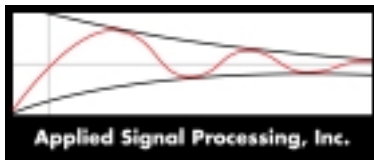


Active Noise Control

Architectures and Application Potentials

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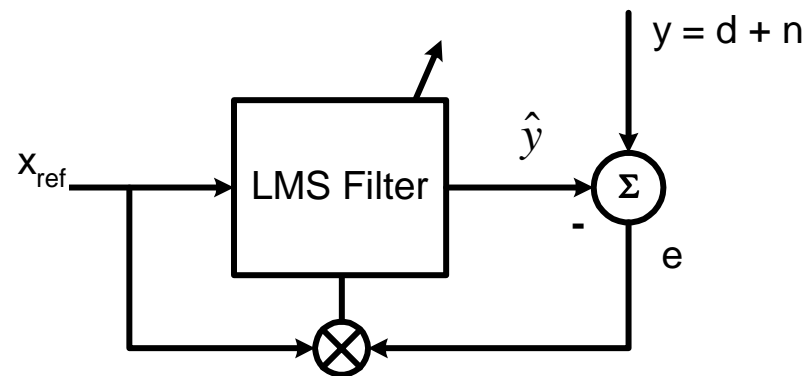
General Problem Definition:

- A measurable signal, y , contains a desired signal component, d , and a noise component, n , which is to be removed from y . The measurable signal can be a humanly observable event such as a vibration or sound, or an electrically observable event such as radio frequency interference.

$$y = d + n$$

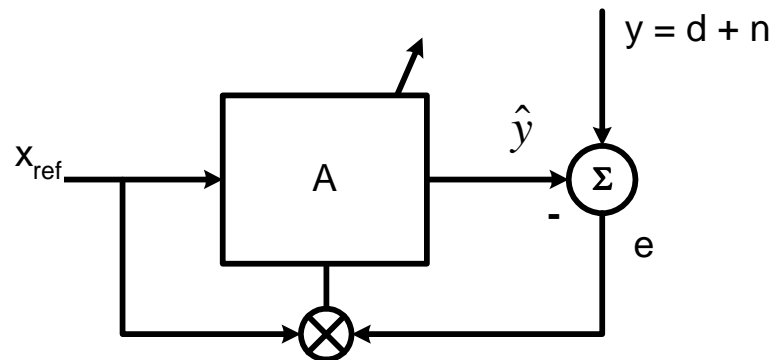
The Active Noise Control Solution

- Feed Forward Adaptive Active Noise Control uses an LMS Adaptive filter to create and introduce a control signal, \hat{y} which when subtracted from y , results in an error signal whose power is minimized in a mean square sense.



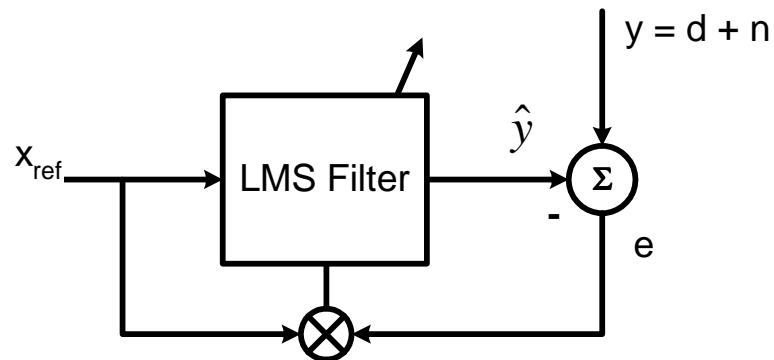
LMS Adaptive Filter

- Minimizes the error between the observation, y , and the estimate, \hat{y} .
- Matches/Removes only the components y which are correlated to the reference signal.
- Update EQ: $\mathbf{A}(k+1) = \mathbf{A}(k) + \mu \mathbf{X}^* \mathbf{e}(k)$



An Active Noise Control System needs:

