Active Noise Control

Architectures and Application Potentials

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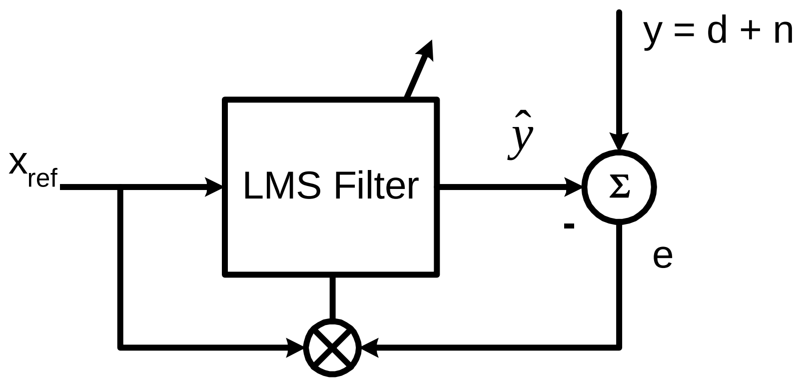
General Problem Definition:

- 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.

$$y = d + n$$

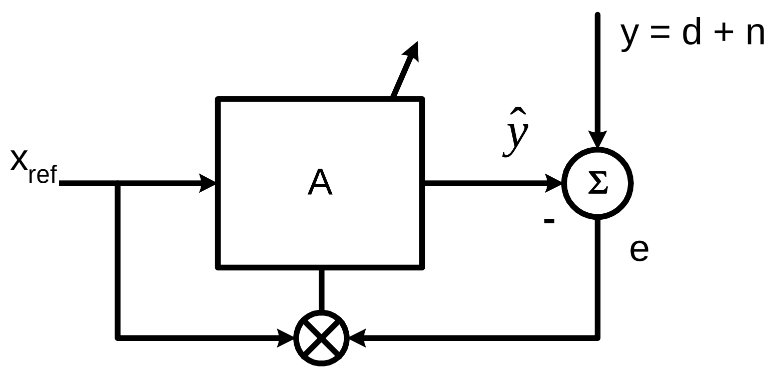
The Active Noise Control Solution

- 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.



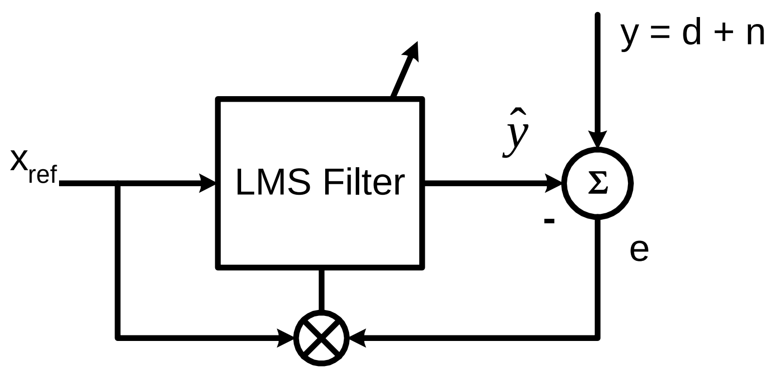
LMS Adaptive Filter

- 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: **A**(k+1) = **A**(k) + mu***X**(k)*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)

