Software Injection Tests on Deepclean: Long Single Frequency Injection

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Software Injection based on Noise Injection Tests

- **PEM injection before/after O3GK**
- **Hardware Injection:** 15:21 NoInjection_6.xml
- **Strain channel:** K1:CAL-CS_PROC_C00_STRAIN_DBL_DQ
- **PEM channel:** K1:PEM-MIC_PSL_TABLE_PSL4_Z_OUT_DQ
- **Frequency Filter:**
  - 10Hz wide, centered at the injected frequency
  - 120Hz ~ 150Hz
- **Training Time:** 1275891678 ~ 1275891998 (320 seconds)
- **Cleaning Time:** 1275891678 ~ 1275891998 (320 seconds)
Injection: Training Data

- 1275891678 ~ 1275891998
- Inject sine waves with frequencies: 125Hz, 130Hz, 135Hz, ..., 145Hz.
- Each injection lasts for 300 seconds.
- PEM Amplitude: 8e-3 Pa.
- Strain Amplitude: 2e-20.
- No phase shift between PEM and Strain injection.
Injection: Background PEM

TRAIN DATA: Background PEM (125Hz)

Energy Density [Pa]

Time [minutes] from 2020-06-11 06:21:00 UTC (1275891678.0)
Injection: Background Strain
Injection: Injected Sine Wave (125Hz)
Injection: Injected Sine Wave (125Hz)
Injection: Injected PEM (125Hz)
Injection: Injected Strain (125Hz)
PEM ASD: Background and Injected
PEM ASD: Background and Injected

**Graph:**
- **Title:** TRAIN DATA ASD: Raw PEM (130Hz)
- **Axes:**
  - Y-axis: $10^{-3}$ to $10^{-2}$
  - X-axis: Frequency (Hz)
- **Data:**
  - Red line: Background PEM
  - Black line: Raw PEM

**Description:**
The graph illustrates the ASD (Amplitude Spectrum Density) of PEM data at 130Hz. It shows the comparison between background PEM and raw PEM across different frequency bands.
PEM ASD: Background and Injected
PEM ASD: Background and Injected
PEM ASD: Background and Injected
Training Deepclean: 30 Epochs

- Strain channel: K1:CAL-CS_PROC_C00_STRAIN_DBL_DQ
- PEM channel: K1:PEM-MIC_PSL_TABLE_PSL4_Z_OUT_DQ
- Training Time: 1275901678 ~ 1275901998 (320 seconds)
- Frequency Filter: 115Hz ~ 150Hz
- Loss Function: \( J_{asd} = \frac{1}{M} \sum_{i=0}^{M-1} \sqrt{\frac{S[r,r][i]}{S[h,h][i]}} \).
- FFT Length: 4
- Batch Size: 32
- Epochs: 30
- Weight Decay: 1e-5
115Hz ~ 150Hz-Band: 125Hz
115Hz ~ 150Hz-Band: 125Hz
115Hz ~ 150Hz-Band: 125Hz
115Hz ~ 150Hz-Band: 125Hz
115Hz ~ 150Hz-Band: 125Hz
115Hz ~ 150Hz-Band: 125Hz
115Hz ~ 150Hz-Band: 125Hz
115Hz ~ 150Hz-Band: 125Hz
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115Hz ~ 150Hz-Band: 135Hz
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$115\text{Hz} \sim 150\text{Hz}$-Band: 135Hz
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- Batch Size: 32
- Epochs: 30
- Weight Decay: 1e-5
10Hz-Band: 125Hz
10Hz-Band: 125Hz
10Hz-Band: 125Hz
10Hz-Band: 125Hz
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10Hz-Band: 125Hz
10Hz-Band: 125Hz
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10Hz-Band: 145Hz
Summary and Discussion

- We prepare the 5-minute long single-frequency injection to the PEM background and strain background.
- We have shown the training and cleaning on the same segment of the 125Hz, 130Hz, 135Hz, ..., 145Hz injection.
- 10Hz-wide band filter and 120Hz-150Hz band filter have been used and 10Hz-wide band filter performs better on each frequency of injections.
- Next: fake white Gaussian channel with fake transfer function.
Deepclean: Denoising using PEM and Auxiliary Channels

- \( w(t) \): witness channels that record the data from the auxiliary sensors and PEM.
- \( p(t) \): predicted noise in strain.
- Both \( w(t) \) and \( p(t) \) are timeseries with the same sampling rate and duration.
- Ref: 2005.06534, 2108.12430

![Diagram of the Deepclean model](image)

Encoder (down-sampler)  
Decoder (up-sampler)
Deepclean: Training and Inferencing

- $h(t)$: raw strain data.
- $r(t) = h(t) - p(t)$: residual.
- Loss function: $J_{asd} = \frac{1}{M} \sum_{i=0}^{M-1} \sqrt{\frac{S[r,r][i]}{S[h,h][i]}}$. 

Encoder (down-sampler)  \hspace{1cm} Decoder (up-sampler)
Noise Estimation via Injection Tests

- The experiment is performed on 2020/06/11.
- The acoustic noise at the input optics (Pre-Stabilized Laser room and Power Recycling booth) is focused.
- Confirmation of the frequency conversion and PSD linearity (so we can set $\varepsilon$ to 1) are performed by single-frequency PEM injection varying the injection power.
- Acoustic injection: 200 frequencies from approximately 70.0 Hz to 1070.0 Hz, 10 s for each frequency.
Noise Estimation via Injection Tests

Figure 4. Correlation between the injection frequency $f'$ and output signal frequency $f$ derived from the single frequency acoustic injections in the PSL room (left) and in the PR booth (right).
Noise Estimation via Injection Tests

**Figure 5.** Snap shot of the single frequency acoustic injection in the PR booth at $f' = 115$ Hz. Top left: PSDs of the interferometer signal for injection data and background data. Bottom left: Same as the microphone signal and the approximated function of the injected noise. Top right: Ratio of injection PSD and background PSD (SNR) for the interferometer signal. Bottom right: Response function and its upper limit at $f' = 115$ Hz.
Noise Estimation via Injection Tests

**Figure 6.** PEM projection of acoustic noise in the PSL room (top) and in the PR booth (bottom).
Noise Estimation via Injection Tests

Figure 7. Results of the broadband acoustic noise injection test in the PR booth. Top: PSDs of the microphone signal. Middle: PSDs of the interferometer signal. Bottom: The pure acoustic noise in the interferometer signal (blue) and the projection for them (red).