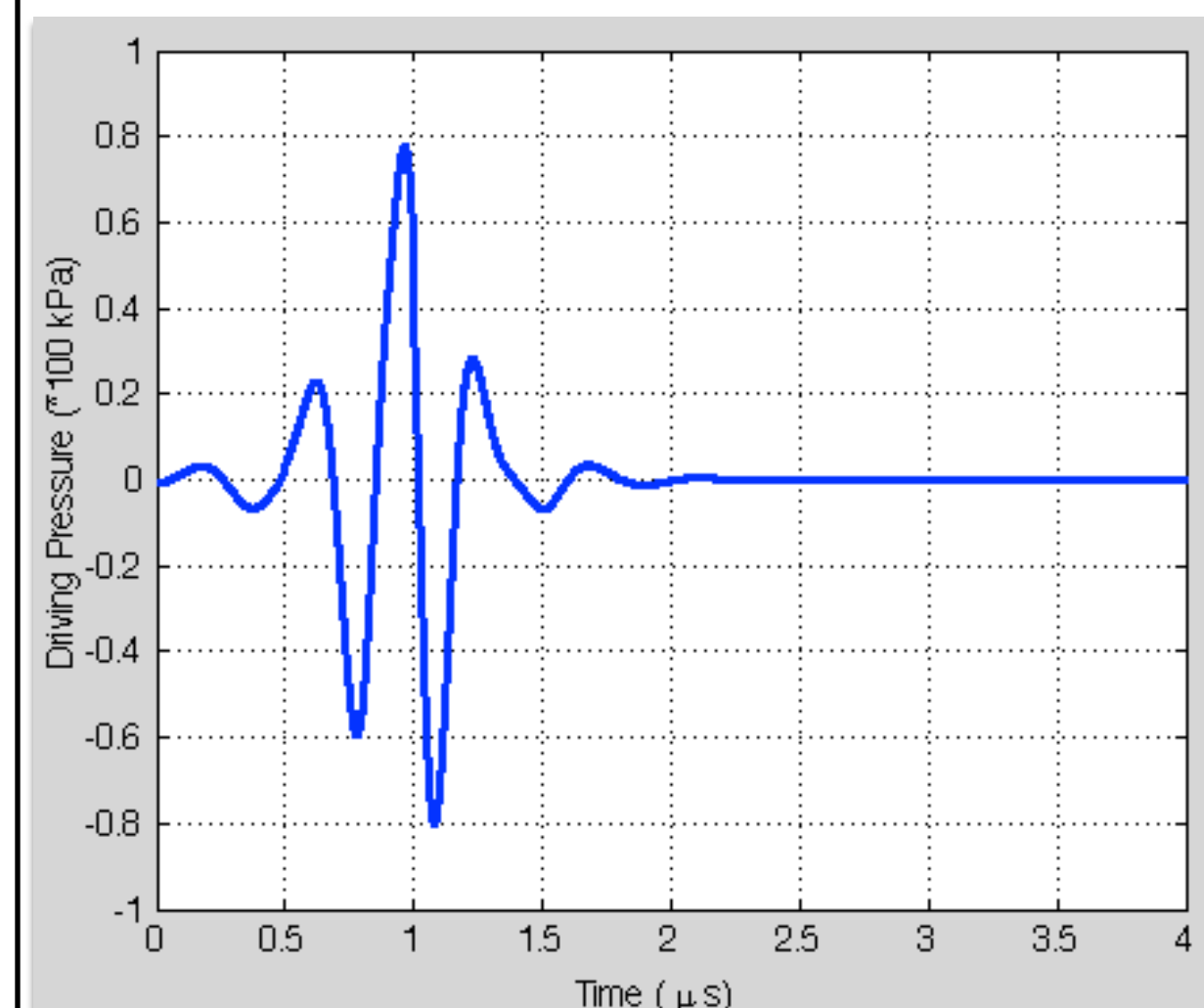
Emission/Reception

- \nearrow Transducer: Bandwidth 63%

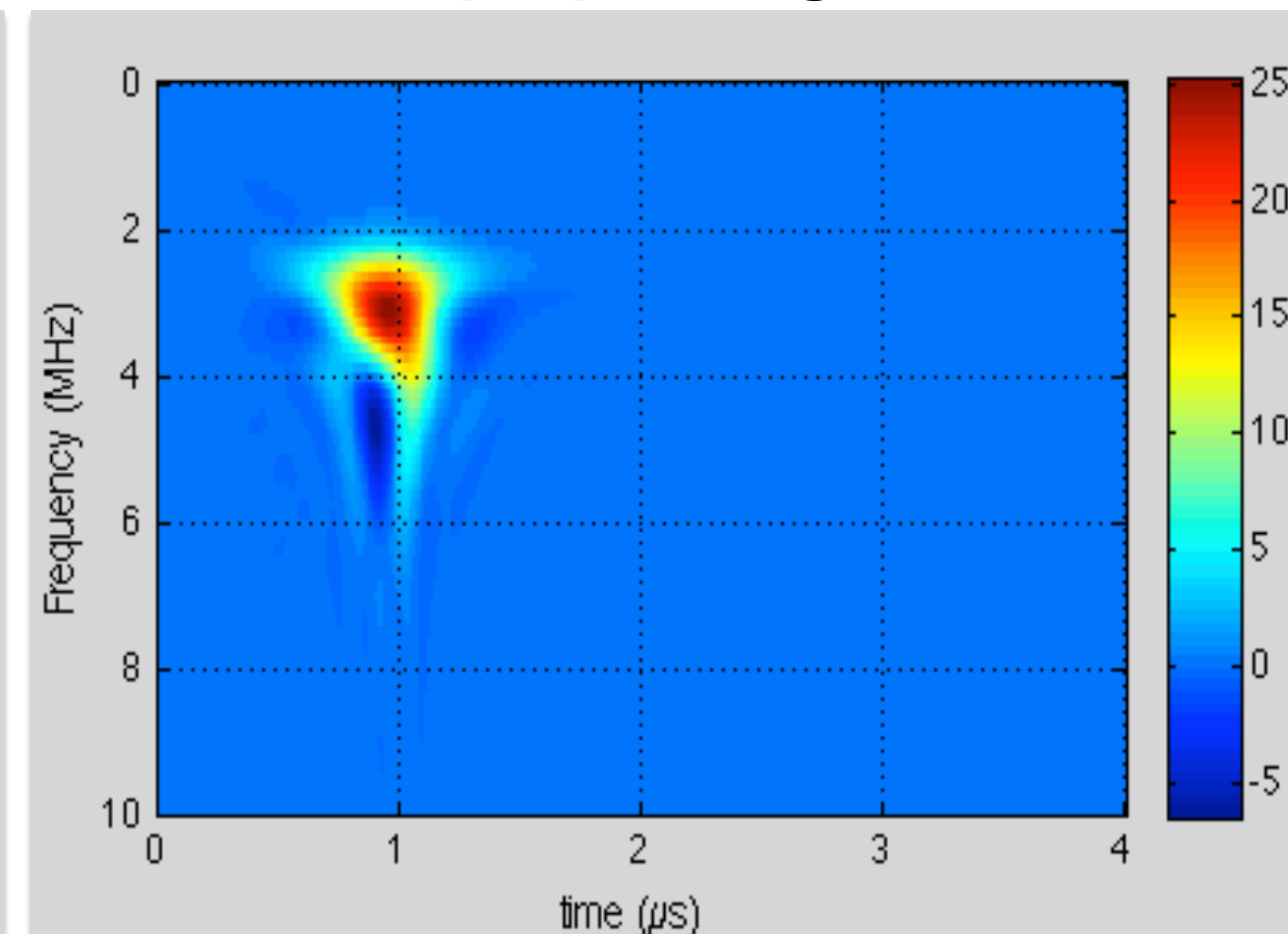
Chirp Excitations

- \nearrow Frequency modulated \rightarrow Linear frequency modulation (FM) law
- \nearrow Initial driving pressure \rightarrow 100 kPa \rightarrow NonLinear Response
- \nearrow Envelope \rightarrow Gaussian

