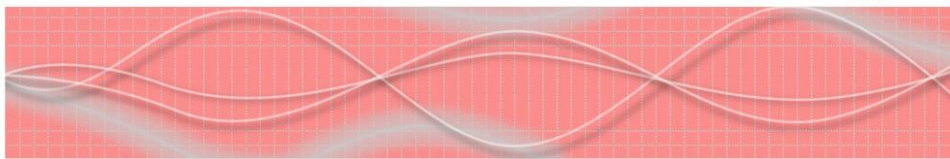




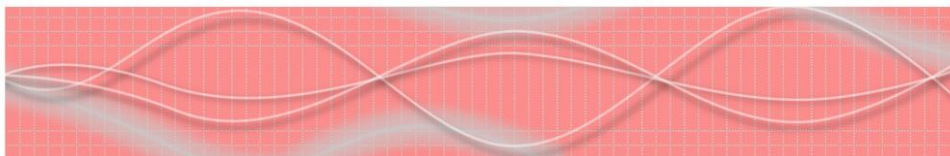
*Professional Signal & Spectrum Analysis*



WHITE PAPER

# Bearing Fault Detection via Envelope Analysis

*Diagnosing rolling-element bearing defects with SIGVIEW*



**SignalLab e.K.**

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# Bearing Fault Detection via Envelope Analysis

*Diagnosing rolling-element bearing defects with SIGVIEW*

## Overview

Rolling-element bearings are among the most common failure points in rotating machinery. A spalled raceway or damaged ball produces a small impact each time the defect passes a load zone. These impacts ring the bearing housing at its structural resonance, and the impact rate carries a unique signature for each defect type — outer race (BPFO), inner race (BPFi), ball (BSF), and cage (FTF). Envelope analysis is the standard technique for extracting these signatures, and SIGVIEW provides every step in a chainable workflow.

This paper walks through the complete procedure: load a vibration signal, band-pass filter it around the bearing-housing resonance, demodulate the amplitude envelope using the Hilbert transform, and compute the envelope spectrum. Characteristic defect frequencies and their harmonics appear as clear peaks against a low noise floor, allowing positive identification of the failing component.

## Background

### Why direct FFT is not enough

A raw vibration FFT of a faulted bearing is usually dominated by shaft-related lines (1x, 2x, 3x rpm) and by the resonance the impacts excite. The defect repetition frequency itself often sits at low amplitude and can be buried in noise. Envelope analysis solves this by recognizing that the impacts amplitude-modulate the carrier resonance: extracting the modulating envelope and computing its spectrum reveals the defect rate directly.

### Characteristic defect frequencies

For a bearing with  $n_b$  balls of diameter  $d$ , pitch diameter  $D$ , contact angle  $\beta$ , and shaft speed  $f_s$  (Hz):

- **BPFO (outer race):**  $f_s \cdot (n_b/2) \cdot (1 - (d/D) \cdot \cos \beta)$
- **BPFi (inner race):**  $f_s \cdot (n_b/2) \cdot (1 + (d/D) \cdot \cos \beta)$
- **BSF (ball spin):**  $f_s \cdot (D/(2d)) \cdot (1 - (d/D)^2 \cdot \cos^2 \beta)$
- **FTF (cage):**  $f_s \cdot 0.5 \cdot (1 - (d/D) \cdot \cos \beta)$

Bearing manufacturer catalogues list these multipliers for each model. For a SKF 6205-2RS at 1797 rpm (29.95 Hz), BPFO  $\approx$  107.4 Hz and BPFi  $\approx$  162.2 Hz.