- A Reference Signal, x (either correlated to d or n).
- A measurable observation y or a measurable Error Signal $e = (y - \hat{y})$
- A method for adding/mixing the control signal \hat{y} into the system. (either in the digital or physical domain)

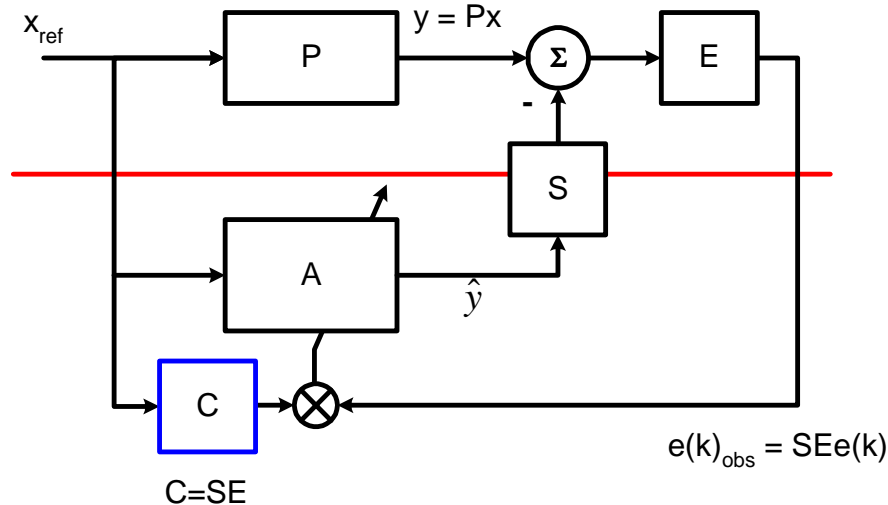


