Adaptive Mixed-Signal System Design

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Jan 30, 2006

Outline

- Motivations
- Challenges
- Algorithms
- Examples
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Motivations

- In contemporary radio receivers for mobile applications, the front-end is **inflexible**.
- The modern radio environment, however, is **highly variable**.
- The result is that a receiver is usually designed to perform under the **worst-case** conditions.
- The solution is an **adaptive/reconfigurable** RF front-end

Motivations

- Adaptive circuitry can extend the reliability, parametric performance of many mission-critical systems.
- Adaptive radio front-end can change itself to the form which fits the actual reception situation best.

Challenges

- The design of today’s adaptive circuits, when at RF frequency and digitally controlled, requires consideration of design domains whose tools and methodologies have **traditionally been partitioned**, i.e., mixed-signal design flow problem, mixed-signal CAD tools’ compatibility.

Challenges

- As mentioned before, adaptive RF front-ends need digital control feedback signal, but where does this digital control signal come from? And how do we generate it?
- Possible solution: non-classical system partitioning using ancillary ADCs/DACs.

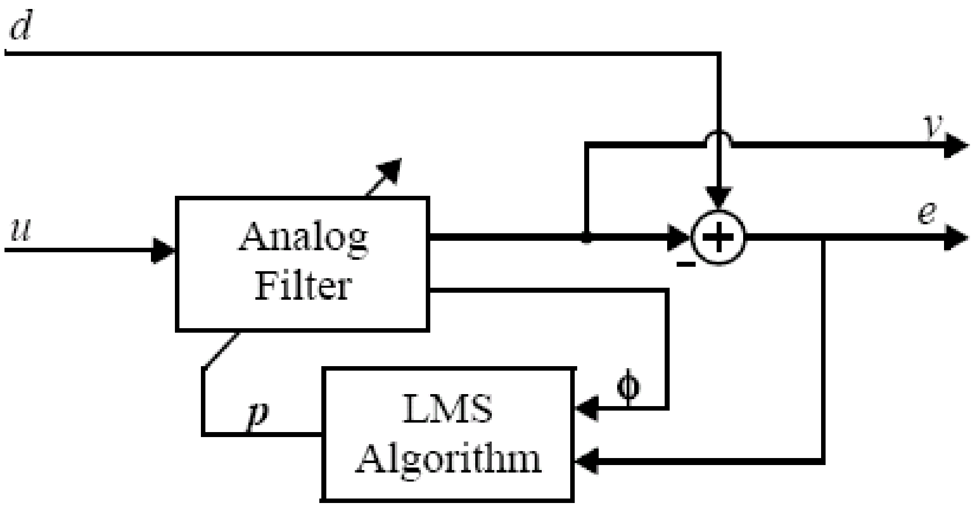
Challenges

- Since we want to introduce feedback to adaptively adjust certain parameters of the system, we must face the issue of stability.
- The frequencies that the RF front-end is operating at makes it necessary to consider distributed effects, i.e., design might be layout-driven rather than top-down, schematic-based flow.

Algorithms

- Steepest Descent
- Least Mean Square (LMS)
- Least Square (LS)
- Recursive Least Squares (RLS)

Least Mean Square (LMS) Algorithm



$$\varepsilon(\mathbf{p}(k)) = E[(d(k) - y(k))^2] = E[e^2(k)]$$

Least Mean Square (LMS) Algorithm

- How does it work?

  Update p(k) iteratively in a direction opposite the gradient of the error signal at the current p(k)