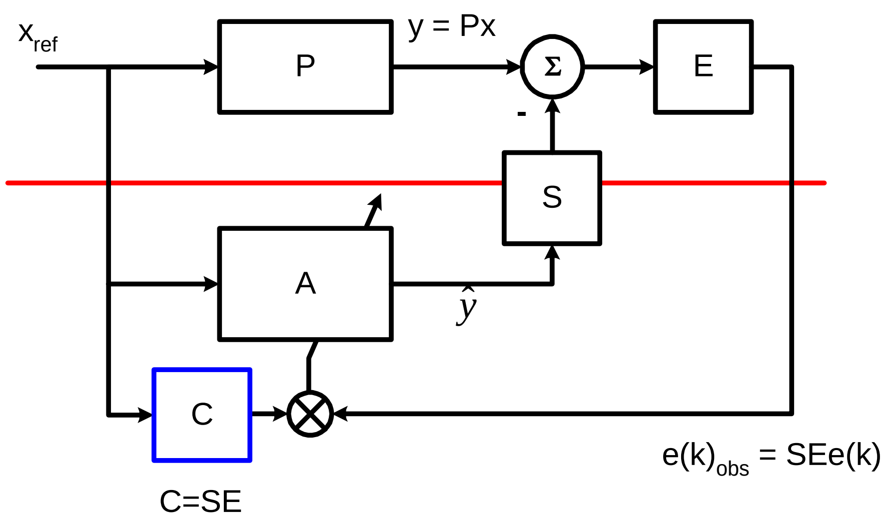


ANC Feed Forward Architectures

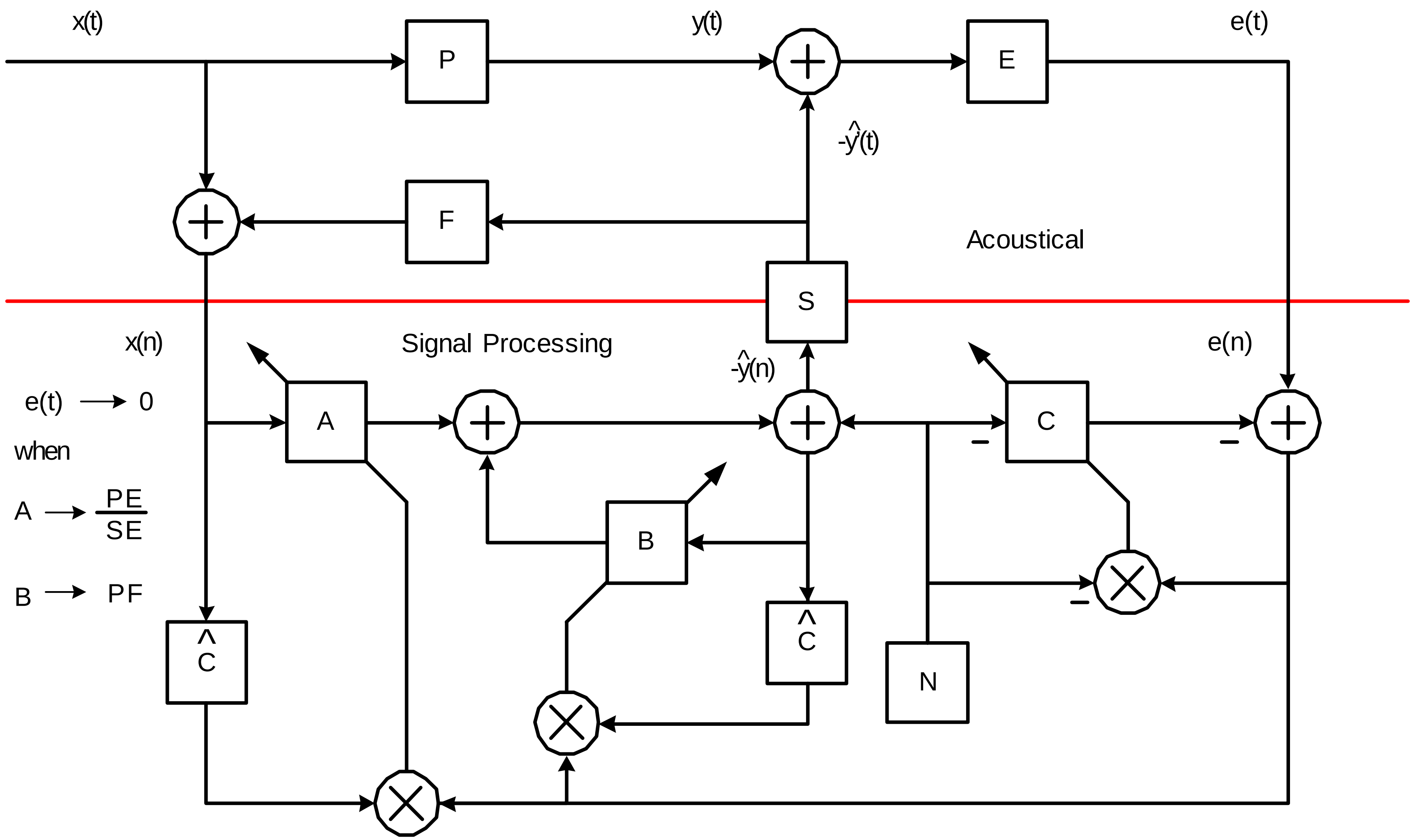
- System or Plant Identification. (For Random and/or Tonal noises)
- Signal Identification (For Tonal noises)
- “Filtered-X” variants of Plant Id or Signal Id Systems (for acoustic and vibration control.)

