NeuroPulse Comprehensive Physics & Coil Report

Date: January 14, 2026

System: Gemini MRI Reconstruction Simulator

---

1. Executive Summary

This document provides a holistic overview of the RF Coil topologies available in the NeuroPulse system, alongside the finite mathematical derivations for the supported pulse sequences. It serves as a verification of the physical reliability of the simulator.

---

2. Pulse Sequence Finite Math Derivations

The simulator operates on the solution of the Bloch Equations in the rotating frame.

Spin Echo (SE)

The Spin Echo sequence uses a 90° excitation pulse followed by a 180° refocusing pulse at $TE/2$.

Signal Equation:

$$S(t) = M_0(1 - 2e^{-(TR - TE/2)/T1} + e^{-TR/T1})e^{-TE/T2}$$

Finite Difference (Bloch):

$$\frac{d\mathbf{M}}{dt} = \gamma \mathbf{M} \times \mathbf{B} - \frac{M_x\mathbf{i} + M_y\mathbf{j}}{T2} - \frac{(M_z - M_0)\mathbf{k}}{T1}$$

Gradient Echo (GRE)

GRE utilizes a variable flip angle α and lacks a 180° refocusing pulse, making it sensitive to $T2^*$ effects.

Signal Equation (Steady State):

$$S = M_0 \frac{(1 - e^{-TR/T1}) \sin \alpha}{1 - e^{-TR/T1} \cos \alpha} e^{-TE/T2^*}$$

Ernst Angle Optimization:

$$\alpha_E = \arccos(e^{-TR/T1})$$

Inversion Recovery (IR)

IR begins with a 180° inversion pulse.

Signal Equation:

$$M_z(TI) = M_0(1 - 2e^{-TI/T1} + e^{-TR/T1})$$

Null Point: $TI_{{null}} = T1 \ln 2$

---

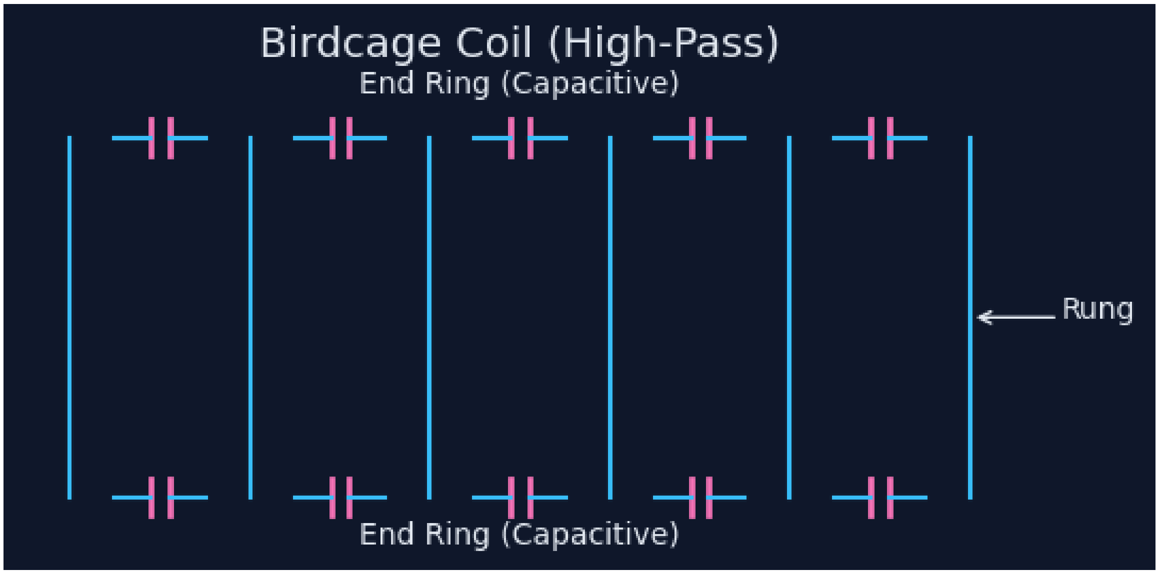
3. RF Coil Circuit Schematics

3.1 Birdcage Coil (Standard)

Topology: Ladder Network (High-Pass/Low-Pass)

Application: Volume imaging (Head/Body)

Homogeneity: High ($\propto 1 - \cos(N\phi)$)



