# Adaptive Feedback Cancellation for Audio signals:

## an Application of Prediction Error Identification with Cascaded Noise Models


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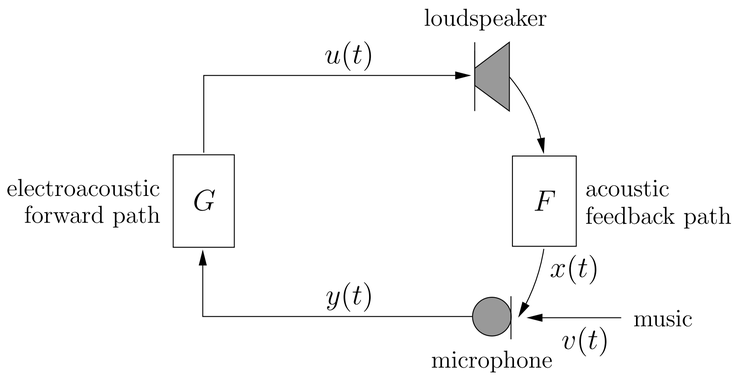
## 1 Acoustic Feedback Problem

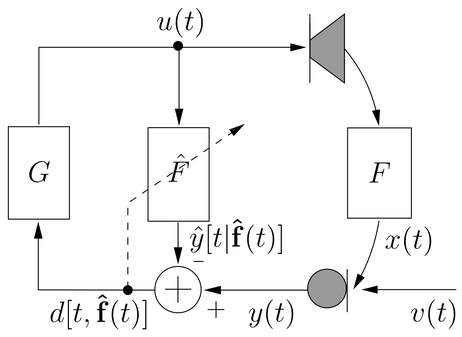



- closed-loop system **instability** if loop gain satisfies Nyquist criterion

$$\begin{cases} |G(\omega,t)F(\omega,t)| \geq 1 \\ \angle G(\omega,t)F(\omega,t) = n2\pi,\ n \in \mathbb{Z} \end{cases}$$

- poor **sound quality** (ringing, reverberation) if gain margin $< 3$ dB

## 2 Adaptive Feedback Cancellation




- closed-loop transfer function after feedback cancellation:

$$\frac{U(\omega,t)}{V(\omega,t)} = \frac{G(\omega,t)}{1 - G(\omega,t)[F(\omega,t) - \hat{F}(\omega,t)]}$$

- adaptive feedback cancellation **objectives**:
  1. to increase the maximum stable gain

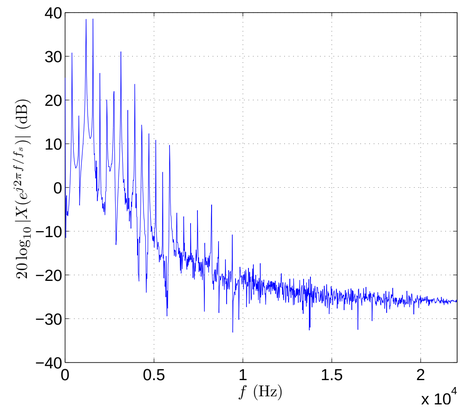
$$\text{MSG}(t) = -20\log_{10}\left[\max_{\omega} |G(\omega,t)[F(\omega,t) - \hat{F}(\omega,t)]|\right]$$

  2. to improve sound quality
- closed-loop identification using the **direct method**:
  - no reference signal (sound quality)
  - noise model is required to obtain consistent estimate
- adaptive feedback cancellation challenges:
  - find suitable noise model structure (audio signals)
  - noise model is unknown and time-varying
  - persistence of excitation is not guaranteed

## 3 Cascaded noise models

- Noise (audio) signal is known to admit a sinusoids+noise representation:

$$v(t) = \underbrace{\sum_{n=1}^{N} \beta_n \cos(\omega_n t + \phi_n)}_{\text{tonal components}} + \underbrace{\frac{1}{C(q,t)} e(t)}_{\text{noise components}}$$




- Noise model is chosen as **cascade of two linear models**:

$$v(t) = \underbrace{\frac{H_1(q,t)}{\text{tonal components model}}}_{\text{tonal components model}} \cdot \underbrace{\frac{H_2(q,t)}{\text{noise components model}}}_{\text{noise components model}} \cdot e(t)$$