Filtered-X LMS

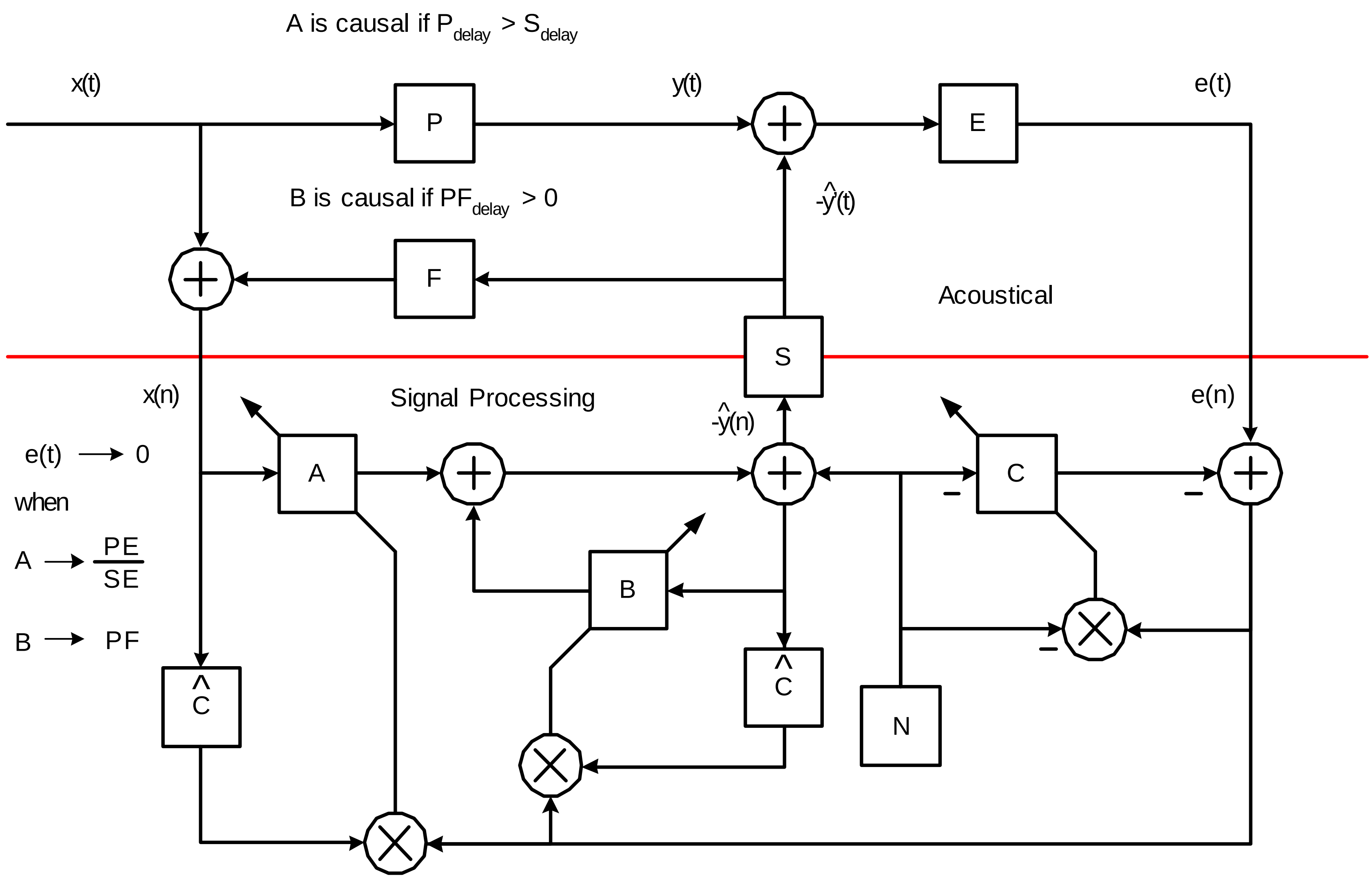
- Typical Adaptive Filter– measures the error signal directly.
- Typical Acoustic Active Noise Control Configuration – measures a filtered version (C) of the error signal.
- Requires use of the “Filtered-X” LMS algorithm.
- Update EQ: **A**(k+1) = **A**(k) + mu*{**CX**(k)}*e_{obs}(k)