ANC Feed Forward Architectures

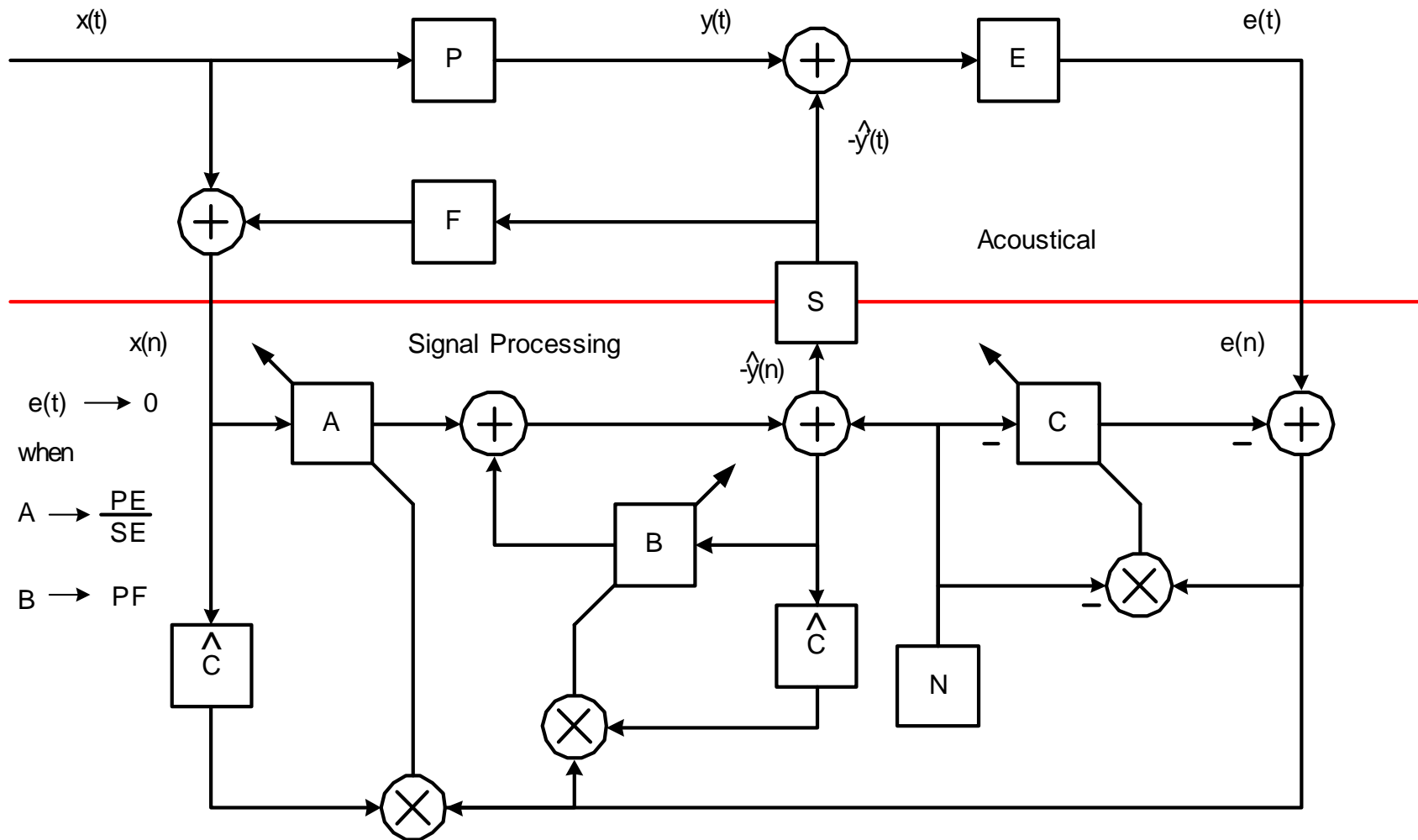
- System or Plant Identification. (For Random and/or Tonal noises)
- Signal Identification (For Tonal noises)
- “Filtered-X” variants of Plant Id or Signal Id Systems (for acoustic and vibration control.)