## Test Signal

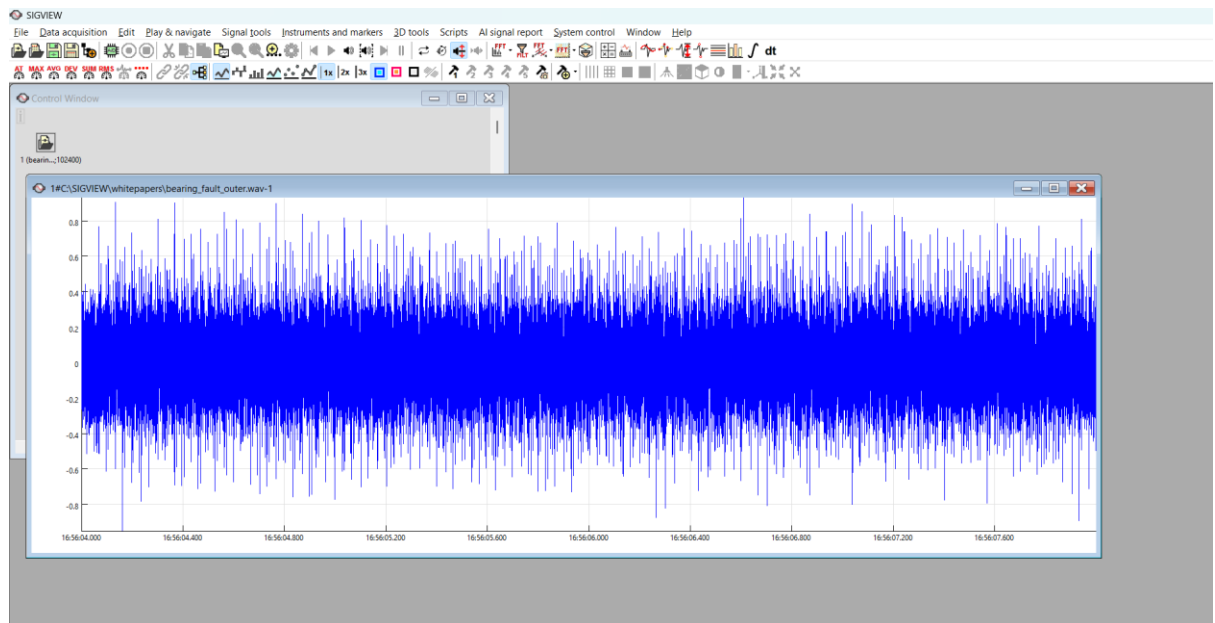
A simulated outer-race fault signal is provided alongside this paper:

- [bearing\\_fault\\_outer.wav](#) — 4 s, 25 600 Hz, mono. Models an SKF 6205 at 1797 rpm with a developing outer-race spall; impacts (BPFO  $\approx$  107.4 Hz) ring a 3 kHz housing resonance with realistic slip jitter and load-zone amplitude modulation.

**Alternative real data:** The Case Western Reserve University Bearing Data Center publishes a free, well-documented dataset of seeded bearing faults at [csegroups.case.edu/bearingdatacenter](https://csegroups.case.edu/bearingdatacenter). Files are Matlab .mat — use the MAT file plugin or pre-convert.

