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Digital Signal Processing for Laser Printer Noise Source Detection and Identification

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DIGITAL SIGNAL PROCESSING FOR LASER PRINTER NOISE SOURCE DETECTION AND IDENTIFICATION

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This presentation will be posted at Herrick E-Pubs: http://docs.lib.purdue.edu/herrick/

PURDUE MECHANICAL ENGINEERING

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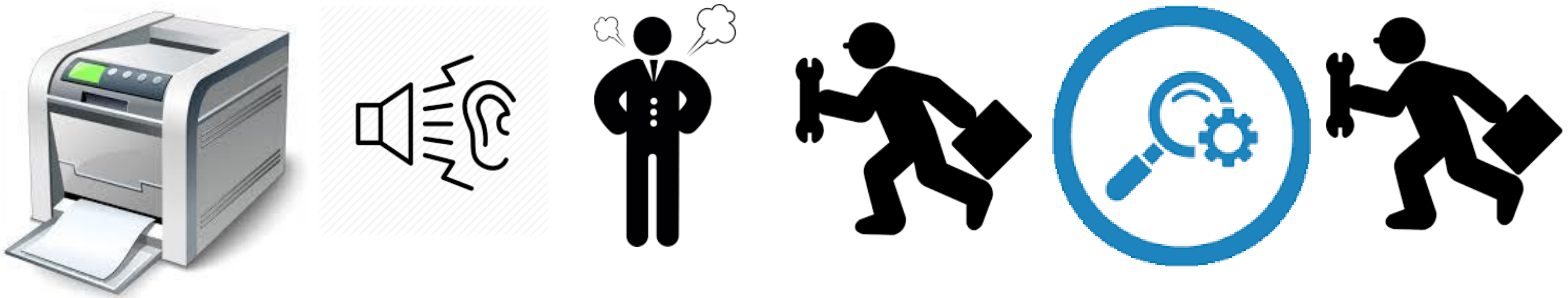
Background

- **Noise problem**



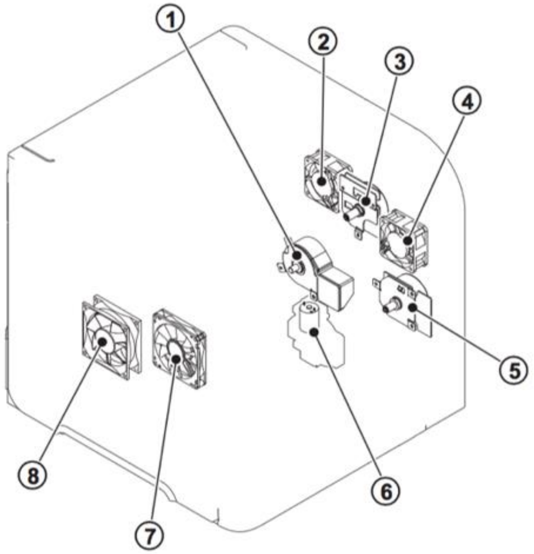
- **Our goal**

Self-detect before noise appears

- **Advantage**
  1. Reducing the cost for service department.
  2. High quality, quiet printer

