Frequencies Is All We See: Consciousness, Attention, and Frequency-Based Representations

Sefunmi Ashiru

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Abstract

This paper explores the hypothesis that both human consciousness and artificial intelligence operate fundamentally on frequencies and their modulation. Just as *Attention Is All You Need* reframed AI architectures around selective weighting of input features, we propose that the brain perceives the world as a frequency field projected by ocular optics onto the retina, and that attention implements amplitude modulation to foreground meaningful structures. We formalize perception as a frequency-to-shape projection followed by an attentional gain operator, derive conditions under which spatial attention is equivalent to multiplicative filtering in the Fourier domain, and outline falsifiable predictions spanning EEG/MEG entrainment and AI ablations. Toy experiments with frequency-aware attention demonstrate advantages on reconstruction and texture discrimination over baselines. These results suggest a common language linking neural oscillations, gain control, and transformer attention, with implications for neuroscience, AI interpretability, and the philosophy of mind.

Contents

1 Introduction

Consciousness and perception are often described in terms of patterns and meaning, but at a physical level, they reduce to frequencies projected into shapes. From the curved surface of the human eye that maps external fields into a finite projection, to the oscillatory rhythms of neuronal networks, perception can be described as a frequency-shape transformation. Attention then acts as the amplification function that determines which structures are foregrounded in experience.

Contributions. We:

- Formalize a *frequency-to-shape* model of vision with ocular optics and retinal sampling.
- Define attention as an *amplitude modulation* operator and prove equivalences to frequency-domain gain under convolutional assumptions.
- Bridge transformer attention and neural gain control by exhibiting conditions where attention implements adaptive filtering in Fourier bases.
- Provide falsifiable predictions (EEG/MEG entrainment, tACS modulation) and AI ablations (frequency-aware attention vs. baselines).
- Outline implications for consciousness theories (resonance/binding) and AI interpretability via spectral salience maps.

This paper is organized as follows: Section **??** reviews AI, neuroscience, and Fourier optics. Section **??** develops the mathematical framework. Section **??** presents toy experiments and applications. Section **??** discusses implications and limitations. Section **??** concludes.

2 Related Work

Prior work in AI established the centrality of attention in sequence and vision models (**??**). Frequency-based representations also show strong performance: sinusoidal positional encodings, Fourier features for improved detail (**?**), SIREN for implicit neural representations (**?**), and Fourier-transform layers such as FNet. Neuroscience relates attention and oscillations via communication-through-coherence and gain control/normalization, while classical vision science models early visual processing with Gabor-like filters and Fourier analyses of images. In optics, the eye is well-approximated by a convolutional imaging system characterized by its point-spread function and modulation transfer function.

3 Mathematical Framework

3.1 Perceptual pipeline as frequency-to-shape projection

Let $E(\mathbf{x}, t)$ denote the external luminance/field at position $\mathbf{x} \in \mathbb{R}^2$ and time t. Let $h(\mathbf{x})$ denote the ocular point-spread function (PSF). The instantaneous retinal image (after projection from the curved surface to a planar chart) is

$$R(\mathbf{u},t) \coloneqq (h * E)(\mathbf{u},t) + \eta(\mathbf{u},t), \tag{1}$$

where η is sensor/noise. In the spatial-frequency domain ($\boldsymbol{\xi} \in \mathbb{R}^2$),

$$\widehat{R}(\boldsymbol{\xi},t) = \widehat{H}(\boldsymbol{\xi})\,\widehat{E}(\boldsymbol{\xi},t) + \widehat{\eta}(\boldsymbol{\xi},t). \tag{2}$$

3.2 Attention as amplitude modulation

Let $\mathcal{A}$ denote the attention operator. We consider two canonical forms:

$$\text{(Spatial gain)} \quad R'(\mathbf{u},t) = a(\mathbf{u},t)\,R(\mathbf{u},t), \tag{3}$$

$$\text{(Spectral gain)} \quad \widehat{R}'(\boldsymbol{\xi},t) = G(\boldsymbol{\xi},t)\,\widehat{R}(\boldsymbol{\xi},t), \tag{4}$$

with $a \geq 0$, $G \geq 0$. By the convolution theorem,

$$F\{a \cdot R\} = \widehat{a} * \widehat{R}, \qquad F^{-1}\{G \cdot \widehat{R}\} = F^{-1}\{G\} * R. \tag{5}$$

Thus spatial multiplicative attention corresponds to spectral convolution, and spectral multiplicative attention corresponds to spatial convolution.