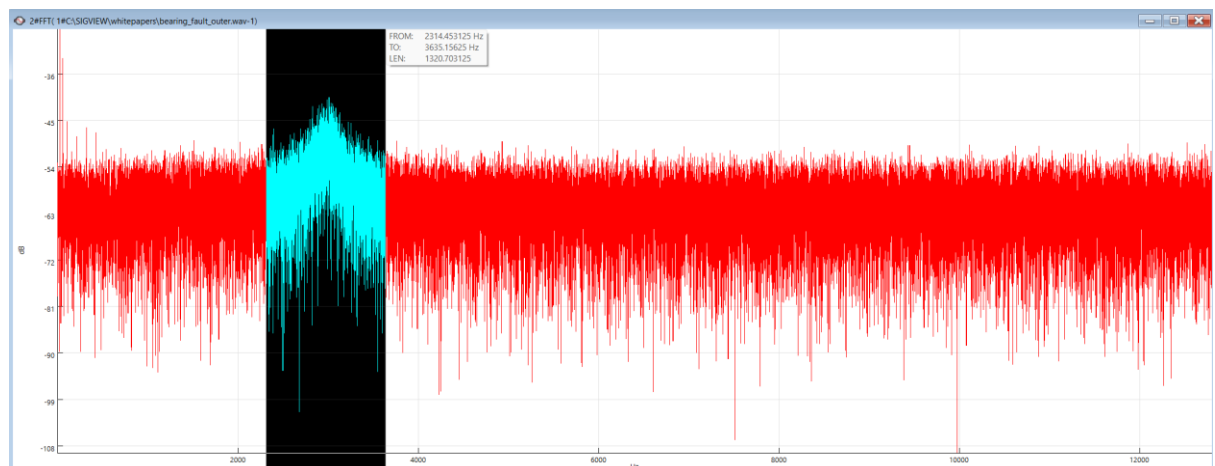
## Procedure in SIGVIEW

1. **Load the signal.** Use File / Open signal... and select bearing\_fault\_outer.wav. A new signal window opens displaying the time waveform.



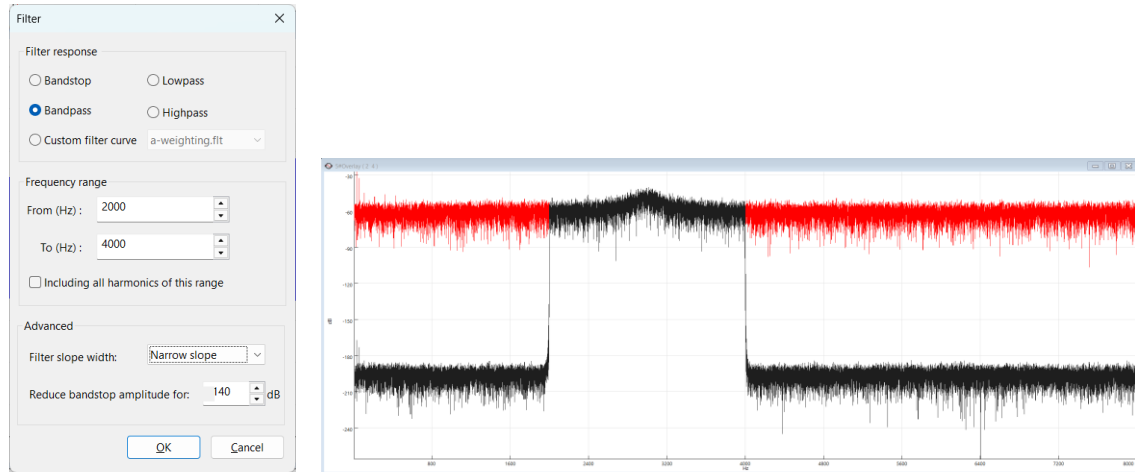
Main SIGVIEW window with the bearing\_fault\_outer.wav time-domain signal loaded. The trace appears noise-like with subtle amplitude bursts; no defect is obvious yet by eye.

2. **Inspect the raw spectrum to locate the resonance.** With the signal window selected, press Ctrl+F (or choose Signal tools / FFT). Switch Y-axis to dB in the Properties of the FFT window or set it as a default settings before calculating FFT. The magnitude spectrum shows a broad lump centered around 3 kHz — this is the bearing-housing resonance band that carries the modulating impacts.



FFT magnitude window. Y-Axis in dB units. A broad energy peak is visible roughly between 2.5 and 3.5 kHz. Below 200 Hz, shaft-related lines are weak and the defect rate is not yet visible.