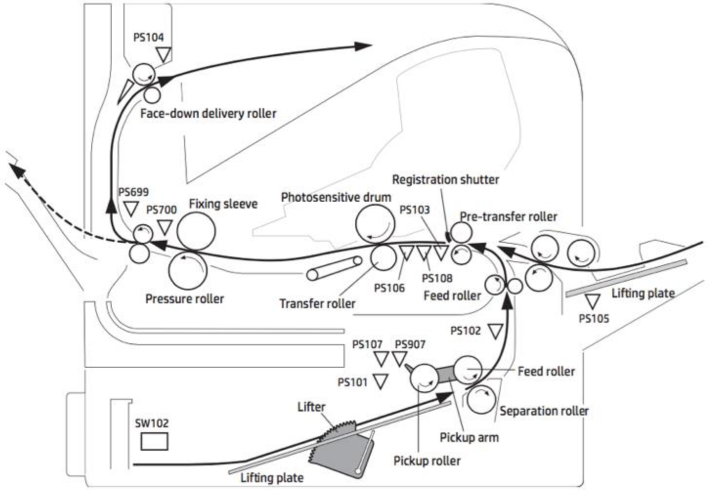
Target Printer

- **Motors and fans of HP LaserJet M603**



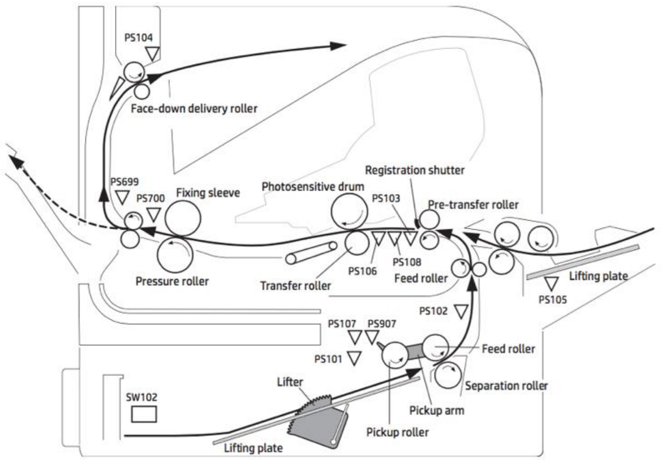
1: Fuser motor (M299)
2: Fan (FN104)
3: Drum motor (M102)
4: Fan (FN102)
5: Feed motor (M101)
6: Lifter motor (M103)
7: Fan (FN103)
8: Fan (FN101)

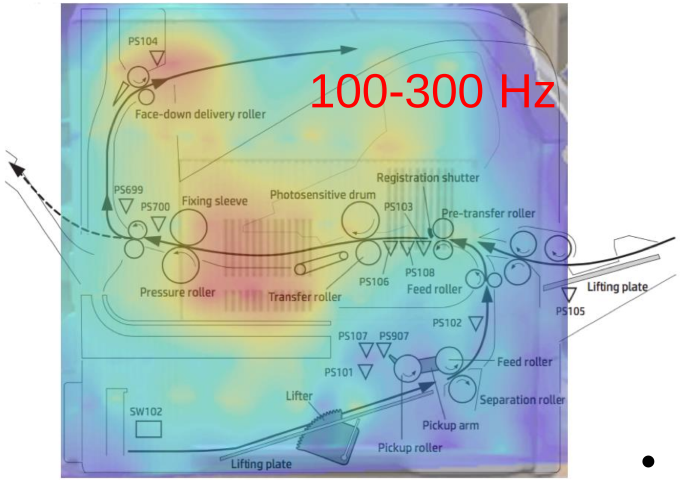
- **A side view of the inner structure to show the complexity of the paper path**