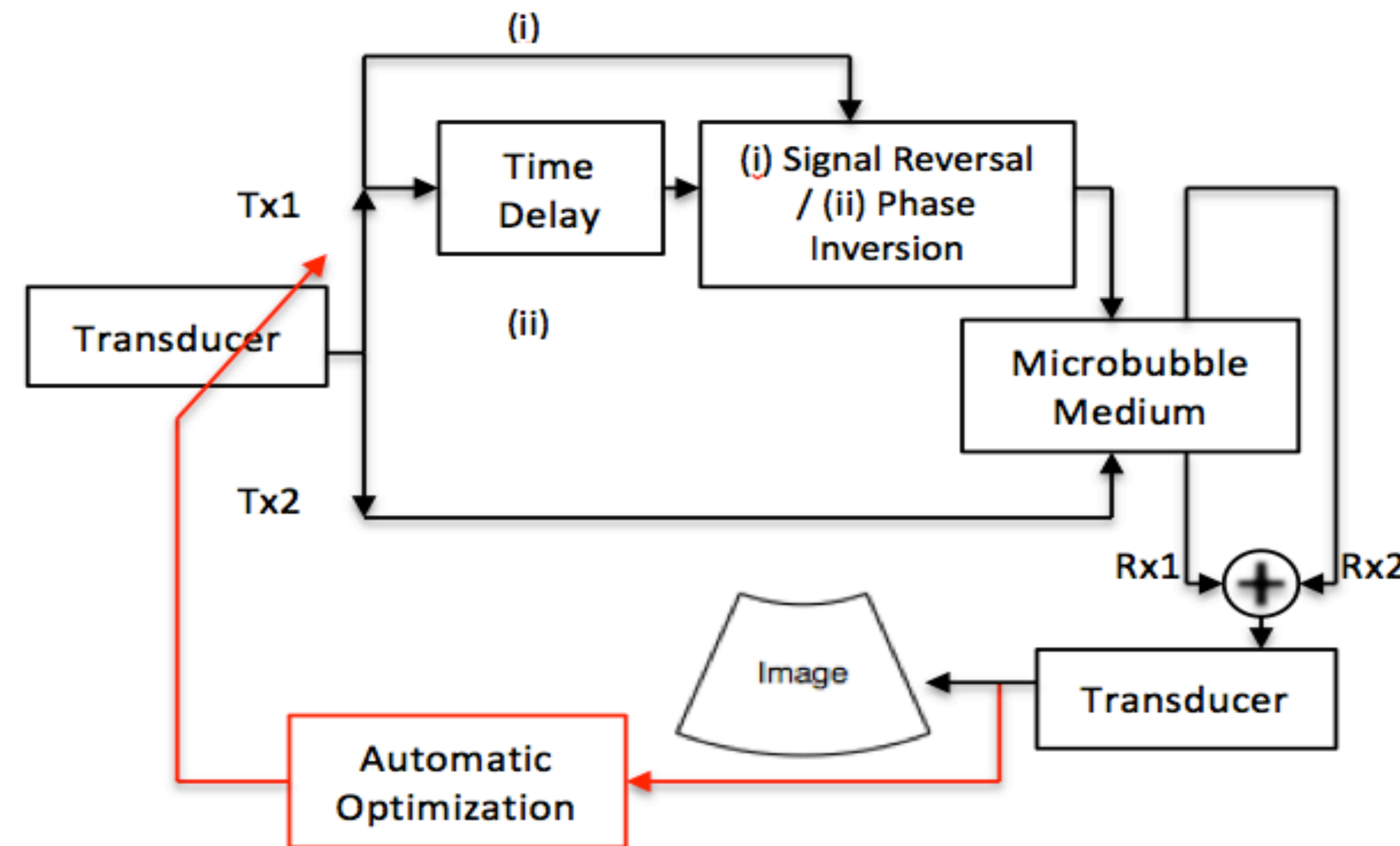
Transmitted Chirp ($\beta=0.03\text{MHz/s}$, $f_0=1.5\text{MHz}$)



