Acoustic Echo Cancellation

Special Assignment- 3EC2102 Adaptive Signal Processing

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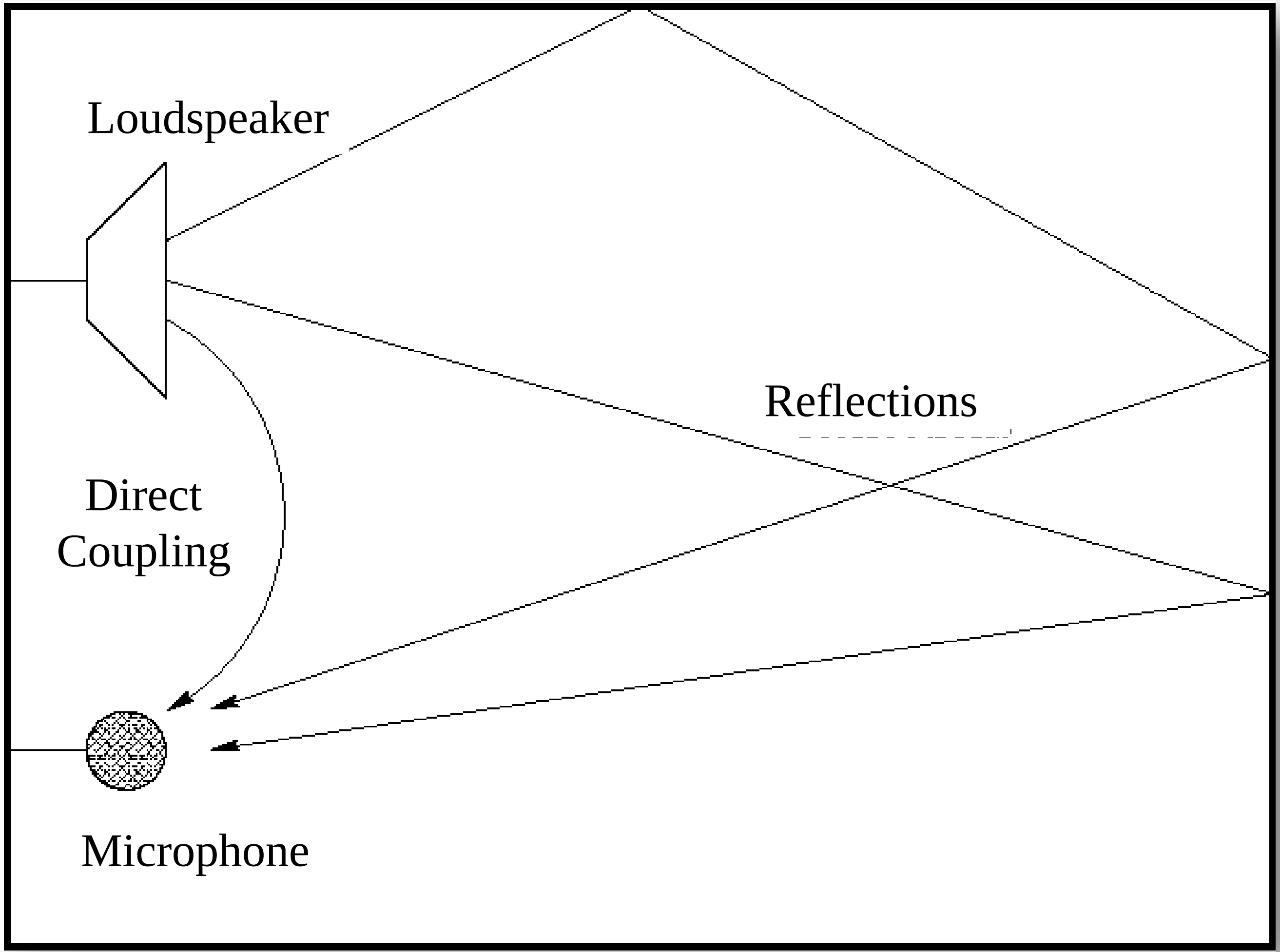
Echo

- Velocity of sound is approximately 343 m/s at 25°C
- Echo occur if
  - Any reflecting object placed more than 11.3 m far from the sound source produce echo
  - Delay is more then 32.94 msec
- Reverberation.