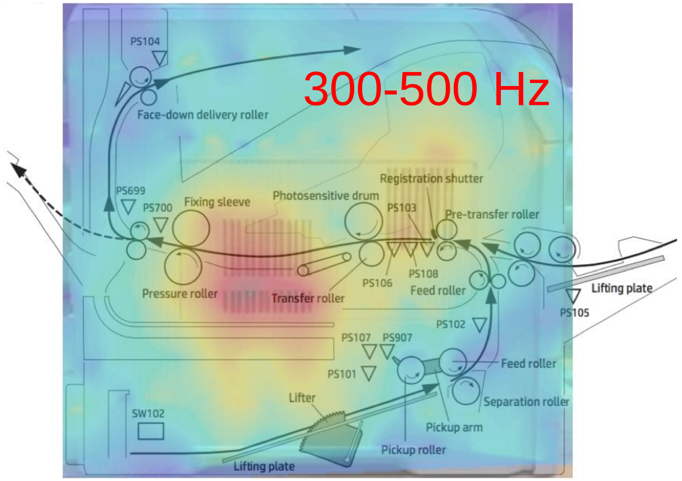


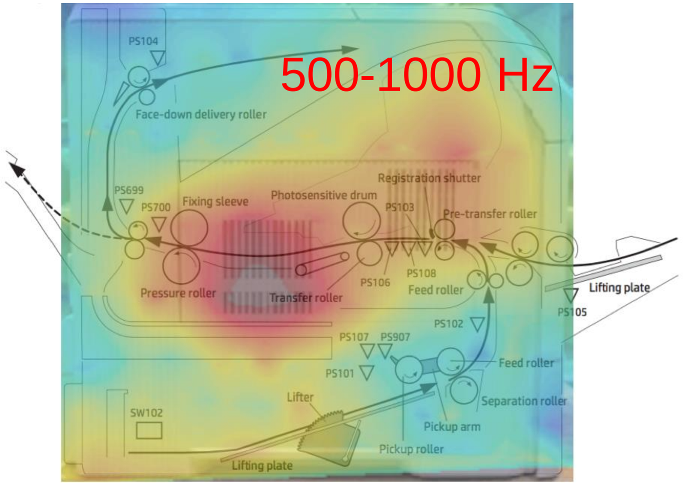
Preliminary Analysis

- **Sound pressure level scan by Microflown on a normal printer**







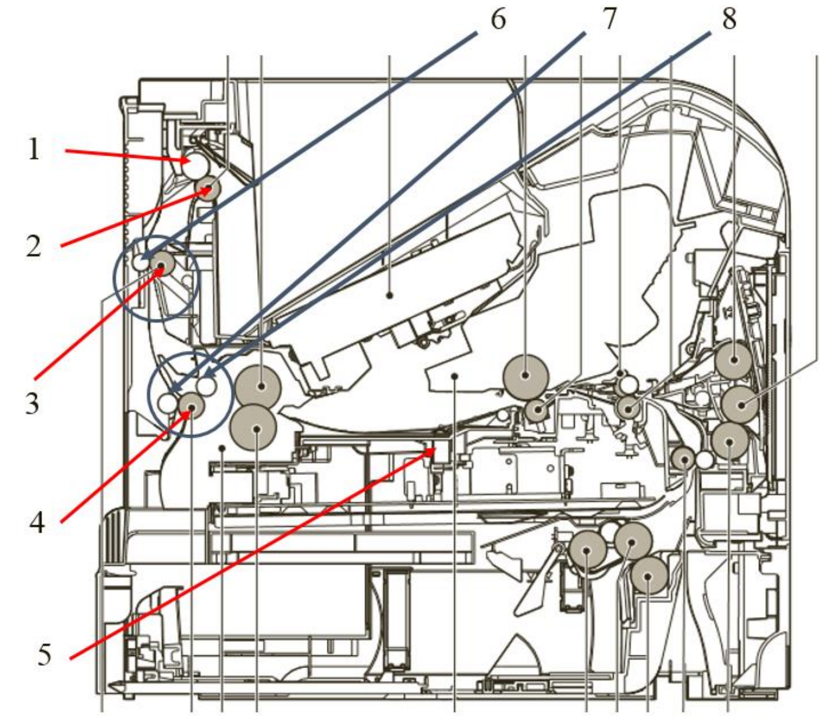


- **Fan noise as the main source**

Preliminary Analysis

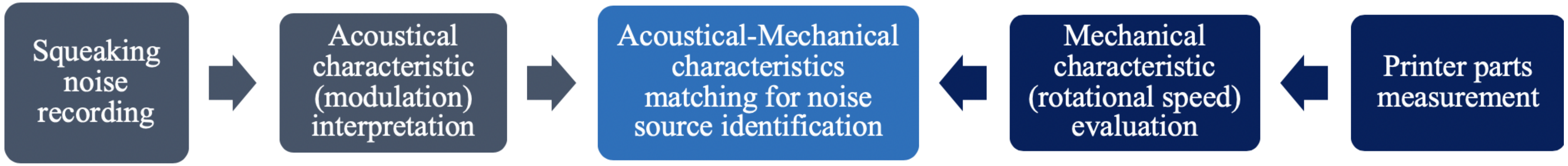
- **Main noise issue with a faulty printer: squeaking noise with strong and high frequency tonal content, caused by rollers' stick-slip motion**

- **Rollers on the paper path**



1: Face-down delivery roller 1
2: Face-down delivery roller 2
3: Intermediate delivery roller
4: Fuser delivery roller
5: Inner delivery roller
6: Idler roller 1 (not driven)
7: Idler roller 2 (not driven)
8: Idler roller 3 (not driven)