Filtered-X LMS

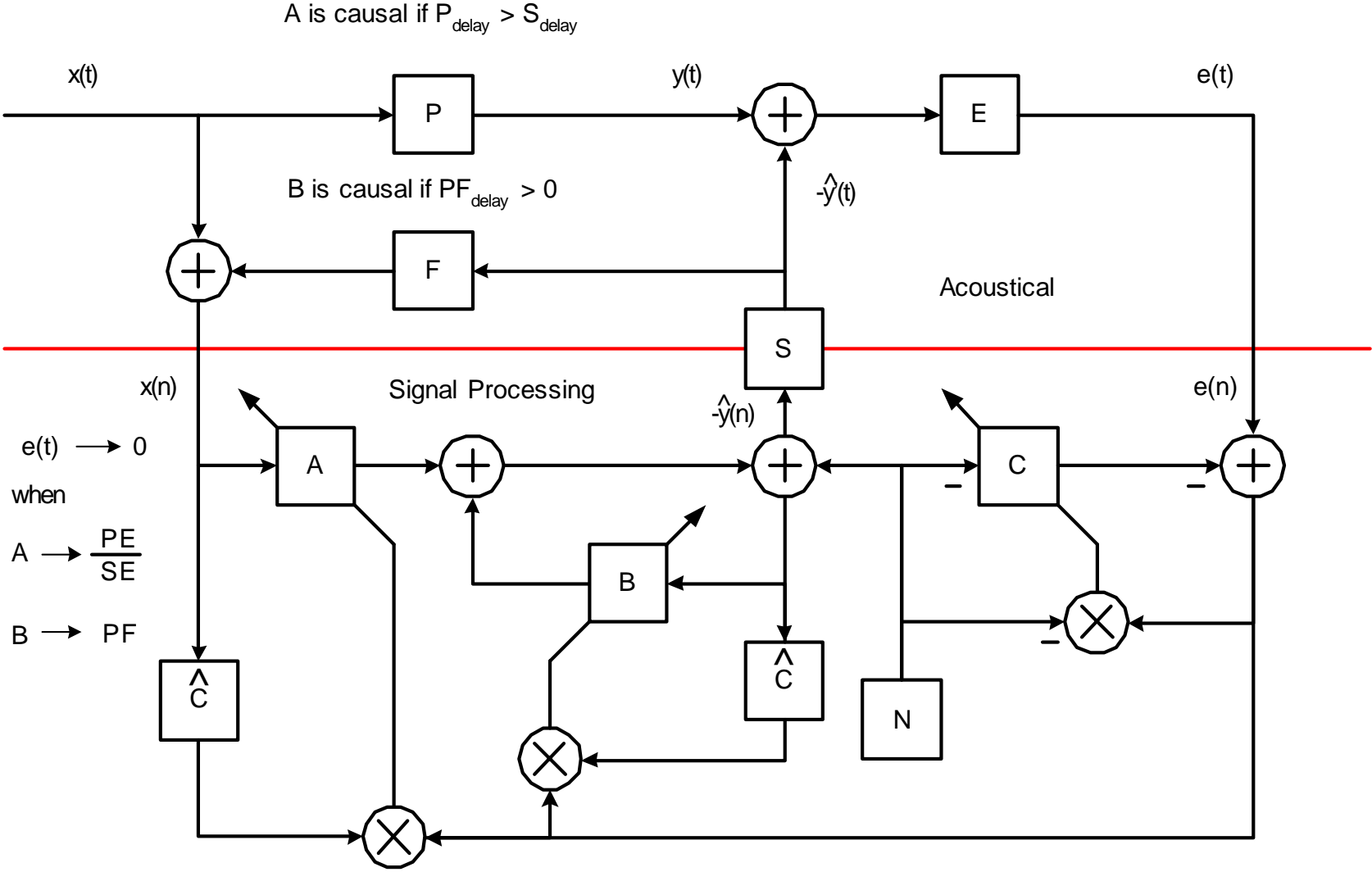
- Typical Adaptive Filter– measures the error signal directly.
- Typical Acoustic Active Noise Control Configuration – measures a filtered version (C) of the error signal.
- Requires use of the “Filtered-X” LMS algorithm.
- Update EQ: $\mathbf{A}(k+1) = \mathbf{A}(k) + \mu \{ \mathbf{C}\mathbf{X}(k) \}^* e_{\text{obs}}(k)$