Acoustic Echo

- Sound from a loudspeaker is picked up by the microphone in the same room
- Problem exists in any communications where there is a speaker and a microphone
- Examples:
  - Hands-free car phone systems
  - A standard telephone or cellphone in speakerphone
  - Physical coupling (vibrations of the loudspeaker transfer to the microphone via the handset casing)

Acoustic Echo



Seriousness of AE compared to network echo in telephony

- Long delay
- The echo path may change according movement of microphone
- The background noise can be strong and non-stationary

Acoustic Room Impulse Response

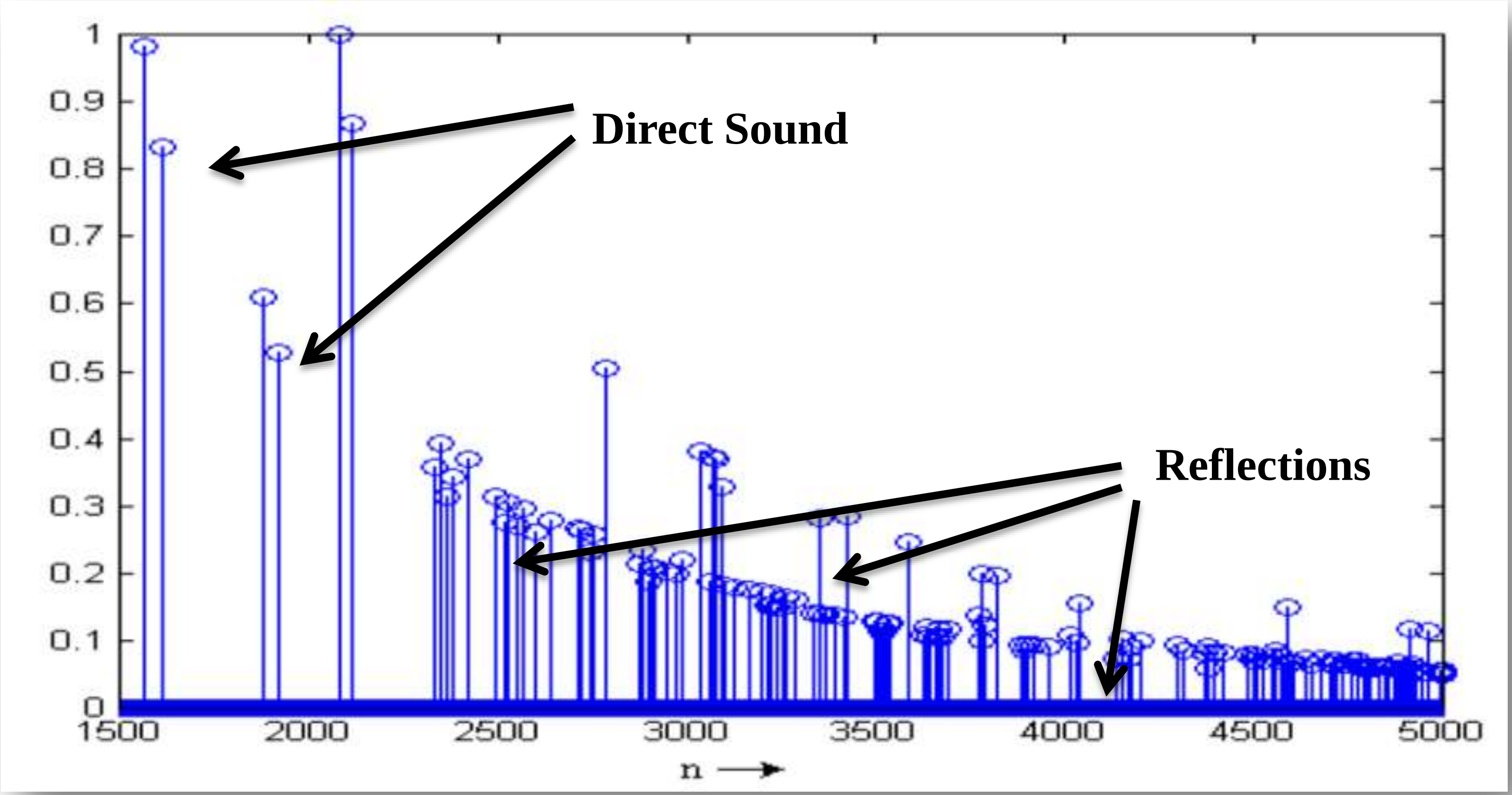
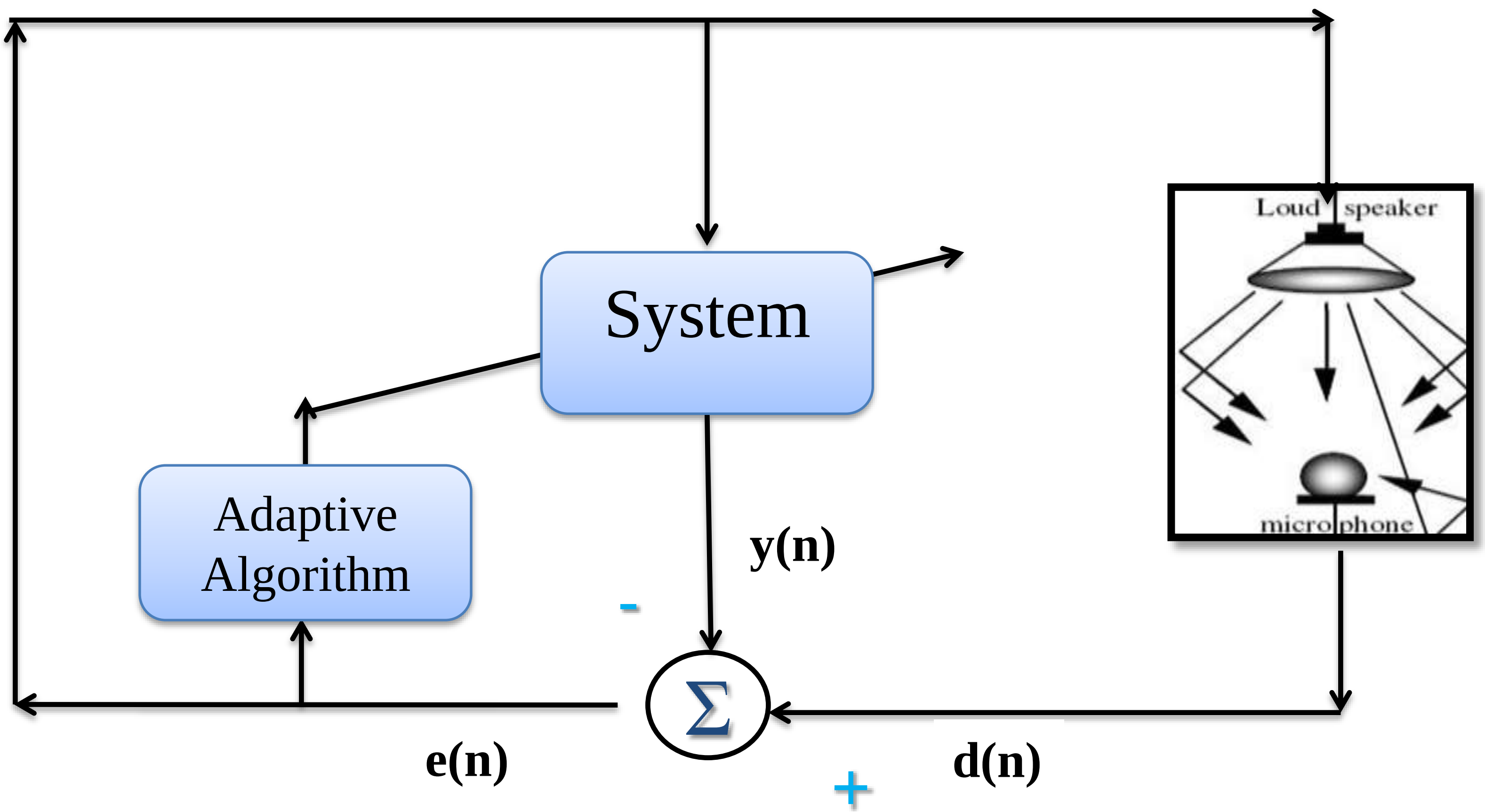


Figure: Impulse Response of Room *

*http://upload.wikimedia.org/wikipedia/commons/thumb/42/b45/Acoustic_room_imp_resp.svg/

Acoustic Echo Canceller



General AEC procedure

- A far-end signal is delivered to acoustic feedback synthesizer.
- The far-end signal is reproduced by the speaker
- A microphone picks up the sound
- The far-end signal is filtered and delayed.
- The filtered far-end signal is subtracted from the near-end signal.
- The resultant signal should not contain any direct or reverberated sound produced by the speaker.