  The update rule is

$$p(k+1) = p(k) - \mu \cdot \nabla_{p(k)} \varepsilon(p(k))$$

Least Mean Square (LMS) Algorithm

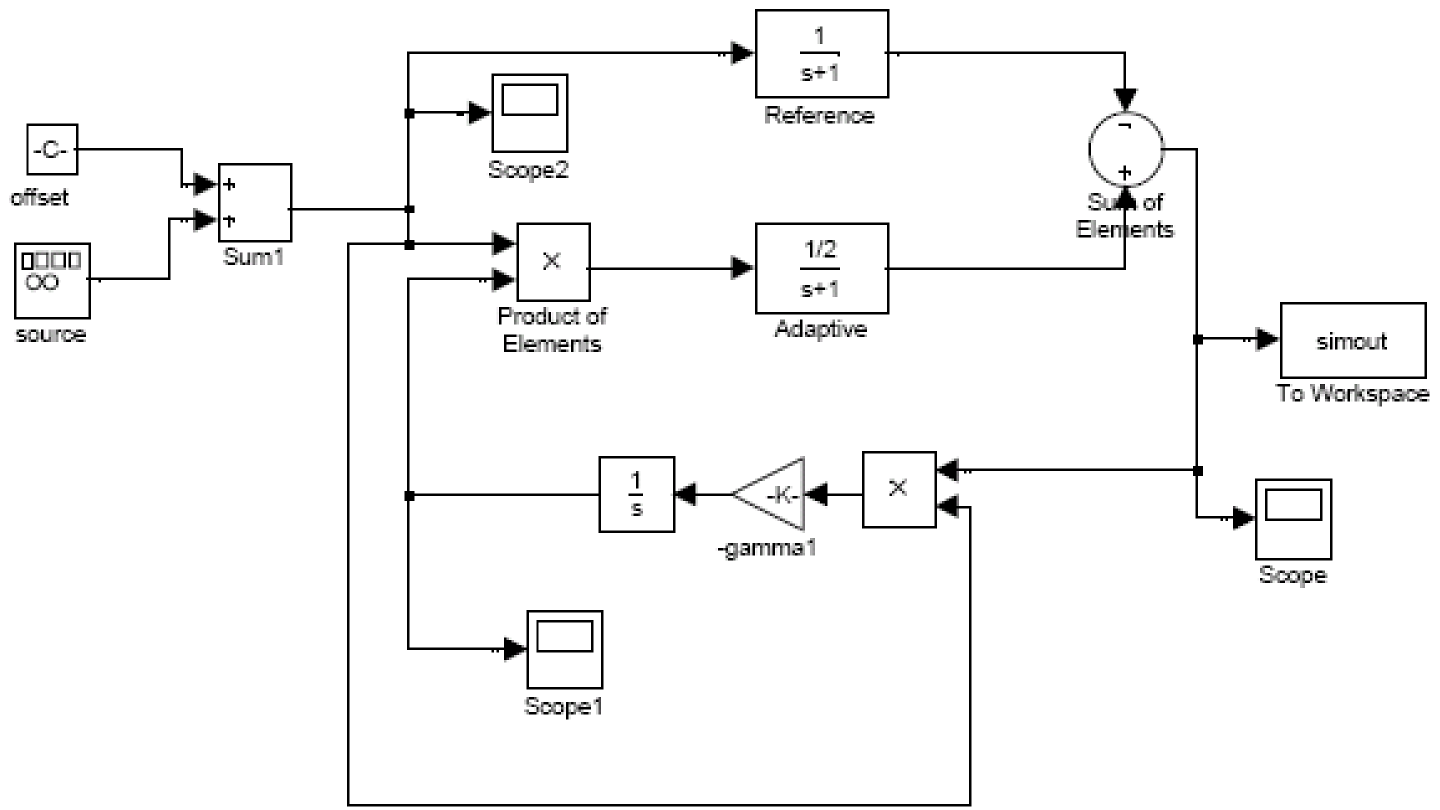
- The most significant leap

$$\varepsilon(\mathbf{p}(k)) = E[e^2(k)] \approx e^2(k)$$

- The resulting update rule

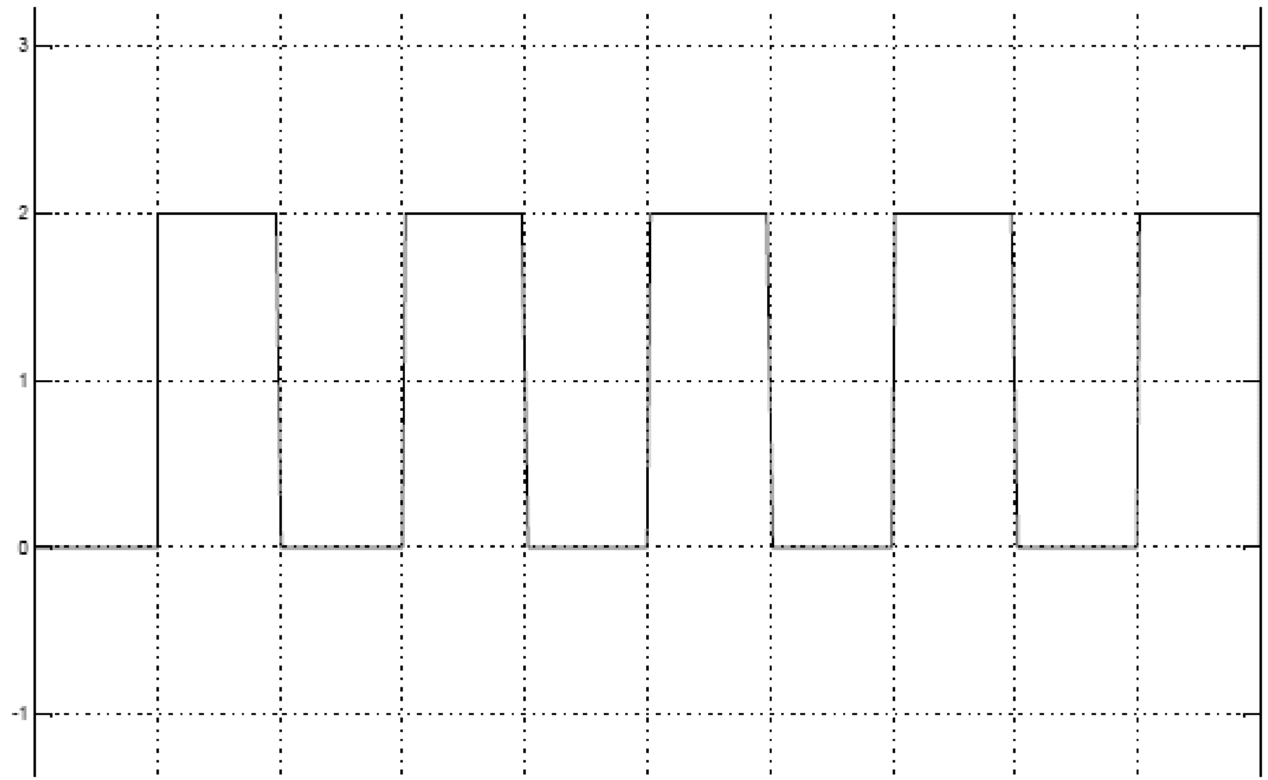
$$\begin{aligned}
\mathbf{p}(k+1) &= \mathbf{p}(k) - \mu \cdot \nabla_{\mathbf{p}(k)} e^2(k) \\
&= \mathbf{p}(k) - \mu \cdot \frac{de^2(k)}{de(k)} \cdot \nabla_{\mathbf{p}(k)} e(k) \\
