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# Quantifying EEG Signal Frequency Without FFT: A PCA and Poincaré Section Approach

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## Abstract

Electroencephalography (EEG) frequency analysis is crucial for understanding brain oscillations, as represented by the alpha band at rest. While the fast Fourier transform (FFT) is standard for quantifying frequency, its assumption of linearity may overlook the nonlinear nature of EEG signals. To address this, we propose a dynamical system-based approach combining principal component analysis (PCA) and the Poincaré section for quantifying EEG frequency without Fourier transform. PCA is used to convert a space spanned by multi-channel EEG signals into a lower-dimensional space while preserving dominant oscillations, and a Poincaré section is placed in this space to estimate frequencies by counting crossings. We applied this method to resting-state EEG data and found it can capture cyclic patterns on a (PC2, PC3)-plane and estimate instantaneous frequencies. The optimal time window of 10 s, as indicated by a clear alpha peak in the frequency histogram and relatively low Kullback–Leibler divergence to the FFT power spectrum (0.221 for PC2 and 0.275 for PC3), suggests that the proposed PCA–Poincaré framework can offer real-time estimates of EEG frequency and be useful in neurofeedback. © The Author(s), under exclusive license to Springer Nature Switzerland AG 2026.

## Author keywords

Electroencephalography; Frequency analysis; Nonlinear dynamics; Poincaré section; Principal Component Analysis

## Indexed keywords

### Engineering controlled terms

Biomedical signal processing; Dynamical systems; Dynamics; Fast Fourier transforms; Nonlinear analysis; Quantization (signal)

### Engineering uncontrolled terms

At rests; Brain oscillations; Fast fourier; Fourier; Frequency Analysis; Multi channel; Nonlinear nature; Poincare sections; Principal-component analysis; Signal frequencies

### Engineering main heading

Electroencephalography; Electrophysiology; Principal component analysis

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