Requirements

- Fast convergence of adaptive filter
- Stable convergence
- No performance degradation for the real speech signal

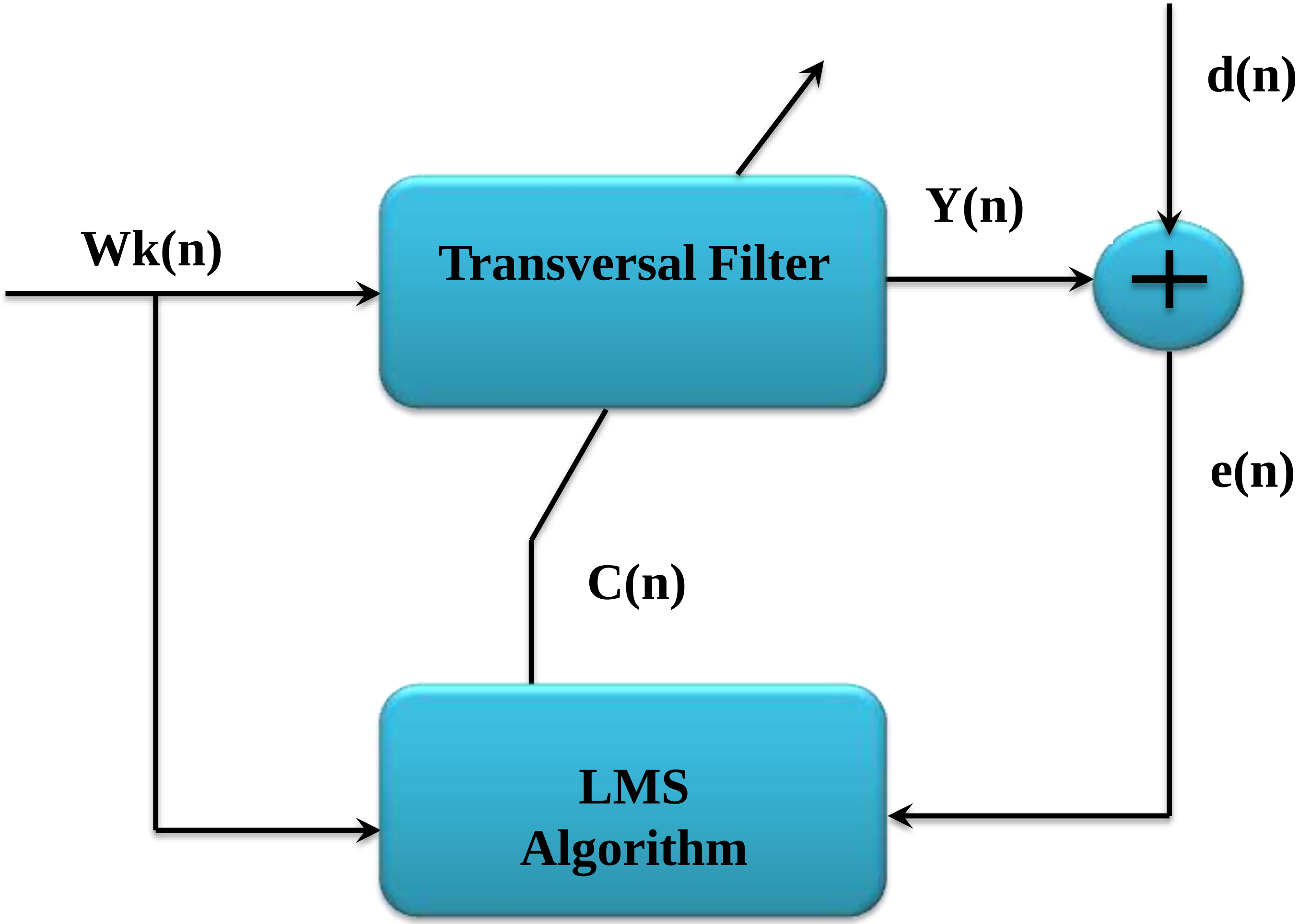
Echo Cancellation Algorithms

- LMS
- NLMS
- RLS
- APA (Affine Projection Algorithm)
- FAP (Fast Affine Projection)
- VSS-APA(Variable Step Size APA)

