Self-Supervised Parallel Transmit RF Pulse Design for 2D Spatially Selective Excitation

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Introduction

Selective excitation is a powerful technique in MRI that enhances imaging flexibility and quality by focusing on a specific region-of-interest (ROI), which requires high-quality radiofrequency (RF) pulses. Traditional RF pulse designs, such as the small-tip-approximation (STA) algorithm, effectively concentrate on the ROI but often leave residual signals outside the target, resulting in Gibbs ringing artifacts. Recently, Jang et al. developed a framework to optimize RF pulses[1], providing an alternative that eliminates reliance on a labeled dataset. However, this method employs a simple network architecture designed for single channel transmit, limiting its ability to capture intricate details inherent in the datasets.

Significance: Using the increasing degrees of freedom provided by pTx, we introduce a self-supervised approach uses a new network and penalty strategies for pTx to ensure accurate ROI excitation in complex regions.

Methodology

Our self-supervised learning framework employs an encoder-decoder architecture (Figure 1): the encoder, utilizing a convolutional neural network (CNN), captures global spatial features of input ROIs to generate RF pulses, while the decoder applies these pulses with gradients to simulate transverse magnetization for the comparison with input ROIs. We generated sufficient binary masks, each containing a closed shape (e.g., ellipse). 4-channel pTx simulations were conducted to obtain the B1+ maps and the gradient waveforms were designed based on a spiral-in trajectory. The overall training was optimized with the combination of several losses like mean-square error (MSE) and novel energy penalties. Additionally, we validated the framework on a single-channel transmit 3T MRI system using a phantom with a water-based central square, testing at 90° flip angles.

