

Engineering Rotating Near-Field Envelopes Without Mechanical Motion

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Abstract

What “rotating field envelope that reinforces its own tail” means in buildable electromagnetics A deterministic design path starts by pinning down which of two different “rotation” targets you actually need, because each has a different (known) solution family: $B = y B \sin \omega t$ Rotating field vector (circular polarization at a point): at a fixed point in space, the magnetic field vector). This is the same idea used in RF magnetic spins with time (e.g., $B = x B \cos \omega t$, resonance, where a circularly polarized field is required for efficient excitation. This is achieved by generating two orthogonal field components with equal amplitude and a

phase shift—often by a quadrature feed.

Rotating spatial mode (a “hotspot” or lobe that travels around a ring): the pattern moves around a circle, e.g., $B(\theta, t) \propto \cos(\theta - \omega t)$. This requires a progressive phase distribution around the structure, not merely two orthogonal bulk components. In practical coil work, the well-known rule for the fundamental rotating mode is: current phase is set equal to the angular position (the mode), which directly creates a traveling/rotating mode around the circumference.

Your phrase “reinforces its own tail prior to decay” maps to standard resonator language: the structure must have field memory (finite ring-down time) long enough that the circulating/traveling mode remains coherent over multiple oscillations. In classical resonators that’s captured by the quality factor, with used in ring-down measurements and resonator characterization.

lifetime relations such as $Q = \omega \tau / 2$ Finally, “clamped to near field” means the system is dominated by non-radiative/reactive behavior close to the source. Near-field behavior is characterized by different spatial falloffs than true radiation (e.g., reactive terms can scale as $1/r^2$ the in-phase relationship of far-field waves. vs radiative $1/r^3$ or), and by phase quadrature between H rather than $1/r$ Experimentally proven buildable motifs that generate rotating magnetic fields Polyphase windings create rotating fields (industrial and laboratory reality) A rotating magnetic field is routinely produced by multiphase excitation: distribute conductors around a region and drive them with phase shifts that track the spatial angle. This is the same physical mechanism used for non-contact electromagnetic stirring, where single-phase or multiphase alternating fields induce currents and generate a generally rotational Lorentz force that can be engineered into desired flow patterns.

While stirring is not your application, it is a hard experimental anchor: multiphase → rotating field/ forcing is not speculative; it’s engineered and tunable.

MRI-class solutions: birdcage-style resonators produce a rotating RF magnetic field MRI coil engineering is one of the cleanest “buildable” references for what you want: rotation without mechanical motion, near-field dominance, and resonant persistence. A classic birdcage description shows the mechanism in almost the same

form you’ve been trying to induce geometrically: a phase shift between successive rungs (e.g.,) produces a resonantly rotating $360 / N^\circ$ field.

More importantly, an open cage (birdcage variant) design paper explains the deterministic rule-set:

treat the structure as a transmission-line-based coil with unit cells;

choose a target phase shift per unit cell;

control the characteristic/Bloch impedance to avoid reflections (reflections destroy the intended traveling rotation);

enforce a rotating mode by setting current phase equal to rung angular position for the mode;

drive the coil in quadrature with two ports

apart for circular polarization mode.

That “phase = angular position” statement is the exact deterministic analog of “the field reinforces its own tail”: it is the eigenmode of a periodic ring network, and the design objective is to realize that eigenmode with minimal reflection/discontinuity.

Plasma RMF antennas: rotating magnetic fields used to drive currents (and extend lifetimes) The rotating-magnetic-field (RMF) technique is used in plasma experiments to drive currents and sustain configurations—again demonstrating nonmechanical rotation as a practical tool. A high-power RMF system description (built at Los Alamos National Laboratory and used at the out of phase so their summed field rotates; the antennas are embedded as the inductors of resonant) explicitly states the core engineering: two antenna systems are driven University of Washington tank circuits. A separate RMF plasma formation report from Princeton Plasma Physics Laboratory describes “odd-parity RMF” applied at MHz to form and control plasma, reinforcing the idea that phase-controlled rotating fields are physically robust and measurable. The relevance to your build goal is structural: RMF systems implement rotation with (a) orthogonal coil sets, (b) quadrature phase control, and (c) resonant power electronics, rather than hoping the conductor path delay alone generates the required phase relationships.

