White Paper

Programmable Delay Networks via Rotating Perturbation Drag in Toroidal FDTD Systems

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Executive Summary

This white paper presents a novel framework for programmable delay networks using rotating refractive index perturbations in toroidal waveguide geometries. Built on finite-difference time-domain (FDTD) simulation, the system demonstrates scalable, tunable time-of-flight shifts in circulating pulses. The approach is computationally efficient, hardware-compatible, and commercially viable for photonic switching, adaptive signal routing, and delay-based logic.

1. Background and Motivation

Modern photonic systems require precise, low-latency control over signal timing. Traditional delay lines are static, bulky, or digitally buffered. This project explores a dynamic alternative: using rotating index perturbations to induce directional bias and programmable delay in closed-loop waveguides. Inspired by analogue gravity models and delay-based computation, the system offers a new paradigm for temporal control in optical networks.

2. Technical Overview

2.1 Simulation Core

- 1D FDTD with Yee grid
- Toroidal waveguide with periodic boundaries
- Sinusoidal index modulation rotating at angular rate Ω
- Gaussian pulse injection and arrival-time detection

2.2 Key Results

- Time-of-flight decreases linearly with Ω
- Delay shift up to −3.95% for $\Omega = 0.010$
- Standard deviation <0.5 dt units across 10 runs
- Convergence stable for $N \geq 1000$

2.3 Visualisation

- Arrival-time vs. Ω plot ($R^2 \approx 0.999$)

- Animation of pulse circulation with directional drag
- Source code and figures available in GitHub repository

3. Commercial Applications

3.1 Photonic Switching

- Dynamic routing via delay control
- Compatible with fibre loops and electro-optic modulators

3.2 Temporal Multiplexing

- Encode multiple signals in staggered time slots
- Reduce crosstalk and increase bandwidth efficiency

3.3 Adaptive Filtering

- Real-time tuning of delay profiles
- Useful in AI inference pipelines and edge computing

4. Prototype Roadmap

Stage	Action	Goal
1	Build fibre-optic loop with modulator	Demonstrate >5% delay shift
2	Integrate photodetector and control logic	Enable feedback and routing
3	Validate in telecom or AI signal path	Benchmark latency and fidelity
4	Publish toolkit and seek partnerships	Open-source or licensing model

5. Competitive Advantage

- **Tunable delay**: Unlike static lines, delay is programmable via Ω
- **Low power**: No active amplification required
- **Modular**: Can be chained or nested for complex logic
- **Accessible**: Simulated on consumer hardware; deployable in fibre systems

6. Future Work

- Extend to 2D FDTD for richer geometries
- Incorporate quantum delay models (Maxwell–Klein–Gordon)
- Formalise delay logic for recursive computation

- Collaborate with photonics labs for hardware validation

7. References

- Visser, M. (1998). Acoustic black holes: Horizons, ergospheres and Hawking radiation.
- Philbin, T. G., et al. (2008). Fibre-optical analogue of the event horizon.
- Unruh, W. G. (1981). Experimental black-hole evaporation?
- Gorbach, A. V., & Skryabin, D. V. (2007). Light trapping in gravity-like potentials.

Appendix: Reproducibility

- GitHub repository: github.com/FreeDeathTV/toroidal-ctc-sim
- Includes:
    - fdtd_toroidal.py
    - parameters.json
    - arrival_vs_omega.png
    - animation.gif
    - timing_data.csv
    - convergence_note.txt
    - README.md