ANC - Plant Identification Architecture



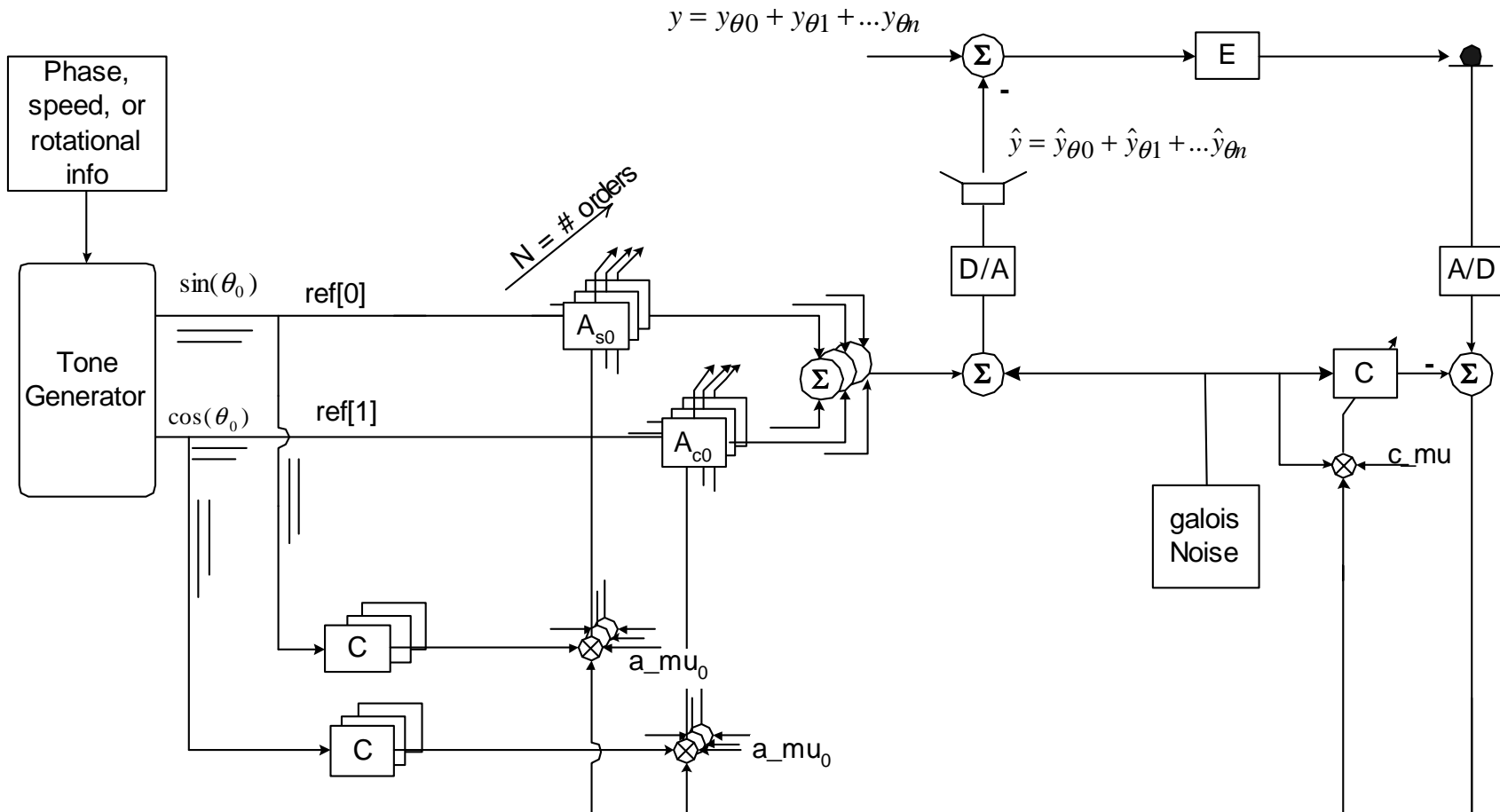
Plant Id – Causality Requirements



ANC - Plant Identification Architecture

- Advantages:
 - Can cancel random noise.
 - Once converged, no need to re-adapt to track changes in reference signal
- Disadvantages:
 - Needs longer physical plant lengths to meet causality requirements.
 - Requires Persistence of Excitation for proper convergence.
 - Computationally intensive for higher filter order (# of taps) when more frequency resolution is needed.
 - Requires higher filter order for better low frequency tonal performance.

ANC – Signal Identification Architecture



ANC – Signal Identification Architecture

- Reference Signal Generator (from a phase or frequency observation.)
- Two Tap Quadrature Adaptive Filter (One Pair for each frequency to be controlled) matches phase and amplitude of frequency component, y_{θ_n} , within y .
- Output and Update Equations:

$$\hat{y}_{\theta_n}(k) = \hat{A}_{\cos \theta_n}(k) \cdot \cos_{\theta_n}(k) + \hat{A}_{\sin \theta_n}(k) \cdot \sin_{\theta_n}(k)$$

$$\hat{A}_{\cos \theta_n}(k+1) = \hat{A}_{\cos \theta_n}(k) + \mu \cos_{\theta_n}(k) e(k)$$

$$\hat{A}_{\sin \theta_n}(k+1) = \hat{A}_{\sin \theta_n}(k) + \mu \sin_{\theta_n}(k) e(k)$$

ANC – Signal Identification Architecture

- Advantages:
 - Fast Convergence.
 - Computational Simplicity.
 - Excellent frequency resolution.
- Disadvantages:
 - Tonal or Periodic Noise Applications only.
 - In Filtered-X LMS applications, requires $2N$ separate filtering operations for each frequency component.

Why is Acoustic Active Noise Control Difficult?