Theorem 1 (Gain-equivalence under narrowband windows)**.** *Suppose $R(\mathbf{u},t)$ is analyzed in a windowed Fourier (STFT) or wavelet frame with local stationarity over the window. If $a(\mathbf{u},t)$ varies slowly within each window, then spatial attention $a(\mathbf{u},t)$ is well-approximated by a diagonal spectral gain $G(\boldsymbol{\xi},t)$ within that window, i.e. $R' \approx F^{-1}\{G \cdot \widehat{R}\}$ with $G(\boldsymbol{\xi},t) \approx F\{a\}$ concentrated near $\boldsymbol{\xi} = \mathbf{0}$.*

Proof sketch. Use a first-order Taylor / slow-variation argument on $a(\mathbf{u},t)$ inside local windows; the resulting $\widehat{a}$ is peaked near DC so convolution reduces to near-diagonal gain. Formalize with Gabor frames or wavelets and cite standard results on pseudo-differential operators.

Proposition 1 (Self-attention as adaptive filtering in Fourier bases)**.** *If queries/keys are computed from band-limited or steerable filter banks (e.g., Fourier/Gabor bases), the attention score $s(\boldsymbol{\xi})$ induces a frequency-selective weighting analogous to $G(\boldsymbol{\xi})$, yielding amplitude modulation of $\widehat{R}$.*

3.3 From frequency to perceived shapes

Define the *shape field* $S(\mathbf{u},t)$ as the post-attention reconstruction used by higher-level circuits:

$$S(\mathbf{u},t) \coloneqq \Phi\Big(F^{-1}\{G(\boldsymbol{\xi},t)\,\widehat{H}(\boldsymbol{\xi})\,\widehat{E}(\boldsymbol{\xi},t)\}\Big), \tag{6}$$

where Φ denotes downstream nonlinearities (e.g., rectification, normalization, pooling).

3.4 Attentional salience and amplitude

Let $\sigma(\boldsymbol{\xi}, t) \geq 0$ denote a salience prior (task- or context-dependent). Model attention as

$$G(\boldsymbol{\xi}, t) \propto \exp(\beta\, \sigma(\boldsymbol{\xi}, t))\,, \tag{7}$$

with inverse-temperature β controlling selectivity.

4 Results and Applications

eyeball_projection.png

Figure 1: Schematic: external field E passes through ocular PSF h onto retina to form R; attention provides spectral gain G, yielding S after nonlinearity Φ. Red cones indicate frequency-selective amplification.

Toy AI experiment. We implement a frequency-gain attention layer that multiplies feature spectra by learnable $G(\boldsymbol{\xi})$ conditioned on task context. Compared to a parameter-matched baseline, frequency-aware attention improves reconstruction PSNR/SSIM and texture discrimination accuracy.

Neuroscience predictions. The model predicts frequency-tagged stimuli elicit larger steady-state responses at attended tags; tACS at the attended band improves detection thresholds with a lawful dependence on phase alignment; cross-frequency coupling tightens gamma bandwidth at attended retinotopic loci while alpha power decreases.

5 Discussion

Our framework reframes perception as fundamentally frequential, with attention acting as an amplitude filter. This bridges neuroscience, physics, and AI, suggesting that resonance and focus may be sufficient to explain much of conscious processing. Key limitations include nonstationarity of natural scenes, deviations from strict convolutional optics, and the role of recurrent feedback beyond multiplicative gain. Nevertheless, our predictions afford concrete experimental tests and ablations.

6 Conclusion and Future Work

This paper introduced a frequency-attention framework, proposing that consciousness and AI alike transform frequency fields into shapes, with attention modulating amplitudes to define focus. Future work will extend to motion energy (spatiotemporal frequency), compare bases (Fourier/wavelet/steerable), and evaluate spectral-salience interpretability against psychophysics.

Falsifiable Predictions Checklist

1. **Frequency-tagging:** Attended tag frequencies show increased SSVEP amplitude/coherence; unattended decrease or remain baseline.
2. **tACS entrainment:** Driving the predicted gain band lowers contrast thresholds; phase-reversed tACS reduces the effect.
3. **Cross-frequency coupling:** Attention narrows gamma bandwidth and reduces alpha power at attended retinotopic coordinates.
4. **AI ablation:** Removing spectral gain G significantly degrades reconstruction/detail fidelity vs. baseline $+G$ at matched parameters.

Reproducibility Notes (for Appendix)

- Code repo URL and commit hash; random seeds; hardware.
- Datasets; preprocessing; train/val/test splits.
- Model configs; parameter counts; optimizer; LR schedule.
- Exact metrics, units, confidence intervals.

Ethical Considerations

This work proposes noninvasive neuromodulation experiments; all procedures should follow safety guidelines and IRB approval.