Geometries that enforce “tail reinforcement” via resonance and modal phase control Ring resonators: the most literal “tail meets head in phase” condition If the physical idea is “a wave goes around and adds to itself,” the canonical buildable form is a ring resonator. Its simplest resonance condition is geometric: This is written explicitly for a microstrip ring resonator as $2\pi r = n \lambda g$, mean circumference = $n \lambda g$ This is the deterministic version of “reinforcing its own tail”: after one loop, the phase returns to $2\pi n$

supports a stable mode. However, a crucial practical point: a passive resonator can store and shape energy, but cannot amplify net energy. “Amplification” must mean either (a) increased local field magnitude due to modal concentration, or (b)

active drive/feedback that replenishes losses—exactly what RMF power systems and RF resonators do. Periodic ring networks: birdcage/opencage as a controlled phase-advance lattice The opencage/birdcage approach is essentially a periodic lattice of unit cells around a circumference, where you explicitly choose:

per-cell phase advance (your “rotation rate around the ring” target), and impedance matching (Bloch impedance) to suppress reflections that would turn a traveling/rotating mode into a distorted standing-wave mixture.

This is directly relevant to your spiral-segment idea because it says: if you want a rotating mode around a perimeter, you do not guess the phase from wire length alone—you design the network so the eigenmode has the desired phase progression. Lumped-mode resonators (split-ring / loop-gap): compact MHz–GHz near-field magnetic sources Where ordinary cavities are bulky, split-ring and loop-gap resonators are used as compact magnetic resonance structures. A loop-gap resonator is cited as producing a large, uniform microwave magnetic field per incident power, with high homogeneity/filling factor (reported advantages for echo spectroscopy). Engineering guidance for multi-loop/multi-gap forms emphasizes a key property you care about: the magnetic flux “return path” can be confined near the resonator, raising control over where the field energy lives (helpful when you want near-field confinement rather than radiation).

Strongly coupled resonant “tails”: mid-range near-field coupling as a documented phenomenon If your intuition is “use a weak tail field but keep it coherent long enough to matter,” that is extremely close to the physics of strongly coupled resonant wireless power transfer. The coupled-mode formalism in the Massachusetts Institute of Technology theoretical treatment explicitly frames the mechanism as coupling via localized, slowly-evanescent near-field patterns and defines the operational requirement: coupling rate must exceed loss rates (strong coupling). The experimental demonstration (published in Science) shows efficient nonradiative (near-field) magnetic resonant induction at MHz and highlights use of resonant objects coupled “through the tails of their nonradiative fields.” This does not automatically create a rotating envelope by itself, but it provides a rigorously validated “tail can matter before decay” regime—provided the resonant system is designed so that coupling and coherence dominate losses.

What really extends the effective radius of a near-field emitter A near-field source does not have a hard “boundary,” but its usable radius is controlled by a few engineering levers: Increase the source’s magnetic dipole strength (more current and/or larger effective loop area). The near-zone magnetic field of a small loop is treated as a calibration standard by the National Bureau of Standards, and the work emphasizes that accurate near-zone computation must include finite propagation-time corrections at higher frequencies. That’s a reminder that near-field strength is ultimately set by current distribution and geometry; it is not arbitrary.

Raise resonator

to increase stored energy (field “memory”). High

means losses are low and the field persists longer, enabling coherent interaction in the tail region (this is a central point in resonant near-field coupling theory and experiments). Shape the field with multiple elements (phasing/focusing). Polyphase and quadrature methods can synthesize rotating or traveling modes; by controlling spatial phasing you can concentrate energy or create a moving lobe rather than a static dipole-like pattern. This is exactly how opencage/birdcage designs pick the phase rule and then realize it electrically.

Suppress unwanted radiation channels so your input power stays reactive/stored instead of radiated. Radiation dominates at distance because radiative terms fall off more slowly ($\sim 1/r$) than reactive near-field terms ($\sim 1/r^2 \sim 1/r^3$ or).