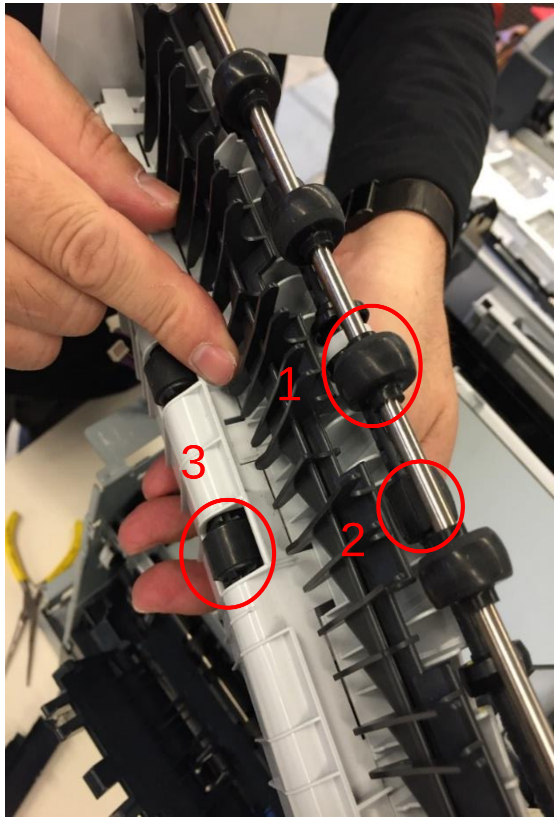
General Approach

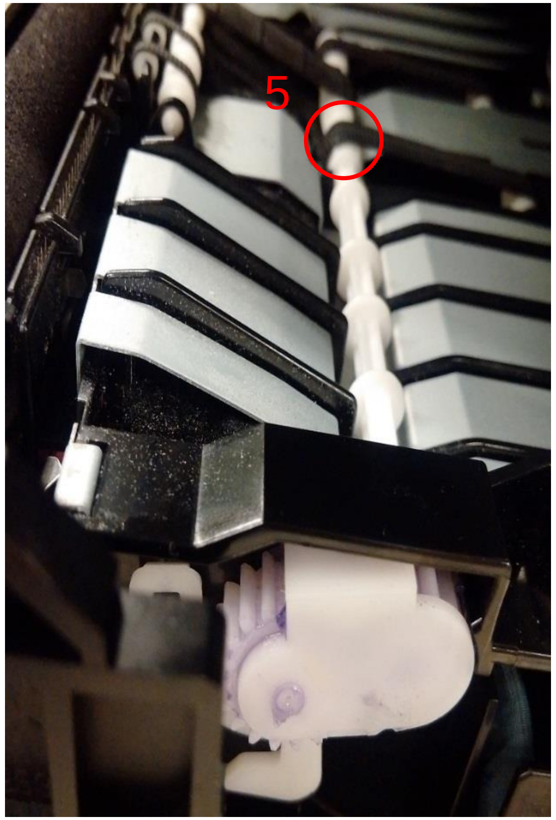


- **Mechanical characteristics (rotational speed) evaluation:** $U = \frac{RL}{\pi D}$
  - Based on output rate, *R* (1.28 page/min), paper length, L (279.4 mm), and roller size, *D* (measured)

- **Acoustical characteristics (modulation frequency) evaluation:**
  - Based on digital signal processing methods such as
    - Discrete Fourier transform (DFT) for power spectrum density (PSD) analysis
    - Butterworth IIR filter to isolate the narrowband noise signal
    - Hilbert transform FIR filter to generate the analytic signal