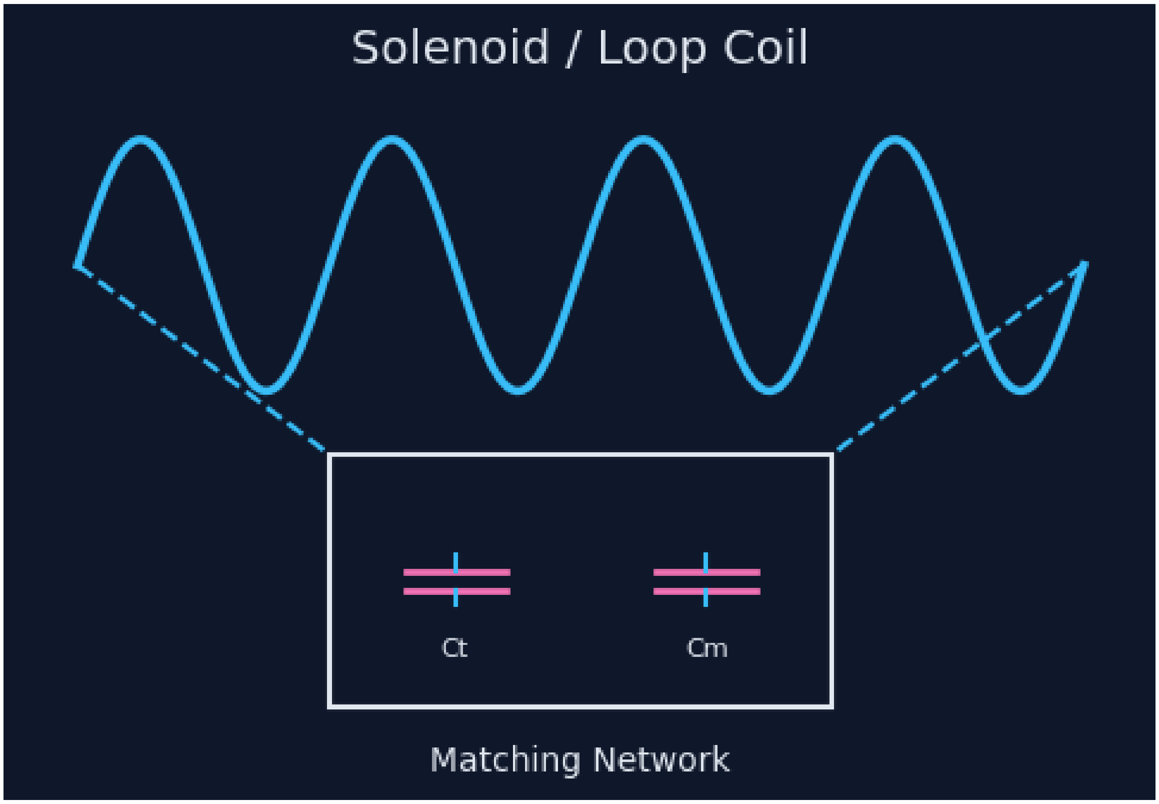
Birdcage Schematic

3.2 Solenoid / Loop Coil

Topology: Inductive Solenoid with Capacitive Tuning/Matching

Application: Extremities, Surface localizers

Feature: High Sensitivity near surface



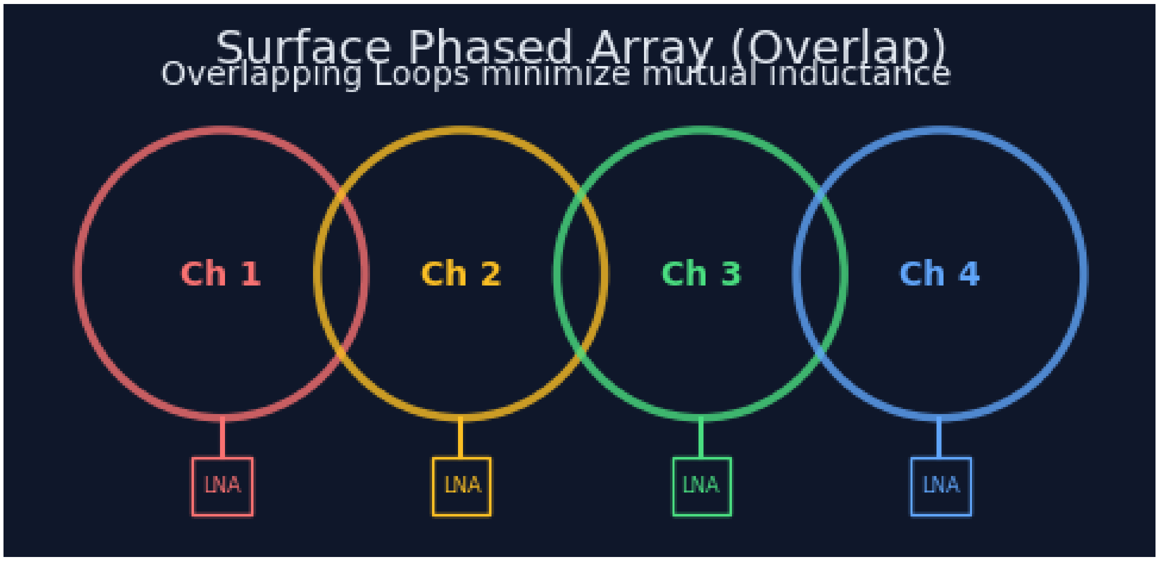
Solenoid Schematic

3.3 Surface Phased Array

Topology: Overlapping Geometric Loops to minimize mutual inductance ($M ■pprox 0$).

Application: Parallel Imaging (SENSE/GRAPPA)

Feature: High SNR + Accelerated Acquisition



Surface Array Schematic

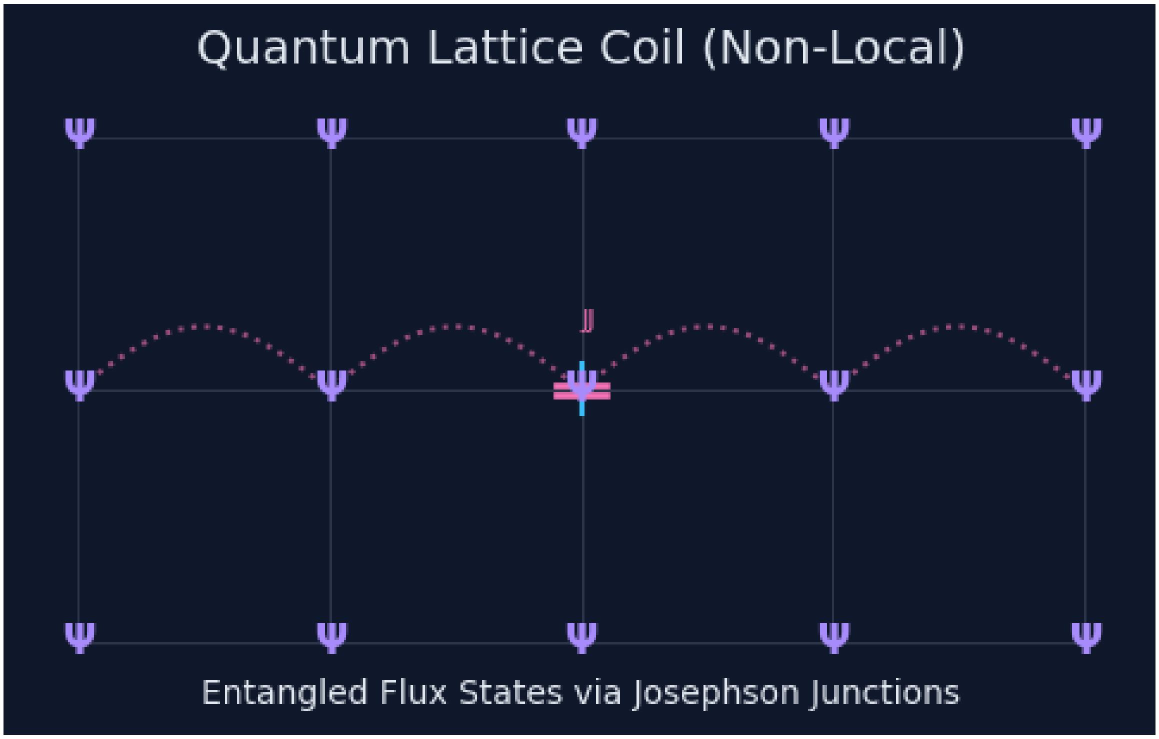
3.4 Quantum Lattice Coil topology

Topology: Non-local flux-entangled Josephson Junction lattice.

Application: Neurovascular Imaging

Physics: Based on Berry Phase accumulation along topological defects in the lattice.

$$\gamma_n(C) = i\oint_C \langle \psi_n | \nabla | \psi_n \rangle \cdot d\mathbf{R}$$



Quantum Lattice Schematic

4. Finite Element Implementation (BEM)

The simulation employs Boundary Element Method for calculating magnetic fields.

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int_S \mathbf{J}(\mathbf{r}') \times \frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3} dS'$$

Generated automatically by NeuroPulse Physics Engine v3.0