LMS Algorithm

- Most popular adaptation algorithm is LMS
  - Define cost function as mean-squared error
- Simple, no matrices calculation involved in the adaptation
- Based on the method of steepest descent
- Move towards the minimum on the error surface to get to minimum gradient of the error surface estimated at every iteration

LMS Algorithm cont..



LMS Algorithm cont..

- **Filter output =** $$y(n) = \sum_{k=0}^{M-1} u(n-k)\, w_k^*(n)$$
- **Estimation error =** $$e(n) = d(n) - y(n)$$
- **Tap-weight adaptation =**

$$w_k(n+1) = w_k(n) + \mu u(n-k)\, e^*(n)$$

$$\begin{pmatrix} \text{update value} \\ \text{of tap-weigth} \\ \text{vector} \end{pmatrix} = \begin{pmatrix} \text{old value} \\ \text{of tap-weight} \\ \text{vector} \end{pmatrix} + \begin{pmatrix} \text{learning-} \\ \text{rate} \\ \text{parameter} \end{pmatrix} \begin{pmatrix} \text{tap-} \\ \text{input} \\ \text{vector} \end{pmatrix} \begin{pmatrix} \text{error} \\ \text{signal} \end{pmatrix}$$

LMS Algorithm cont..

- The LMS algorithm is convergent in the mean square if and only if the step-size parameter satisfy