ANC - Plant Identification Architecture



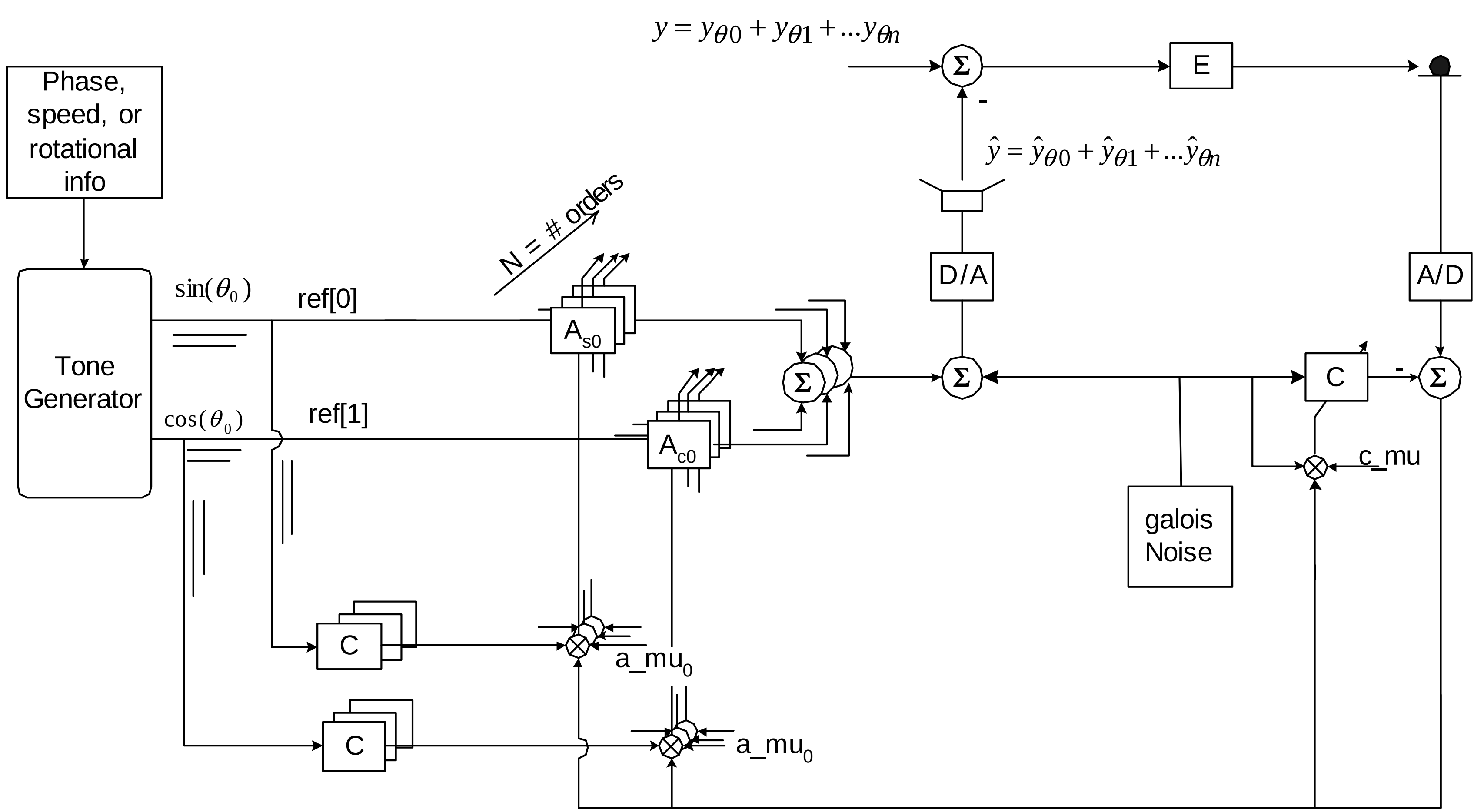
Plant Id – Causality Requirements



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, $y_{\theta n}$, 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 = NUM_ACT * NUM_ERR

Crafting the ANC Solution:

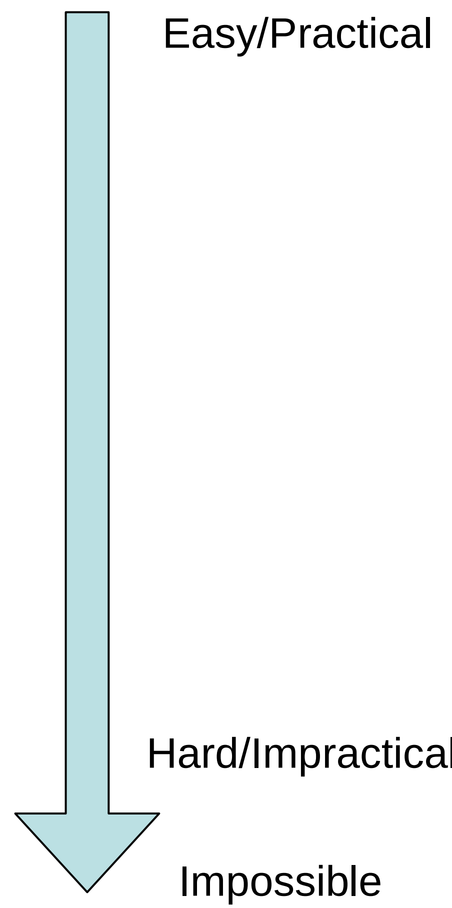
- Evaluate Viability of Active as an Approach.
  - Initial litmus tests – (physics & costs)
  - Noise Analysis – characterize the noise.
  - Market Analysis – cost & end user constraints.
- Choose Configuration:
  - System ID, Signal ID or hybrid.
  - Filtered-X vs. Direct LMS update.
- Simulation and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