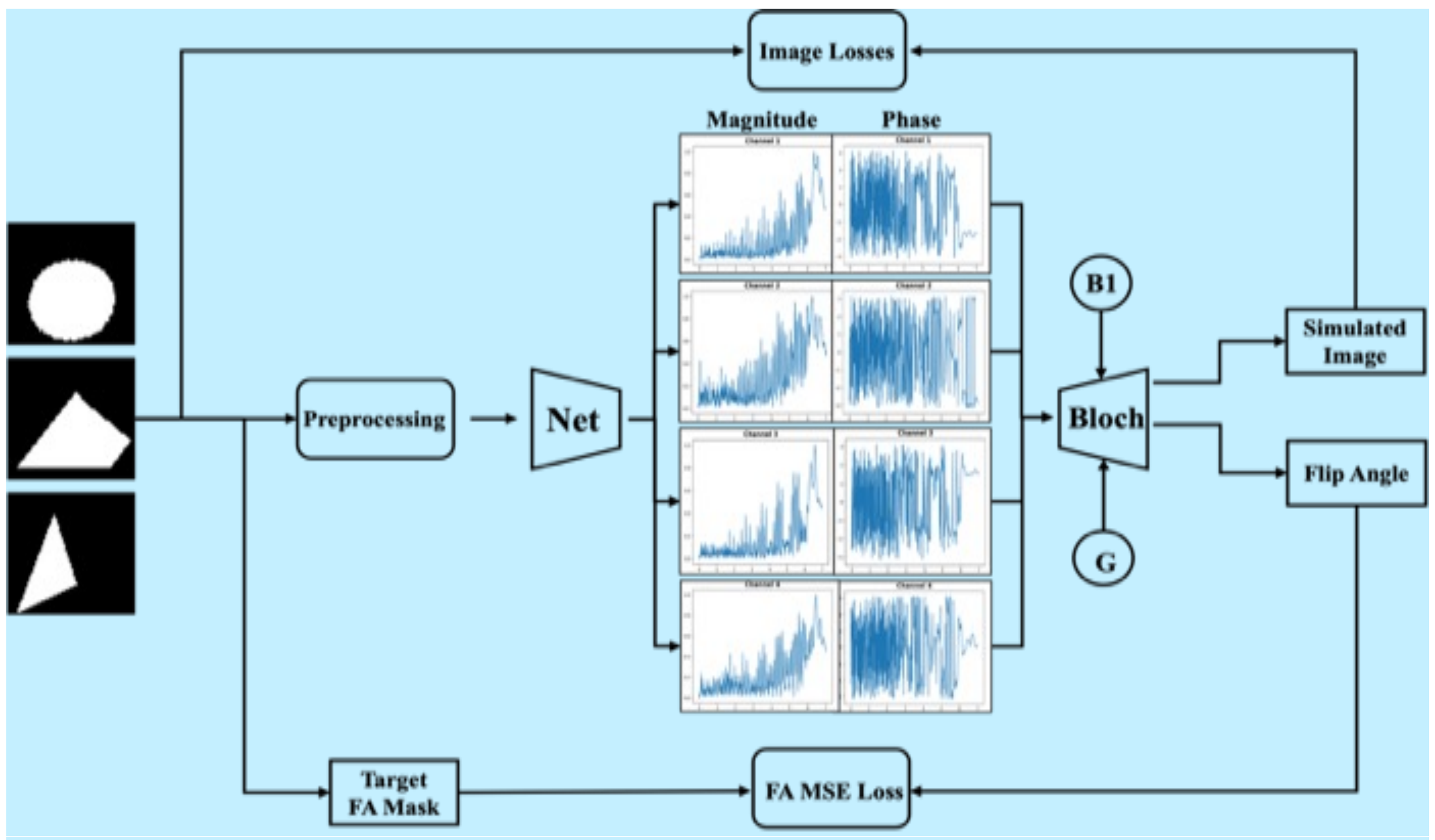

Figure 1. Flowchart of our proposed self-supervised framework for pTx RF pulse design. Target ROIs are input to Net module after a bilateral filter preprocessing, then the 4-channel RF pulse are predicted and then forward to Bloch simulator module to obtain the simulated image which will be used to compute the loss with input ROIs.

Results

The proposed framework successfully generated 2D spatially selective RF pulses for both pTx and single channel to target the ROI. In simulation and phantom plots (Figure 2 & 3), our framework reduced excitation outside the target area, minimizing ringing artifacts with MSE of 0.01, indicating close alignment between the simulated and target ROIs.

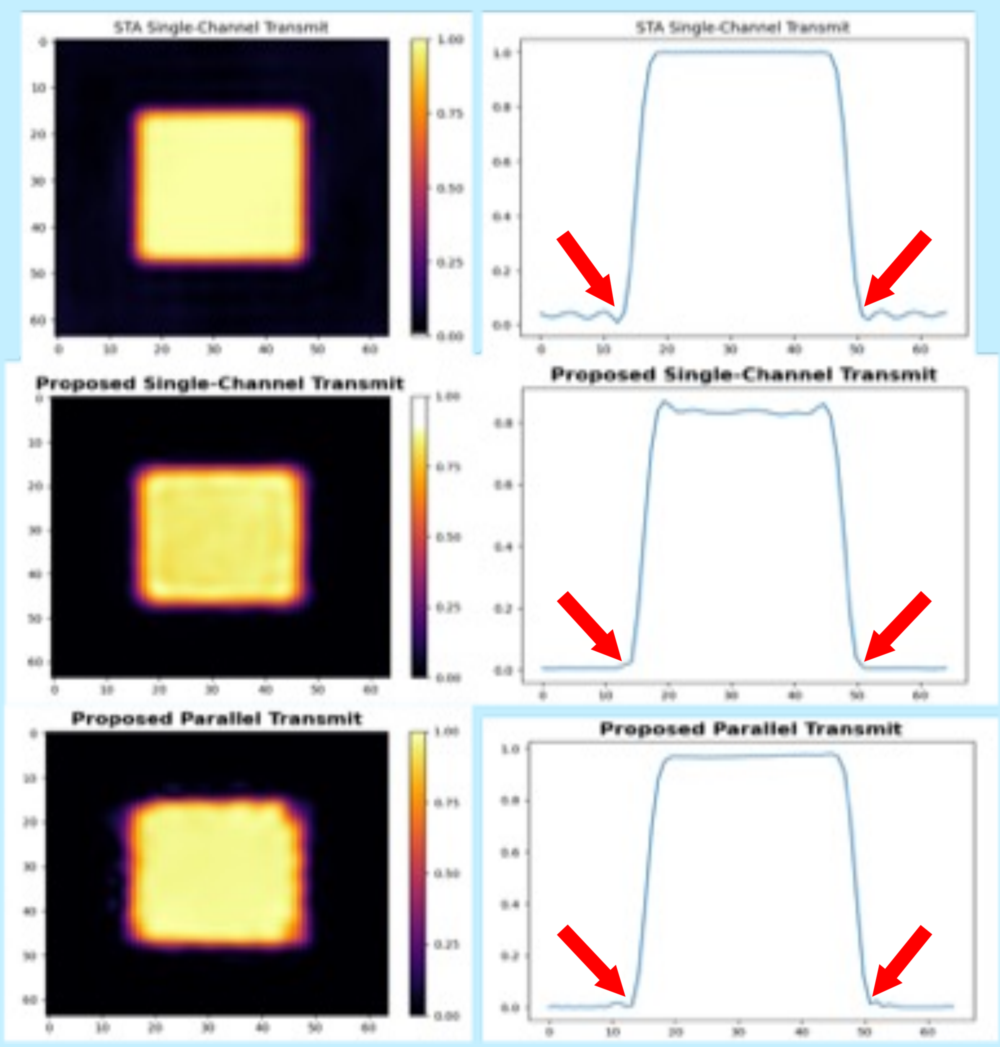

Figure 2. Simulated ROI and vertical slice profile by (**Top**) STA method; (**Mid**) proposed single-channel transmission; (**Bottom**) proposed pTx.