Practical methods include symmetry/balanced feeds, shielding strategies, and magnetic near-field probe concepts (shielded loops reduce E-field pickup and emphasize H-field measurement/interaction). Exotic but conceptually informative: anapole/toroidal configurations demonstrate that far-field radiation can be strongly reduced by destructive interference of multipoles, which is a formal way to say “keep energy localized.” These are often realized in metamaterial or carefully shaped current distributions. They are not

the simplest build path for coils, but they confirm that “near-field strong / far-field weak” is possible in principle when multipole cancellation is engineered. Expected phenomena and energy balance in the rotating near-field regime Energy flow is not the same thing as field rotation A rotating vector or rotating spatial mode does not imply net outward energy flow. In the near-field/ B reactive region, power can flow outward and back within a cycle (what circuit designers call reactive power). Instructional antenna treatments explicitly contrast near-field behavior with far-field plane waves and tie this to the phase relationship of H 25. The Poynting-vector picture: where power actually goes near conductors A didactic analysis by J. D. Jackson shows that energy launched by an antenna is guided near the structure and only later “shakes free” into the asymptotic radiation pattern; close to the source you see strong transverse guidance and localized “squirting” from the feed region depending on geometry. This is a useful lens for your simulations that show field concentration near terminals: terminal/feed regions are real power-flow bottlenecks in many antenna-like structures. Resonance as the only passive “reinforcement” In passive structures, the only way the “tail reinforces the head” is modal coherence plus stored energy. Resonance plays an essential role in improving effective performance relative to nonresonant inductive coupling; in the strongly coupled resonant WPT formalism, efficiency hinges on operating on resonance in the strong-coupling regime.

Deterministic circuit motifs that implement rotation For buildable systems, rotation is typically enforced electrically rather than hoped-for geometrically:

Quadrature hybrid / 90° coupler: single RF input → two outputs equal amplitude, difference, widely used to generate circular polarization. phase

Two orthogonal coil sets + quadrature: simplest rotating-field generator (used explicitly in RMF plasma systems).

Periodic resonator with phase advance per cell: birdcage/opencage logic (set phase progression and impedance per cell; prevent reflections).

Active feedback loop (oscillator): if you truly need sustained circulation beyond passive losses, you need loop gain and phase closure (Barkhausen-style conditions), exactly as RF oscillator theory states. Astrophysical anchor: the light cylinder analogy and its limits The “light cylinder” in pulsar physics is the cylindrical radius where perfect corotation would require tangential velocity . A NASA c technical report on pulsar magnetospheres cites the light-cylinder radius as $R = cT / 2\pi$ and discusses the transition from closed to open field lines near that scale. The canonical pulsar electrodynamics model describes a corotating magnetosphere inside the light cylinder and open field lines passing through it. For engineering purposes, the useful takeaway is narrow:

A “light-cylinder-like” radius is a way to talk about pattern rotation rate ($\tau \omega \sim c$), not a universal boundary where fields must “start” or “stop.” In a small engineered

resonator, the rotating pattern is a mode shape; it can exist well inside structures and does not require a literal corotation surface in free space.

In lab devices, what matters is whether coherence (Q /lifetime) and phasing survive over the region you care about, and whether radiative loss channels are suppressed enough that the system remains near-field dominated. Glossary of terms for this design space Birdcage coil / open cage coil: a distributed RF resonator made of rungs and end rings; supports multiple modes. Driving the fundamental mode with appropriate phase progression and quadrature excitation produces a rotating (circularly polarized) field. Bloch impedance: the effective characteristic impedance of a periodic unit-cell structure; matching it around a ring suppresses reflections so the intended traveling/rotating mode is not corrupted.

Circular polarization (CP) mode: two orthogonal field components equal amplitude in quadrature, producing a rotating vector at a point. In coils, realized by quadrature drive and/or degenerate modes.

Coupled-mode theory (CMT): a framework describing energy exchange between resonant modes; used to quantify strong coupling and efficiency in resonant near-field energy transfer. Electrically small loop (magnetoquasistatic source): a loop with size where near-zone magnetic $\ll \lambda$ fields dominate and can be computed accurately with near-zone formulas; used as calibration standards in metrology.

Light cylinder: in pulsar magnetospheres, the radius where corotation speed equals c ; marks the scale at which field-line topology and current systems change (closed-to-open). Near field (reactive / radiating near-field): regions close to a source where fields are not yet plane-wave-H like; reactive components can dominate and decay faster with distance than radiative terms, and are not necessarily in phase.

Q factor (quality factor): a measure of resonator loss; higher

means longer field persistence ("ring-down") and narrower bandwidth, enabling more coherent interaction before decay. Rotating magnetic field (RMF): a magnetic field vector that rotates in time, typically produced by two orthogonal coil sets driven

out of phase; used in plasma current drive and other applications.

Open birdcage coil for head imaging at 7T - Institut Langevin

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