Rollers on Paper Path

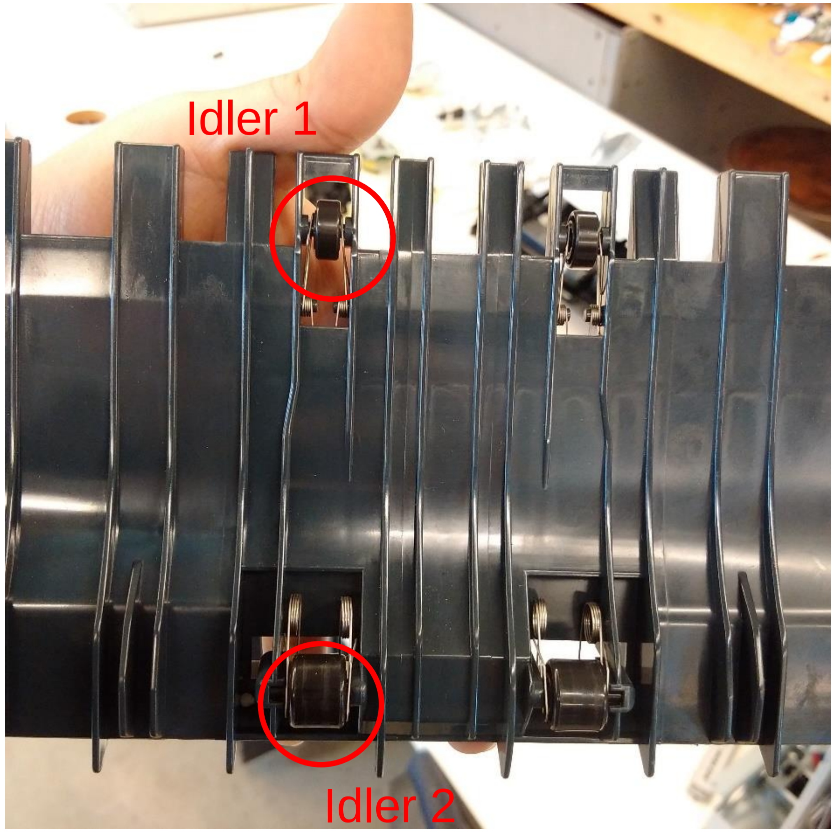


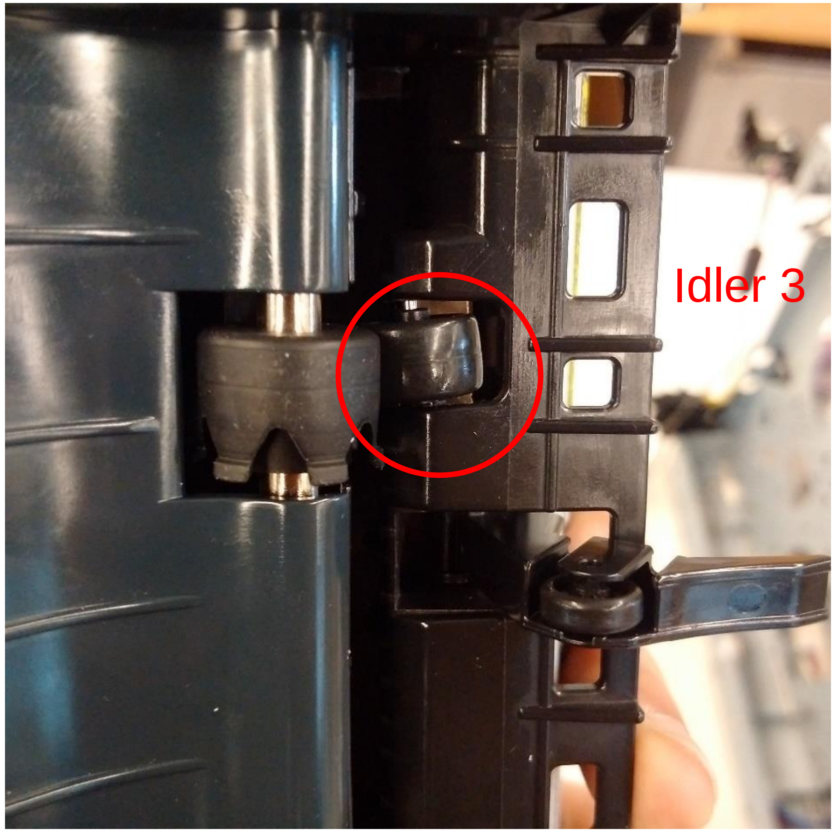


- **Diameter measurement**

1: Face-down delivery roller (up): 18.5 mm
2: Face-down delivery roller (down): 15 mm
3: Intermediate delivery roller: 15.85 mm
4: Fuser delivery roller: 16.6 mm
5: Inner delivery roller: 10 mm

Rollers on Paper Path





- **Diameter measurement**

Idler roller 1: 12.00 mm
Idler roller 2: 13.84 mm
Idler roller 3: 13.99 mm

Rollers on Paper Path

- **Mechanical characteristics (rotational speed) evaluation:** $\boldsymbol{U = \frac{RL}{\pi D}}$
  - Based on output rate, *R* (1.28 page/min), paper length, L (279.4 mm), and roller size, *D* (measured)

Table 1: Rotational speeds of rollers on the paper path.

Parts name	*D* [mm]	*U* [rpm]	*U* [rps]
Face-down delivery roller 1	18.50	370.00	6.17
Face-down delivery roller 2	15.00	457.00	7.60
Intermediate delivery roller	15.85	432.00	7.20
Fuser delivery roller	16.60	413.00	6.80
Inner delivery roller	10.00	654.00	10.90
Idler roller 1	12.00	571.00	9.52
Idler roller 2	13.84	495.00	8.25

Squeaking Signal Recording

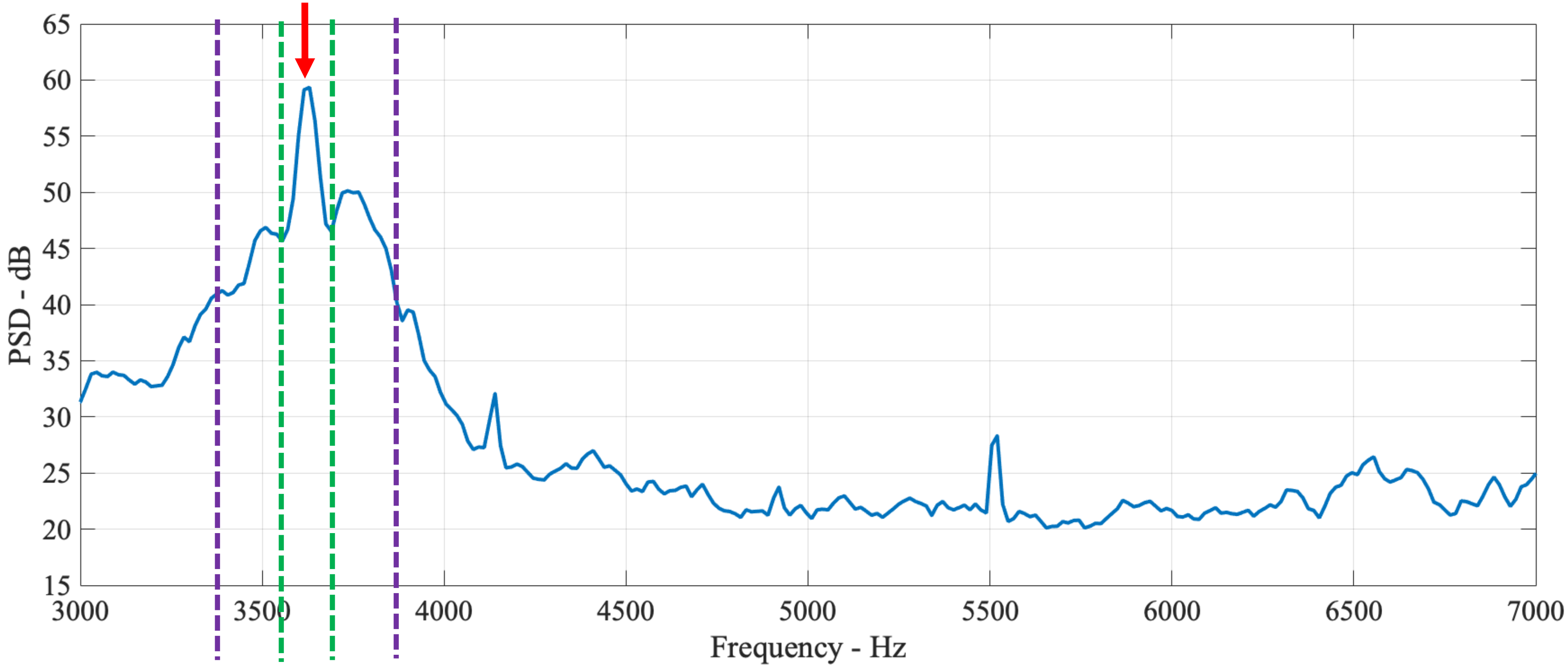
- Noise data acquisition (**f_s = 44100 Hz**): 6 samples were acquired