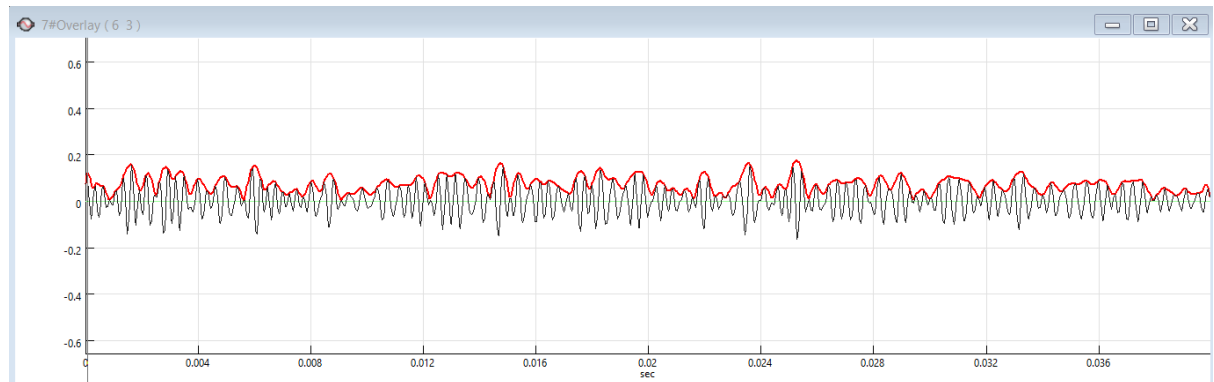
3. **Band-pass filter around the resonance.** Select the time-signal window and choose Signal tools / FFT filter... (or IIR filter if you prefer minimum-phase). Set a band-pass with corners at 2000 Hz and 4000 Hz. Click OK. A new filtered-signal window is created.



FFT filter configuration dialog (Signal tools / FFT filter). Shows the band-pass settings between 2 kHz and 4 kHz. The original spectrum is overlaid in red for reference.

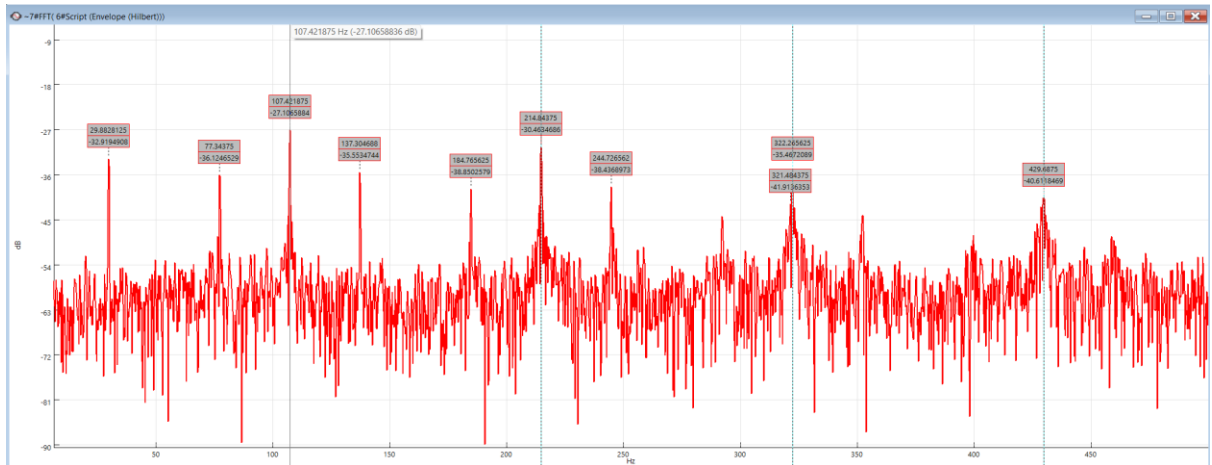
**Tip:** Choose the band wide enough to capture the full resonance lobe but narrow enough to reject low-frequency shaft content. A common rule is  $\pm 20\text{--}30\%$  of the centre frequency.

4. **Compute the envelope using the Hilbert transform.** On the filtered window, choose Signal tools / Use custom tool / Envelope (Hilbert transform). SIGVIEW will execute the Julia-based custom tool that returns the magnitude of the analytic signal — i.e., the amplitude envelope. A new envelope-signal window appears.