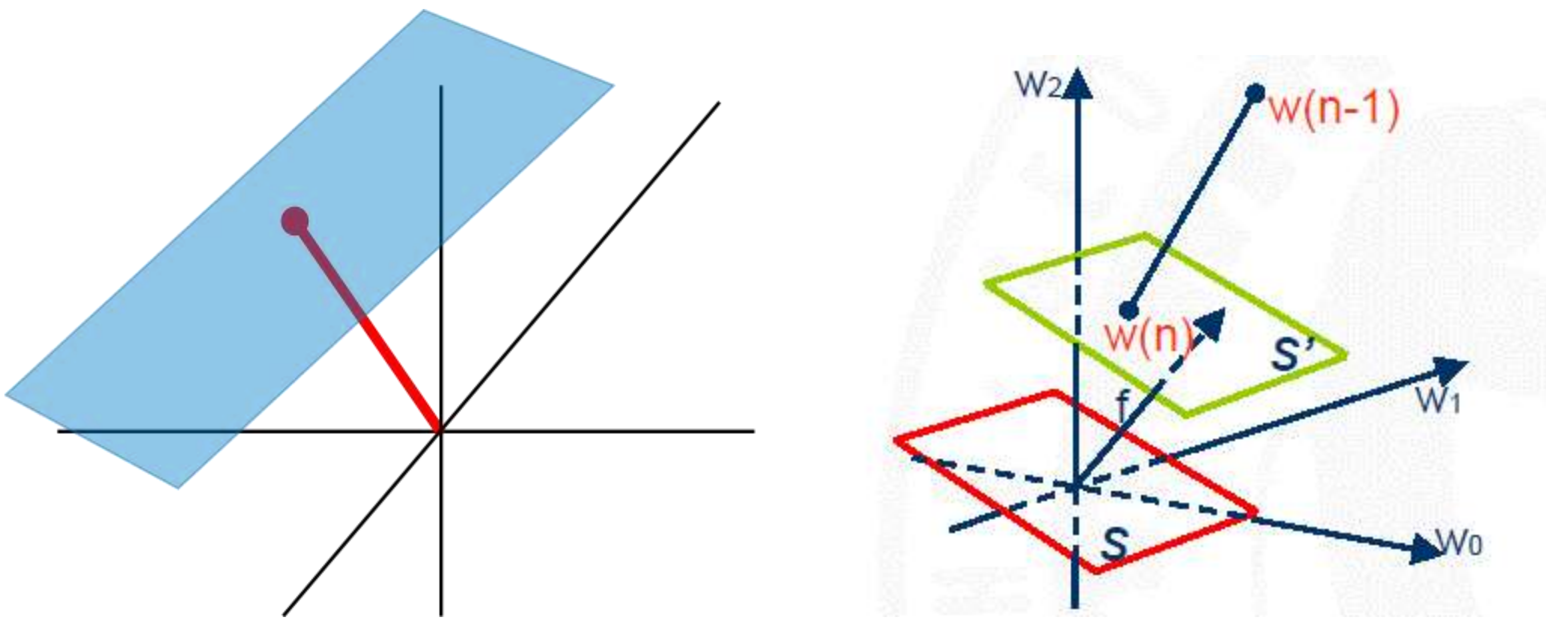
$$0 < \mu < \frac{2}{\lambda max}$$

- λ_{max} is the largest eigenvalue of the correlation matrix of the input data

Affine Projection Algorithm(APA)

- Affine:
  - Type of geometric transformation:
    - A geometric transformation that maps points and parallel lines to points and parallel lines
- Derived From NLMS
- Using *lagrange multipliers* with multiple weighting factors

Affine Projection Algorithm *cont*..



S=linear subspace s'=affine subspace

Figure : Affine Projection*

*http://upload.wikimedia.org/wikipedia/commons/thumb/8/8c/Affine_subspace.svg/500px-Affine_subspace.svg.png

Affine Projection Algorithm *cont*..

- cost function of affine projection filter:

- **J(n)= ||W(n+1) – W(n)||² + …**

$$\dots \sum_{k=0}^{N-1} \boldsymbol{Re}\ [\lambda_k^{*}(\ d(n\text{-}k) - \delta\lambda^{n}(n\text{-}i) * \|W(n)\|^{2}\ \ W^{H}(n+1) * u(n\text{-}k)]$$

- $A^H(n)$= input data matrix in hermitian transpose [N*M]
- $d^H(n)$=desired response vector in hermitian transpose[N*1]
- λ^H= lagrange multiplyer vector in hermitian transpose

- Weight vector

$$W(n+1) = [I - \mu\ AH(n)\ (\ A(n)\ \ AH(n)\ )-1\ A(n)] * W(n) + \dots$$
$$\dots\ \mu\ AH(n)\ (\ A(n)\ \ AH(n)\ )^{-1} * d(n)$$

Affine Projection Algorithm *cont..*

- Fast Convergence compared to NLMS in acoustic environment
- But computational complexity also increases
- Inverse of correlation matrix is required
- Fast Affine Projection (FAP) has been proposed by S. L. gay and tavathia in 1995

Fast Affine Projection * (FAP) *cont*..

- LMS like low complexity and memory requirements
- RLS like fast convergence
- Computationally efficient then APA

- uses a sliding windowed FRLS to assist in a recursive calculation of the solution.

*S. L. Gay and S. Tavathia, "The fast affine projection algorithm," in Proc. 1995 IEEE Int. Conf. Acoust., Speech, Signal Process. (ICASSP), Detroit, MI, May 1995, vol. 5, pp. 3023–3026.

Fast Affine Projection (FAP) *cont*..

- When input is speech signals, FAP converges rapidly compared to other algorithms