  - noise components model $H_2(q,t) = \dfrac{1}{C(q,t)}$
  - tonal components model $H_1(q,t) = \dfrac{B(q,t)}{A(q,t)}$ with

| Model structure | Prediction error filter |
|---|---|
| Conventional LP model (LP) | $A(q,t) = 1 + \sum_{i=1}^{n_A} a_i(t) q^{-i}$ |
| Pole-zero LP model (PZLP) | $\frac{A(q,t)}{B(q,t)} = \prod_{i=1}^{n_A/2} \frac{1 - 2\nu_i \cos\theta_i q^{-1} + \nu_i^2 q^{-2}}{1 - 2\rho_i \cos\theta_i q^{-1} + \rho_i^2 q^{-2}}$ |
| Pitch prediction model (PLP) | $A(q,t) = 1 - \sum_{i=-1}^{1} \alpha_i(t) q^{-K-(l/D)-i}$ |
| Warped LP model (WLP) | $A(q,t) = D_0^{-1}(q,\lambda)[1 + \sum_{i=1}^{n_A} \alpha_i(t) D^i(q,\lambda)]$ |
| Selective LP model (SLP) | $A(q,t) = 1 + \sum_{i=1}^{n_A} \alpha_i(t) q^{-i\Gamma}$ |

## 4 Prediction Error Identification

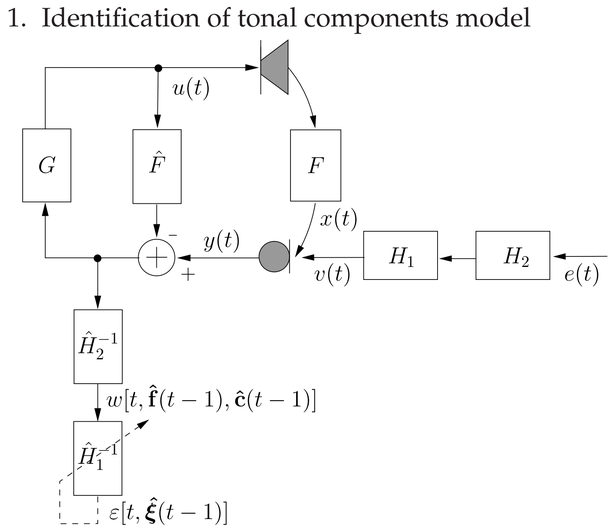
- Prediction error identification **criterion**:

$$\min_{\boldsymbol{\xi}(t)} \frac{1}{2N} \sum_{k=1}^{t} \varepsilon^2[k, \boldsymbol{\xi}(t)]$$

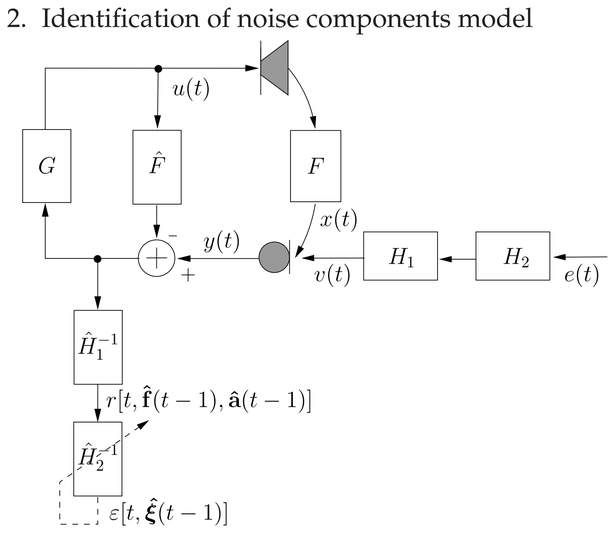
$$\varepsilon[t, \boldsymbol{\xi}(t)] = H_2^{-1}(q,t) H_1^{-1}(q,t)[y(t) - F(q,t)u(t)]$$

$$\boldsymbol{\xi}(t) \triangleq \left[\mathbf{f}^T(t)\ \mathbf{c}^T(t)\ \mathbf{a}^T(t)\right]^T$$

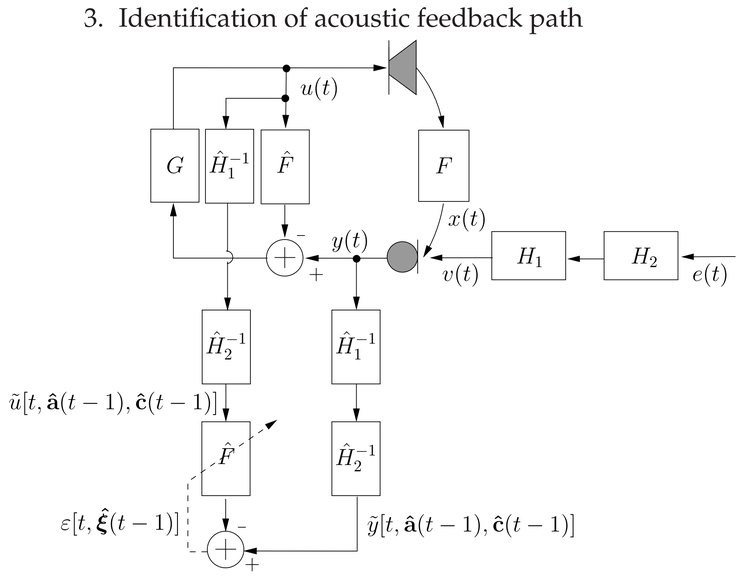
- Prediction error identification is **decoupled** in three stages:
  1. Identification of tonal components model