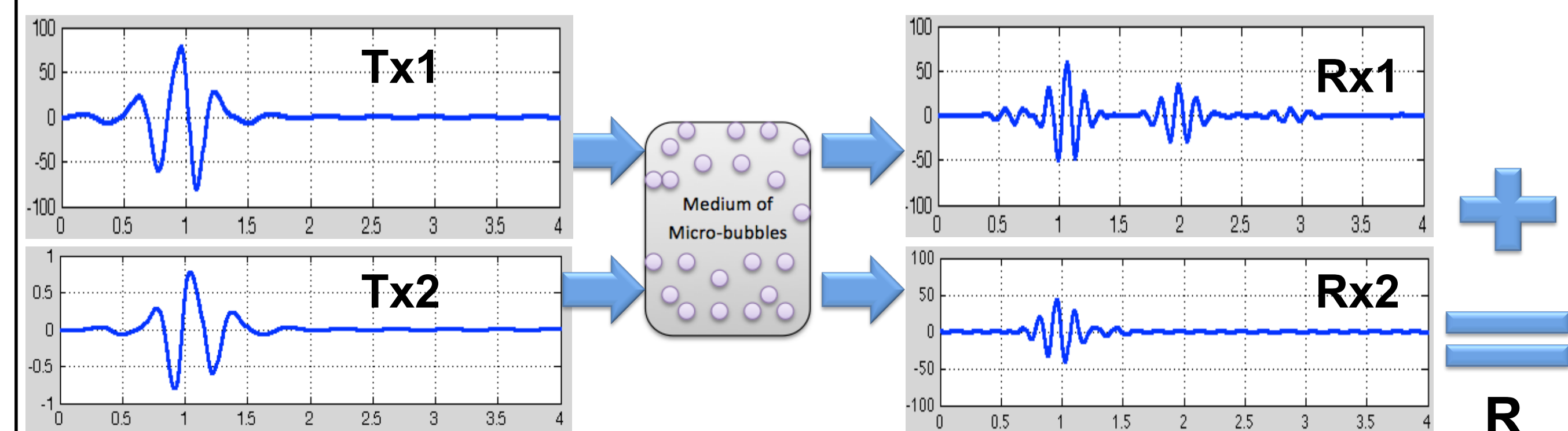
Chirp Spectrogram



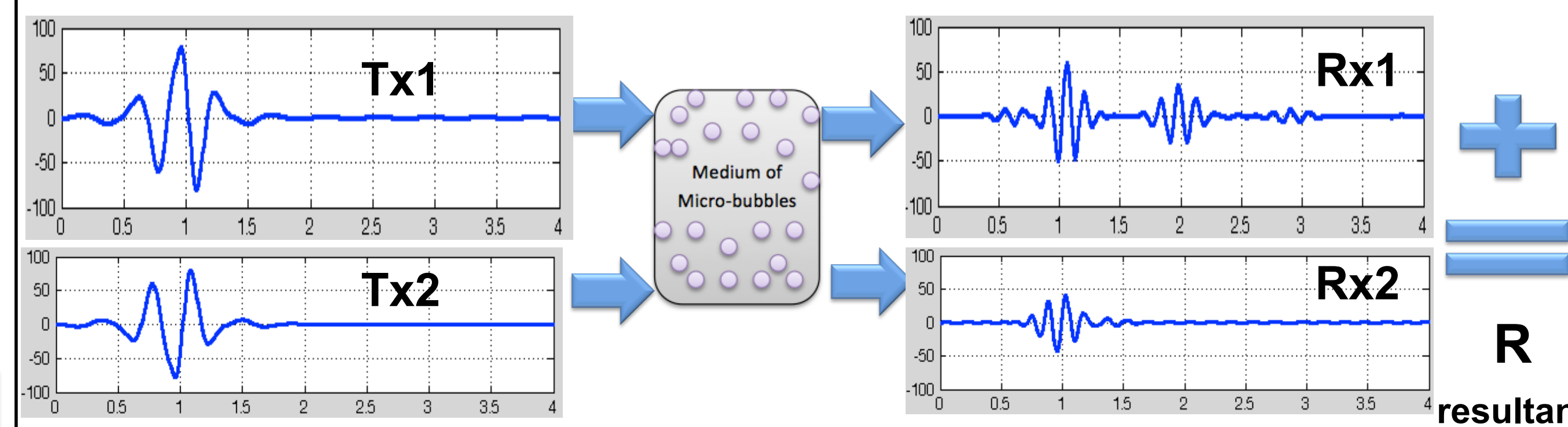
Block Diagram of Chirp Reversal and/or Chirp Inversion post-processing techniques.