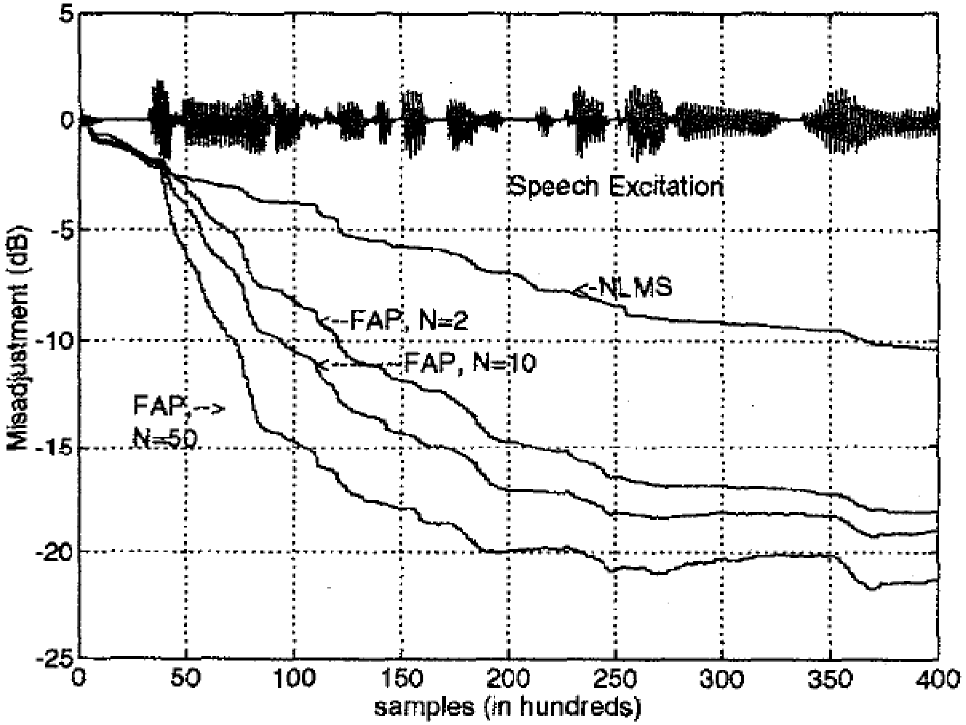


Figure : Comparison of FAP for different orders of projection, N, with speech excitation