Red arrow points to residual signals outside region of ROI.

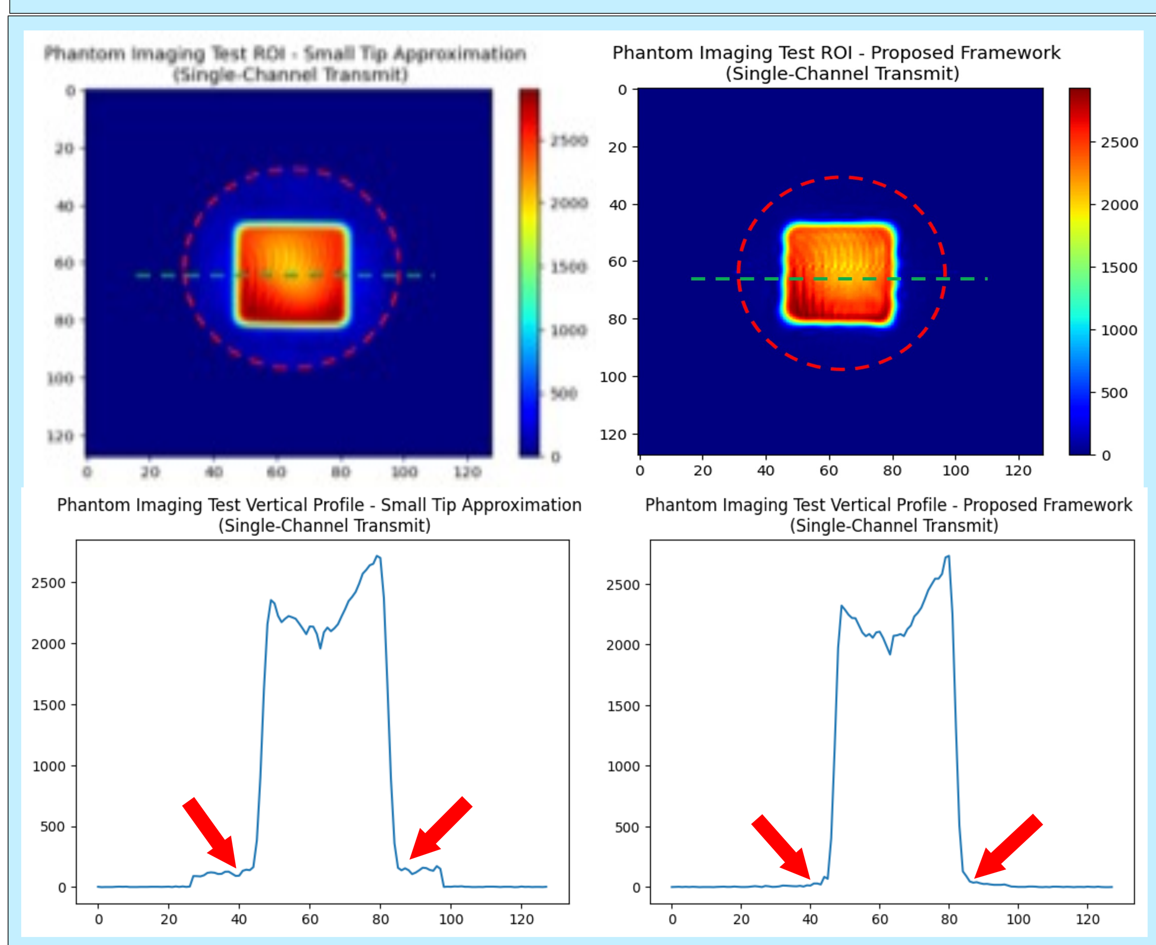

Figure 3. Single-channel phantom results and slice profile at 90° flip angle. (**A**) STA method; (**B**) our framework.

Red arrow points to residual signals outside region of ROI.

Conclusion

We introduced a self-supervised 2D selective excitation framework for pTx, validated by simulation and phantom experiments. This framework shows significant improvements over traditional STA methods. By eliminating reliance on predefined target RF pulses, our approach reduces residual artifacts and achieves a uniform excitation profile within the ROI, with future potential for clinical MRI applications.

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