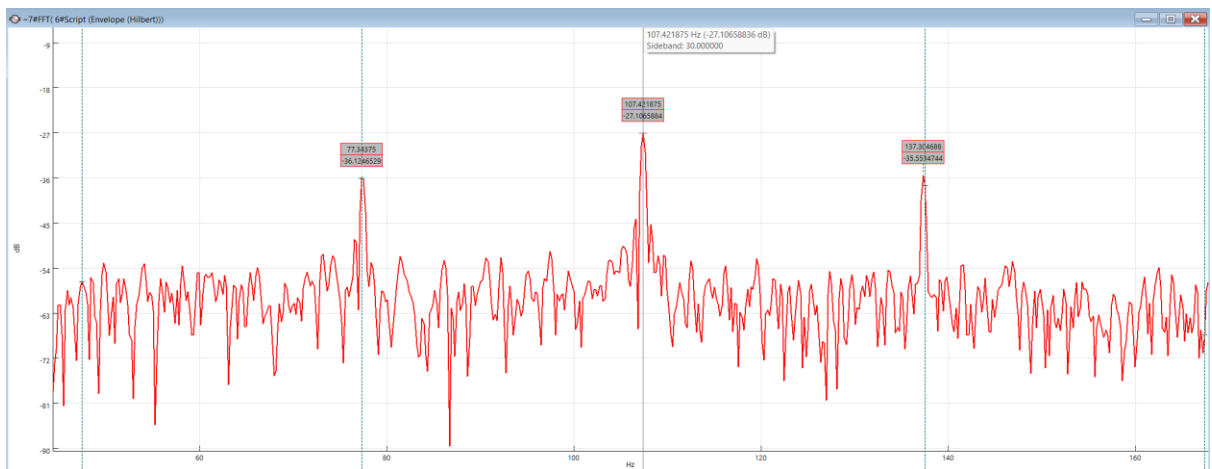


Two overlaid signals: black = filtered band-pass signal (oscillatory burst pattern visible), red = envelope (smooth positive curve following the amplitude peaks of the bursts). A small part of both signals zoomed-in for a better visibility.

5. **Compute the envelope spectrum.** Select the envelope window and press Ctrl+F to take its FFT (dB units). Zoom the X-axis to 0–500 Hz (Edit/Zoom to X samples/values...) — defect frequencies are always in this low band.

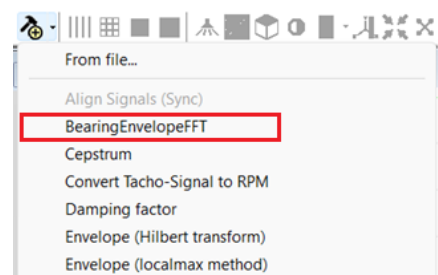
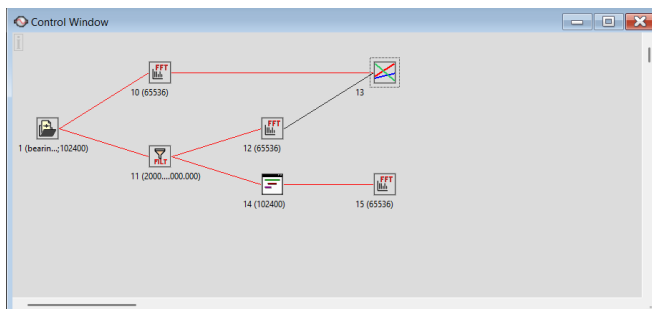


Envelope spectrum. X-axis 0–500 Hz. Harmonic cursor and “Peak detection...” options turned on. A prominent peak appears at ~107 Hz (1× BPFO), with harmonics visible at ~215 Hz, ~322 Hz, ~430 Hz.



Envelope spectrum. X-axis zoomed-in around prominent peak at ~107Hz. Sideband cursor option turned on. Sidebands at ±30 Hz (shaft rate) around each BPFO peak are also visible — these are the load-zone modulation pattern characteristic of outer-race faults.