(a) (b) (d)

DSP on the Sample "Squeaking 6"

- DFT (using FFT algorithm) for PSD analysis & narrowband filtering

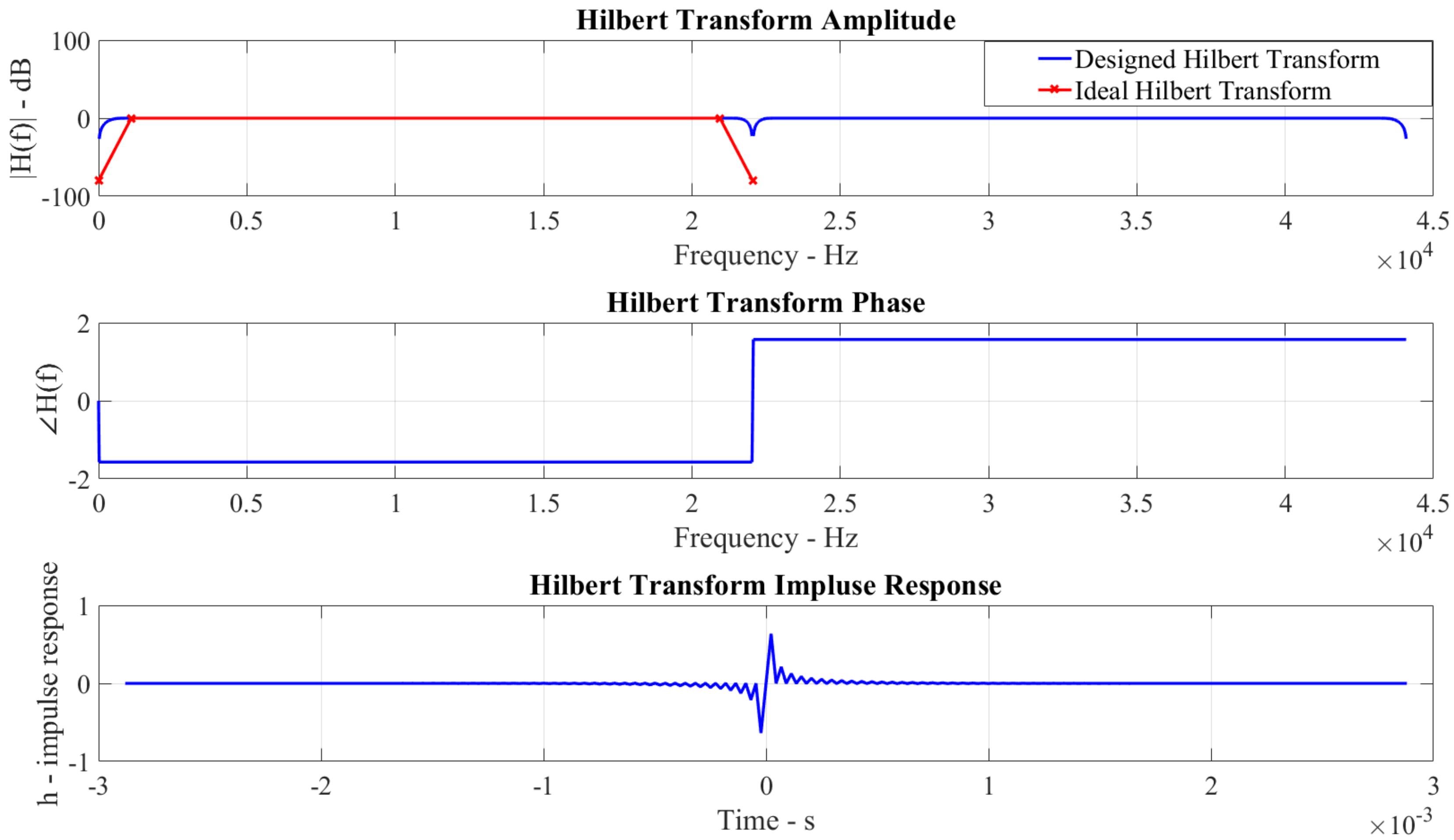
Strong tonal frequency: 3630 Hz



Passband [3580 Hz, 3680 Hz] and stopband [3380 Hz, 3880 Hz] of the Butterworth IIR filter