- Typical Active Noise Control Configuration requires use of the “Filtered-X” LMS algorithm.
- The C path must be known and typically it changes, so an adaptive process for it is also required.
- The most reliable way to model the C path is using an auxiliary noise source. This presents customer acceptance challenges.
- Errors between C and SE effect convergence rates of the adaptive filter and stability requirements.
- Complexity expands in MIMO cases. Number of C models = $\text{NUM_ACT} * \text{NUM_ERR}$

Crafting the ANC Solution:

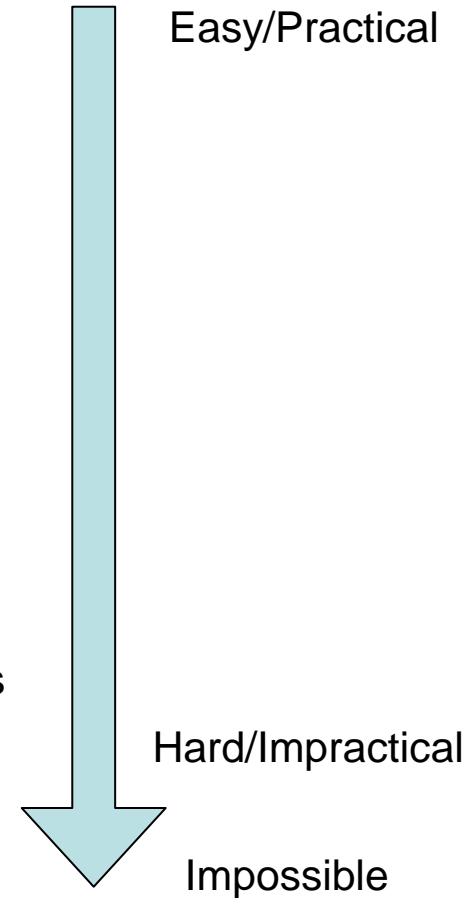
- Evaluate Viability of Active as an Approach.
 - Initial litmus tests – (physics & costs)
 - Noise Analysis – characterize the noise.
 - Market Analysis – cost & end user constraints.
- Choose Configuration:
 - System ID, Signal ID or hybrid.
 - Filtered-X vs. Direct LMS update.
- Simulation and Analysis
- Real Time Implementation.

Viability Considerations of an ANC Solution

- Availability of a reference signal, error signal, and mixing method.
- Power Requirements.
- Cost relative to Target Application.
- Noise Spectrum Characteristics:
 - Tonal, random, or mix.
 - Dynamic or Stationary tonal characteristics.
 - SPL or Vibration Levels.
 - Frequency Range.
 - Geometric Attributes – plane wave, point source, free space.
 - Portion of which can be removed with active with respect to total noise spectrum.
 - Coherence between reference signal and observation or error signal.
- Dimensionality of the system.
- Size/geometry/packaging space.
- Operating environment (hot, cold, caustic)
- Complexity vs. Passive Methods. (Cost/Benefit)

Potential ANC Applications

- Communication Systems (cell phone, two way radios, intercom) within any noisy environment.**
- Audio - Post Production clean up.
- Aircraft – active engine mounts**
- HVAC, Industrial Blowers/Fans**
- Automotive – air induction*
- Aircraft – cabin interior*
- Vibration Isolation – sensitive manufacturing processes.*
- Computer Fan Noise.*
- Automotive - interior*, road noise.
- Automotive – exhaust*,
- Lawn mowers*, vacuum cleaners, dishwashers, refrigerators
- Factory Noise in free space (hard to beat ear plugs)
- Loud impulsive noise (jack hammers, punch presses)
- Snoring, Neighbor or Teenager’s Stereo, Politicians.