6. **Identify the defect type.** Use the mouse cursor in the envelope spectrum to read peak frequencies. Compare against the bearing catalogue values for the suspect machine. In this example, peaks at 107, 215, 322 Hz match 1×, 2×, 3× BPFO for the SKF 6205 at 1797 rpm — a clear outer-race fault.
7. **Save the workflow as a custom tool.** On the filtered-signal window, choose File / Save Window as custom tool / Subtree only.... Name it BearingEnvelopeFFT.swt. Next time, applying this tool to any vibration signal will run the complete chain (filter → envelope → FFT) in one click.



Control Window showing the full analysis chain after applying the saved custom tool. Custom tools context menu with the new item after saving the custom tool.

## Interpreting the Envelope Spectrum

Pattern observed	Likely diagnosis
Peaks at BPFO and harmonics, sidebands at 1× shaft	Outer-race spall in the load zone
Peaks at BPFI and harmonics, sidebands spaced by 1× shaft on each BPFI line	Inner-race defect (rotates through load zone, amplitude modulation by shaft)
Peaks at 2× BSF (ball passes inner + outer raceway per revolution), modulated by FTF (cage)	Ball or rolling-element defect
No discrete envelope-spectrum peaks; broadband elevated noise	Generalized roughness, lubrication starvation, or late-stage wear with multiple defects

## Automating Diagnosis with the AI Signal Report

After computing the envelope spectrum, select that window and choose AI signal report / Generate AI report → Predictive Maintenance Assessment. SIGVIEW packages the metrics (peak frequencies, harmonic ratios, sideband structure, RMS, crest factor) into a JSON report and sends them to your configured LLM provider. Within ~15 seconds you receive a written assessment in your browser: estimated rotational speed, identified fault indicators, severity rating, and maintenance urgency.

**Note:** The AI works only on the numerical metrics. For best diagnostic results, run the AI assessment on the envelope spectrum window (where defect frequencies are exposed), not on the raw time signal.

### 4. Fault Indicator Analysis

- **Bearing Defects:** The data shows a classic signature of a localized bearing defect (likely an outer race fault). Alongside the high crest factor (5.62), the frequency data highlights significant energy in a high-frequency resonant band. While the fundamental running speed is ~30 Hz, the mean dominant frequency over time jumps to **2995 Hz**. The averaged spectrum confirms this by revealing a cluster of high-frequency peaks at **2982.87 Hz, 2990.45 Hz, and 3013.21 Hz**. This indicates that periodic bearing impacts are exciting a structural resonance near 3 kHz.

*A part of AI analysis result (with Google Gemini Pro model) for the above signal.*

## Common Pitfalls

- **Filter band too narrow:** the impact response is impulsive and broadband. A band that is too tight loses transient energy and weakens the envelope.
- **Filter band too wide:** includes non-resonant noise and other modulation sources, raising the envelope noise floor.
- **Insufficient record length:** the envelope spectrum needs enough impacts to average. For BPFO ≈ 107 Hz, a 1 s record contains ~107 impacts — usable but borderline. Aim for ≥ 200 impacts (≈ 2 s minimum here).

- **Confusing 2× BSF with BPFI:** these frequencies can be close. Check sideband structure: BPFI shows shaft-rate sidebands, ball faults show cage-rate (FTF) sidebands.
- **Variable speed:** if the shaft RPM changes during the record, defect frequencies smear. Use Order Tracking (see the companion white paper) to normalize against shaft angle before envelope analysis.

## Summary

SIGVIEW provides every block needed for industry-standard envelope analysis: band-pass filtering, Hilbert-based envelope demodulation as a Julia custom tool, FFT, and harmonic cursors for peak identification. The entire chain can be saved as a single-click custom tool and applied to live data acquisition or to recorded signals. Combined with the AI Signal Report in Predictive Maintenance mode, SIGVIEW delivers a complete bearing-diagnosis workflow from raw vibration to written assessment.