Chirp Reversal



Chirp Inversion



Automatic Optimization Approach

- \nearrow Cost Function $J \rightarrow$ Resultant Backscattered Power

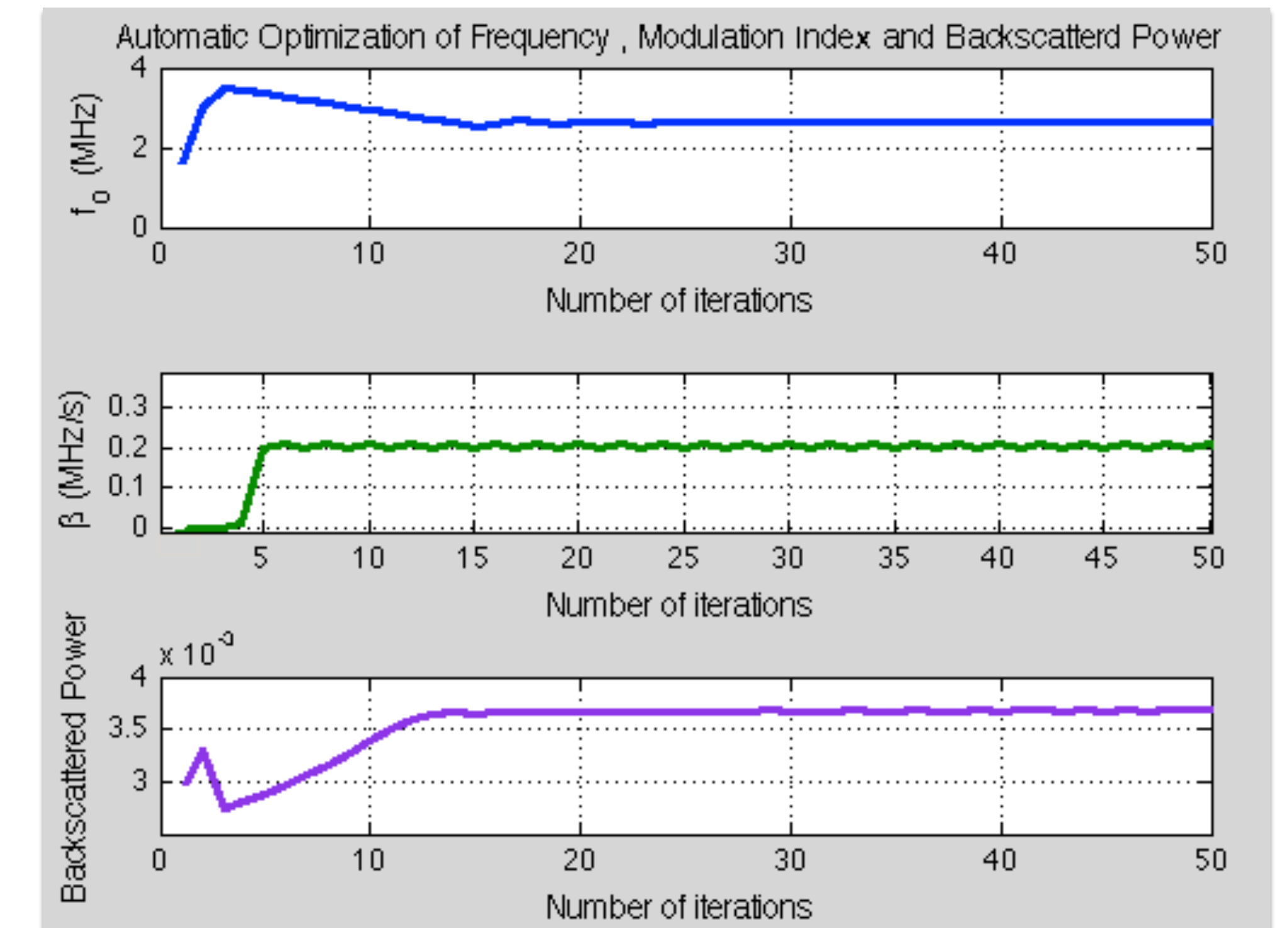
$$w_{k+1} = w_k + \mu_k \cdot \nabla J(w_k)$$

- \nearrow Automatic Optimization: Maximum Number of iterations $k=50$

$$\begin{pmatrix} f_{k+1} \\ \beta_{k+1} \end{pmatrix} = \begin{pmatrix} f_k \\ \beta_k \end{pmatrix} + \begin{pmatrix} \mu_{11} & \mu_{12} \\ \mu_{21} & \mu_{22} \end{pmatrix} \times \begin{pmatrix} \nabla f^P \\ \nabla \beta^P \end{pmatrix} \Rightarrow \text{Optimum}(f_o, \beta)$$

III – Simulation Results

- \nearrow Automatic versus Standard chirp reversal (currently available in literature) Gain \rightarrow 5.4 dB
- \nearrow Automatic versus Standard chirp inversion Gain \rightarrow 2.6 dB
- \nearrow Resultant backscattered power attained after 15 iterations
- \nearrow Central Transmitted frequency \nearrow 1.1 MHz
- \nearrow Frequency modulation index \nearrow 0.23 MHz/s



Processing Technique	Chirp Reversal		Chirp Inversion	
	Auto.	Stand.	Auto.	Stand.
Optimization	Auto.	Stand.	Auto.	Stand.
Modulation Law	Linear FM	Linear FM	Linear FM	Linear FM
Gain (dB)	-24.3	-41.7	-24.5	-31.5
f_0 (MHz)	2.2	3	2.2	2.75
Beta (MHz/s)	0.23	0.2	0.23	0.1

IV – Conclusion

- \nearrow Automatic Optimization by chirp reversal/ inversion converged to similar optimized parameters
- \nearrow Power gain by Chirp Reversal was advantageous over chirp inversion
- \nearrow Power Gain attained by automatic chirp reversal was significant compared to standard technique
- \nearrow The proposed Automatic approach may improve CTR of Ultrasound Images so we tend to validate it by experiment