Variable Step Size APA*

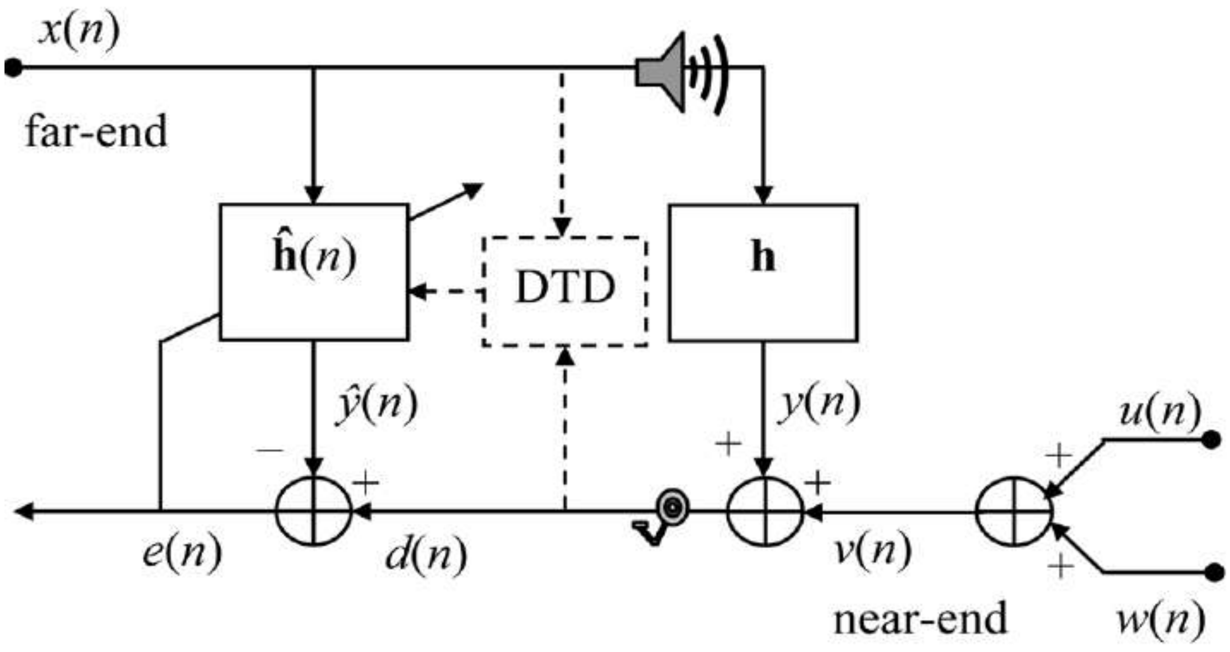


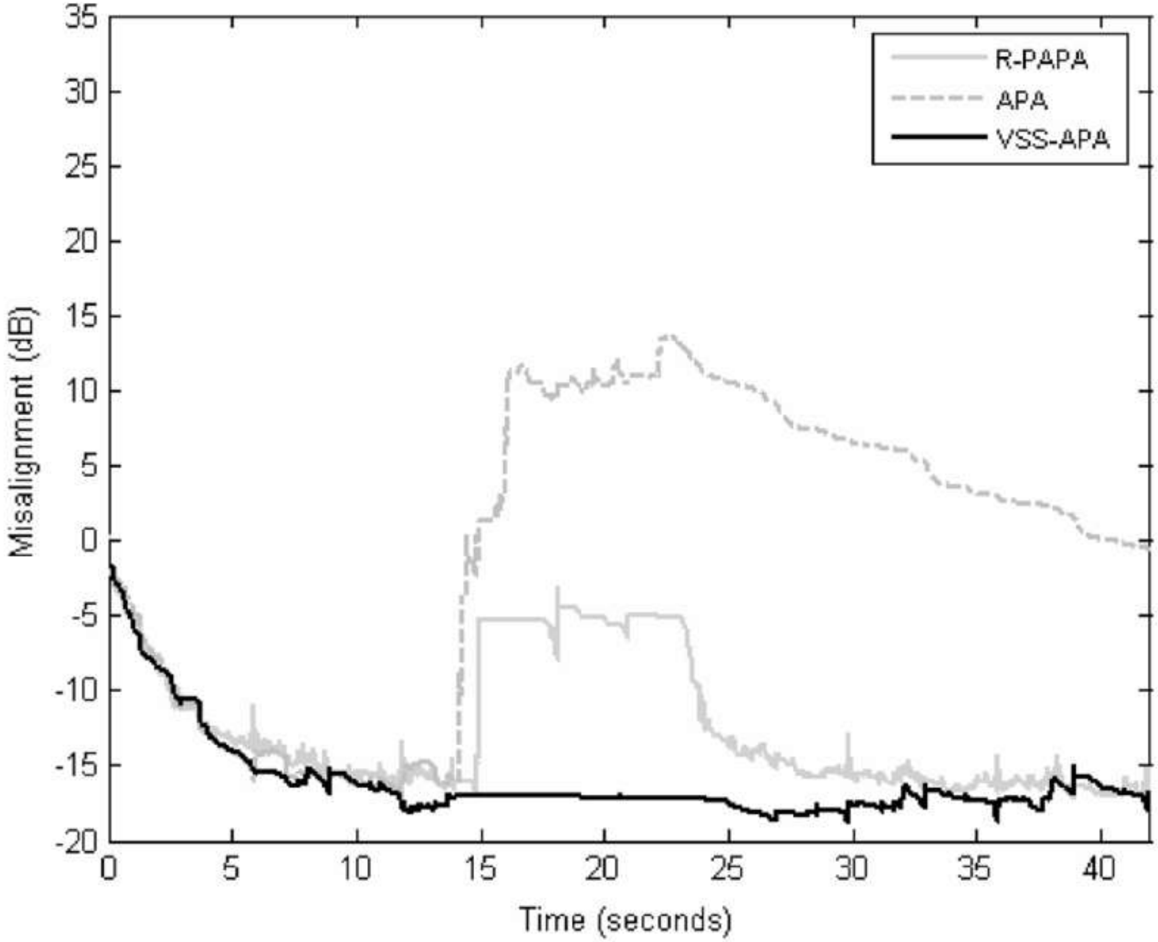
Figure: AEC Configuration

* Constantin Paleologu,, Jacob Benesty at al. ” A Variable Step-Size Affine Projection Algorithm Designed for Acoustic Echo Cancellation”, IEEE Transactions on audio, speech, and language processing, vol. 16, no. 8, november 2008

Variable Step Size APA *cont..*

- Different step size for three different scenario
  - Single talk
    - Background noise only w(n)
  - Double talk
    - Background noise w(n) and near end speech u(n)
  - Under-Modeling
    - Echo caused by the part of the system that cannot be modeled

Variable Step Size APA *cont..*



simulation result: comparison between APA, the robust proportionate APA(R-PAPA) and VSS-APA

Conclusion

- Acoustic Echo is a type of interference in voice communication
- To eliminate it, best method is Adaptive filters
- Different kinds of algorithms
  - Fast = RLS, FAP
  - More efficient = VSS-APA
  - Choose according to requirements

Thank You