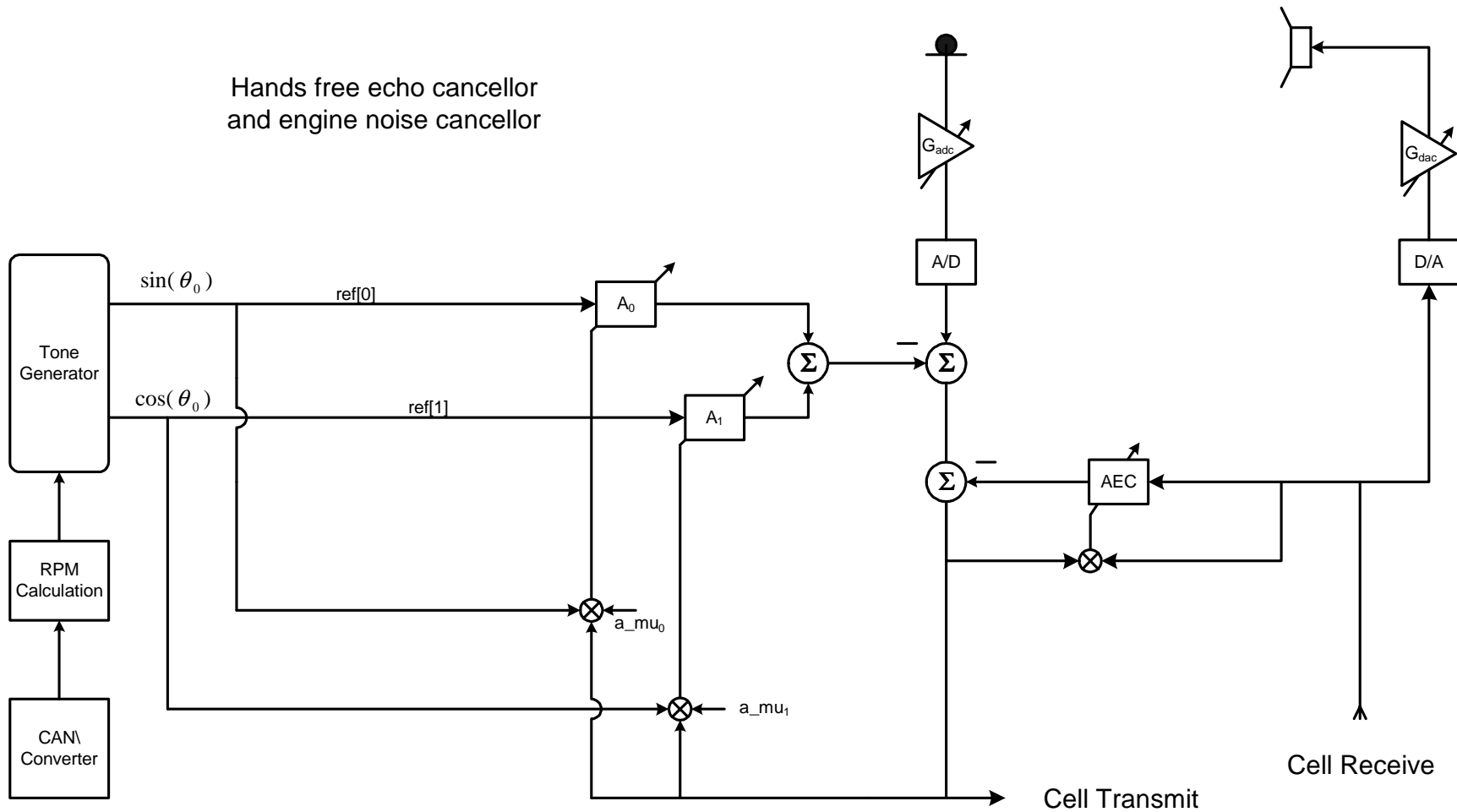


Application Example

- Clean up Outbound Cell Tx in Vehicle During Hands Free operation.
 - Engine noise is tonal. (two tap quadrature can be used)
 - A reference signal can be generated from readily available CAN signals.
 - The mixing environment is in the digital domain - Direct LMS can be applied.

Application Example

Hands free echo cancellor
and engine noise cancellor



Conclusion/Looking Forward

- Increasing MIPS capacity of DSPs can make computationally impractical applications of the past more viable.
- Recent research in highly directional acoustic sources via loud speaker arrays may help expand potential application areas.

References/Further Reading

- “Active Noise Control Systems – Algorithms and DSP Implementations”; Sen M. Kuo, Dennis R. Morgan.
- “Lectures on Adaptive Parameter Estimation”, C. Richard Johnson Jr.
- “Active Control of Sound”; P.A. Nelson & S.J. Elliot.