DSP on the Sample "Squeaking 6"

- Hilbert transform to generate the complex analytic signal



DSP on the Sample "Squeaking 6"

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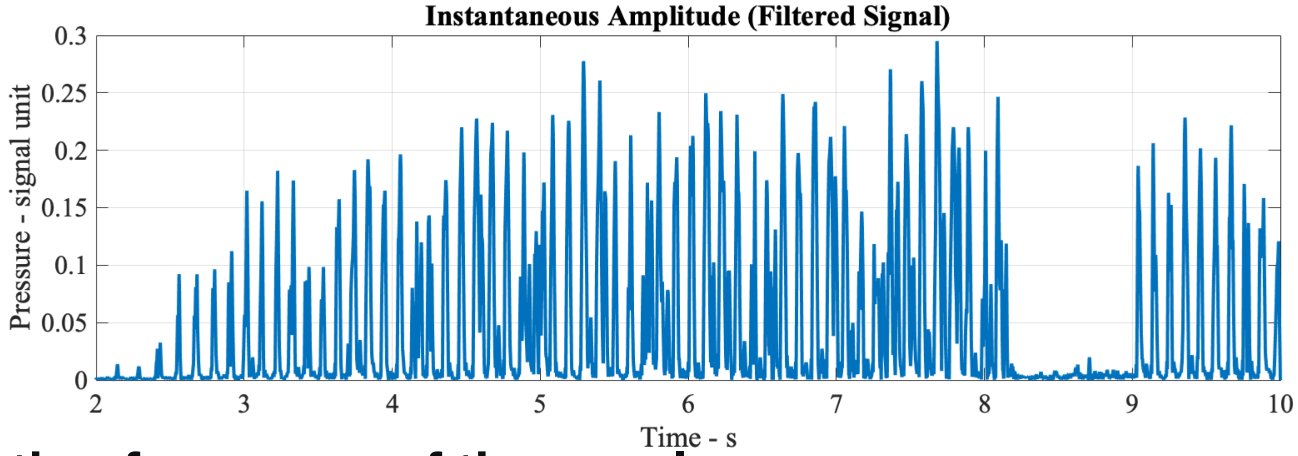
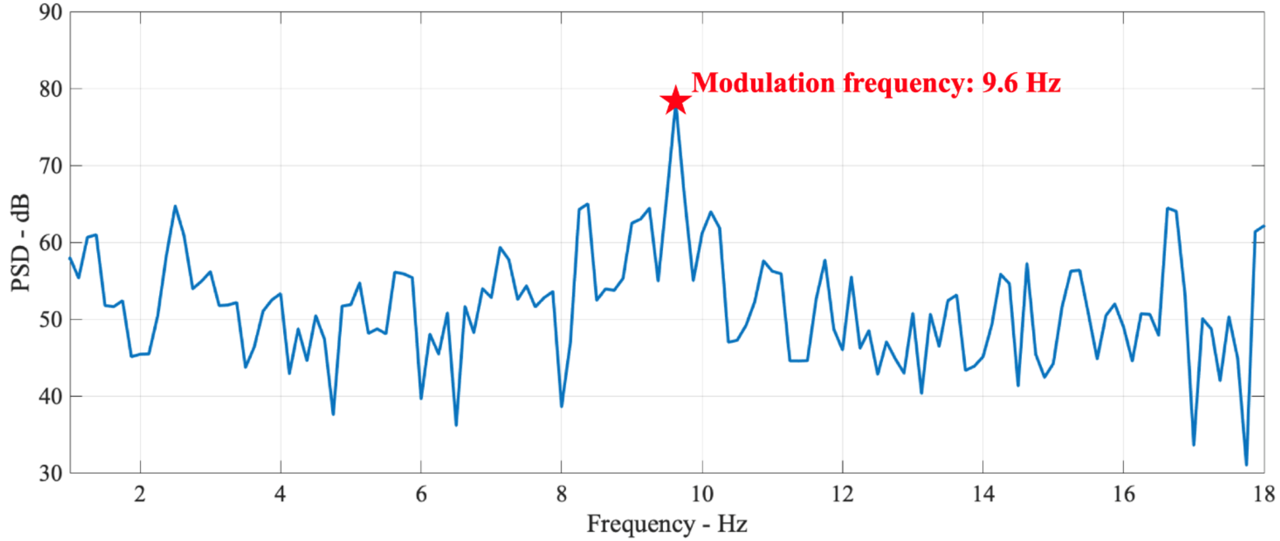
- Envelope of the narrowband filtered complex analytic signal