  2. Identification of noise components model



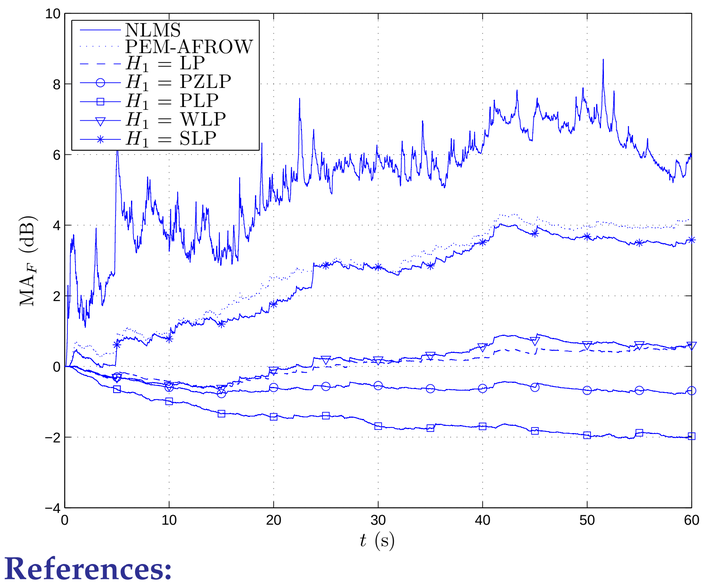

  3. Identification of acoustic feedback path




- **Identifiability conditions**:
  - electro-acoustic forward path $G(q,t)$ contains delay $d_1$
  - acoustic feedback path $F(q,t)$ contains delay $d_2$
  - $d_1 + d_2 \geq n_A + n_C + 1$

## 5 Simulation Results

### Public Address application

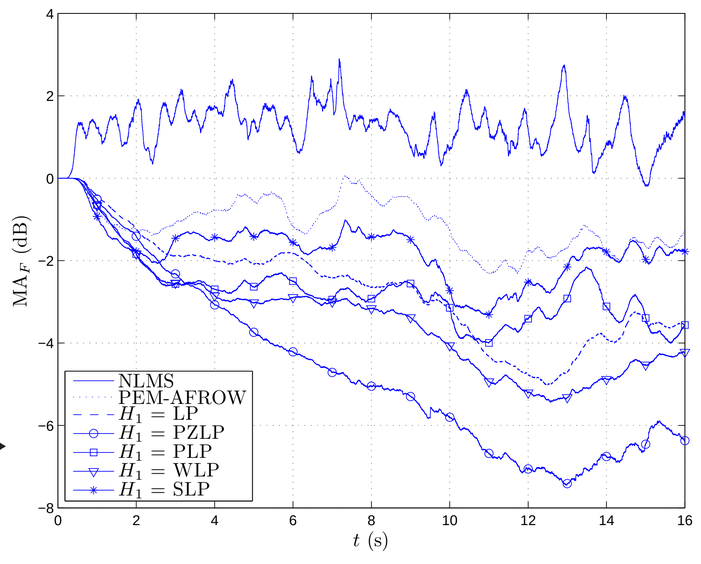



$F(q,t)$ = room acoustic impulse response
$f_s = 44100$ Hz
$n_F = 4410$ (= 100 ms)
$v(t)$ = Partita No. 2 in D minor (Allemande) for solo violin by J. S. Bach

NLMS: no noise models ($n_A = n_C = 0$)
PEM-AFROW: single noise model ($n_A = 0,\ n_C = 30$)
$H_1 =$ ·LP: cascaded noise models ($n_A = n_C = 30$)
Performance measure: $\text{MA}_F(\text{dB}) = 20\log_{10}\dfrac{\|\hat{\mathbf{f}}(t) - \mathbf{f}\|}{\|\mathbf{f}\|}$

$F(q,t)$ = hearing aid acoustic impulse response
$f_s = 16000$ Hz
$n_F = 200$ (= 12.5 ms)
$v(t)$ = Kyrie from Mass in C minor ("Grosse Messe") by W. A. Mozart

### Hearing Aid application





**References:**

1 T. van Waterschoot and M. Moonen, "Comparison of linear prediction models for audio signals," *EURASIP J. Audio, Speech, Music Process.*, submitted for publication, ESAT-SISTA Technical Report TR 07-29, Dec. 2007.

2 T. van Waterschoot and M. Moonen, "Adaptive feedback cancellation for audio applications," *IEEE Trans. Audio, Speech, Language Process.*, to be submitted for publication, ESAT-SISTA Technical Report TR 07-30, Nov. 2008.