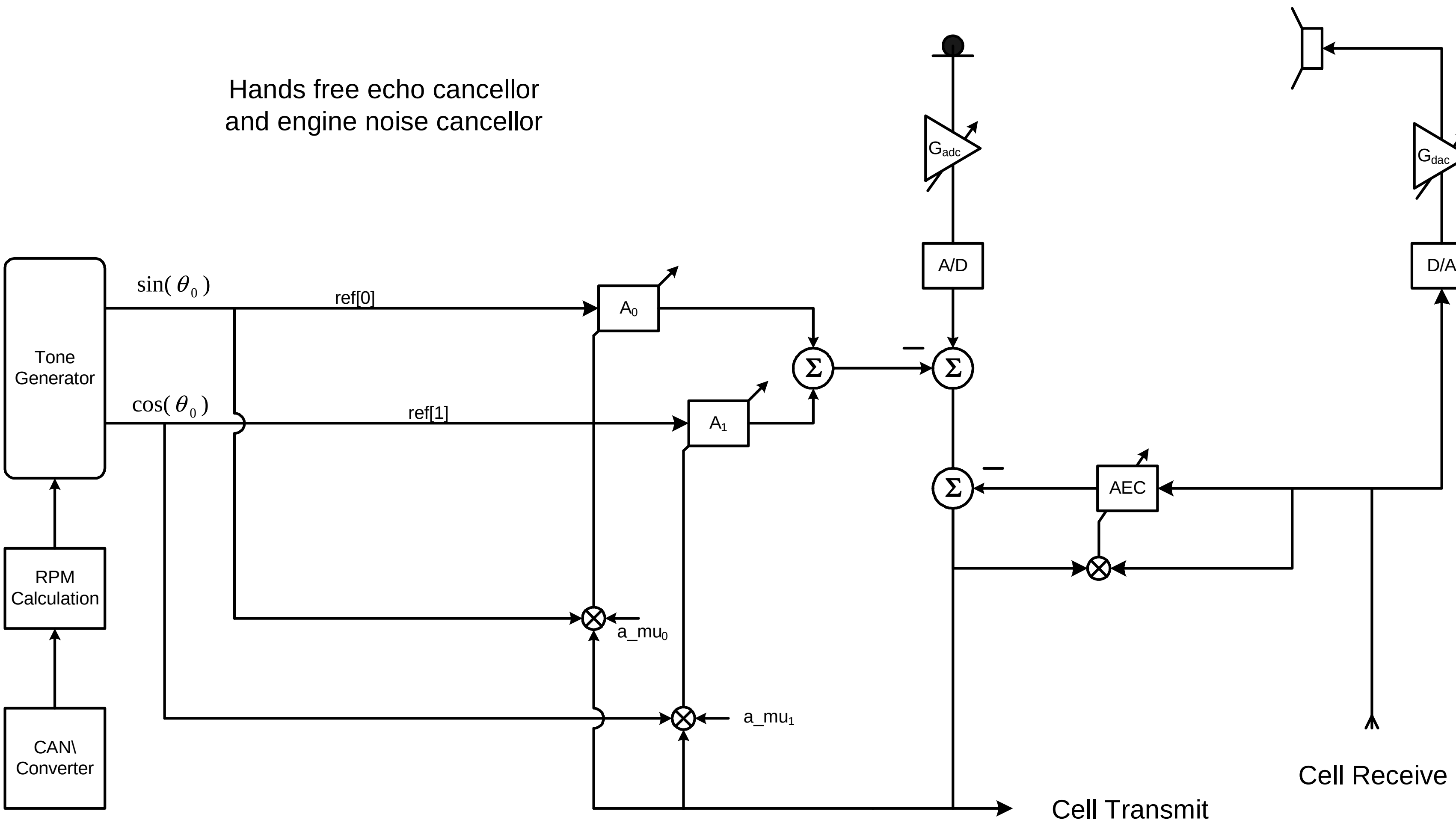


Application Example

- 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.