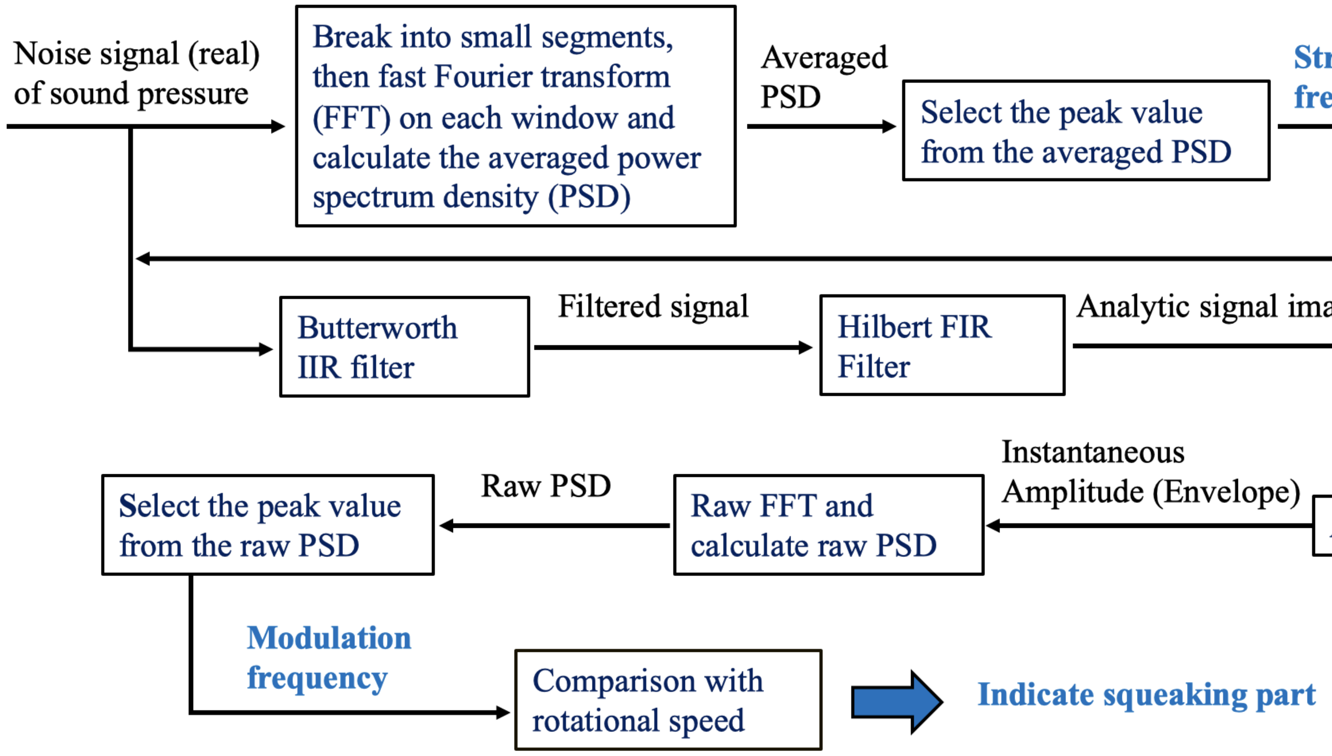


- Modulation frequency of the envelope



Detector Design

- **Design methodology of the to realize squeaking self-detection**



Detection Results

Table 2: Diagnoses results from the squeaking signals.

Noise samples	Strong tonal frequency [Hz]	Modulation frequency [Hz]	Corresponding rotational speed [rps]	Squeaking parts
Squeaking 1	3779	7.93	8.17	Idler roller 3
Squeaking 2	3473	5.80	6.17	Face-down delivery roller 1
Squeaking 3	8797	10.40	10.90	Inner delivery roller
Squeaking 4	3647	5.81	6.17	Face-down delivery roller 1
Squeaking 5	3727	10.40	10.90	Inner delivery roller
Squeaking 6	3617	9.60	9.52	Idler roller 1

Squeaking 1	Squeaking 2	Squeaking 3	Squeaking 4	Squeaking 5	Squeaking 6

Conclusions

- **A squeaking noise source self-diagnosis detector was developed using data from the HP LaserJet M603 printer, by returning the accurate acoustical characteristics (e.g., strong tonal frequency, modulation frequency) from each noise sample, and by matching those acoustical characteristics with the mechanical characteristics (e.g., rotational speed) of different parts, the detector was proven to be capable of providing precise source identification results (verified by HP). Detection + machine learning is the next step.**