&= \mathbf{p}(k) - \mu \cdot (2e(k)) \cdot \nabla_{\mathbf{p}(k)} (d(k) - y(k)) \\
&= \mathbf{p}(k) - 2\mu e(k) \cdot (-\nabla_{\mathbf{p}(k)} y(k)) \\
&= \mathbf{p}(k) + 2\mu e(k) \cdot \phi(k)
\end{aligned}$$

Examples



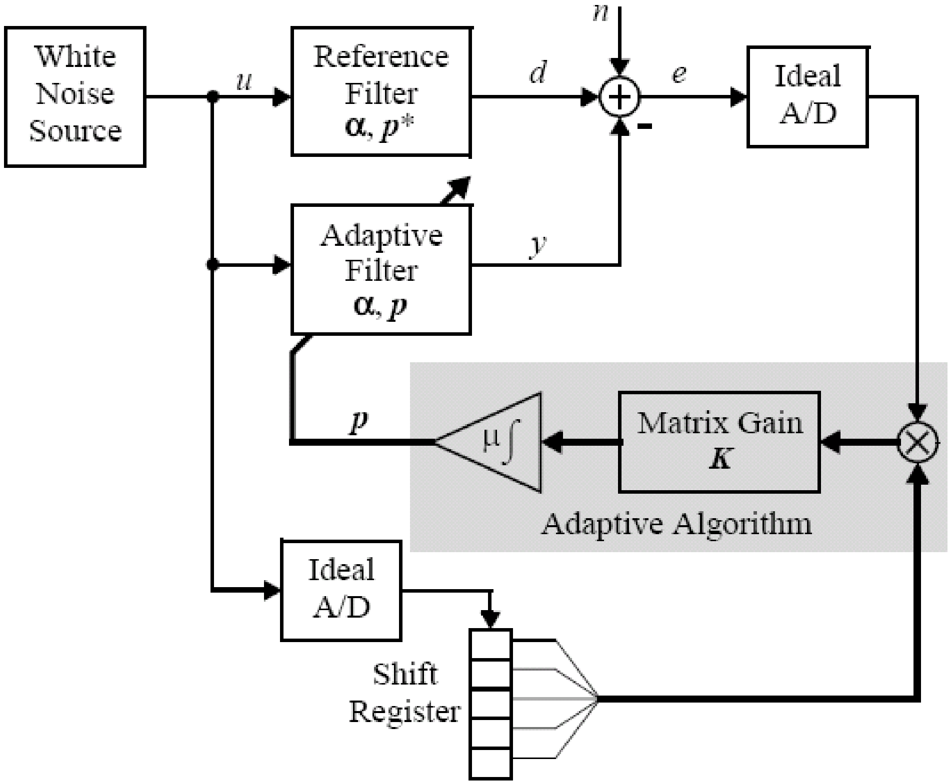
-C-
offset
source
Sum1
Scope2
1
s+1
Reference
Sum of
Elements
Product of
Elements
1/2
s+1
Adaptive
simout
To Workspace
1
s
-K-
-gamma1
Scope
Scope1

Examples

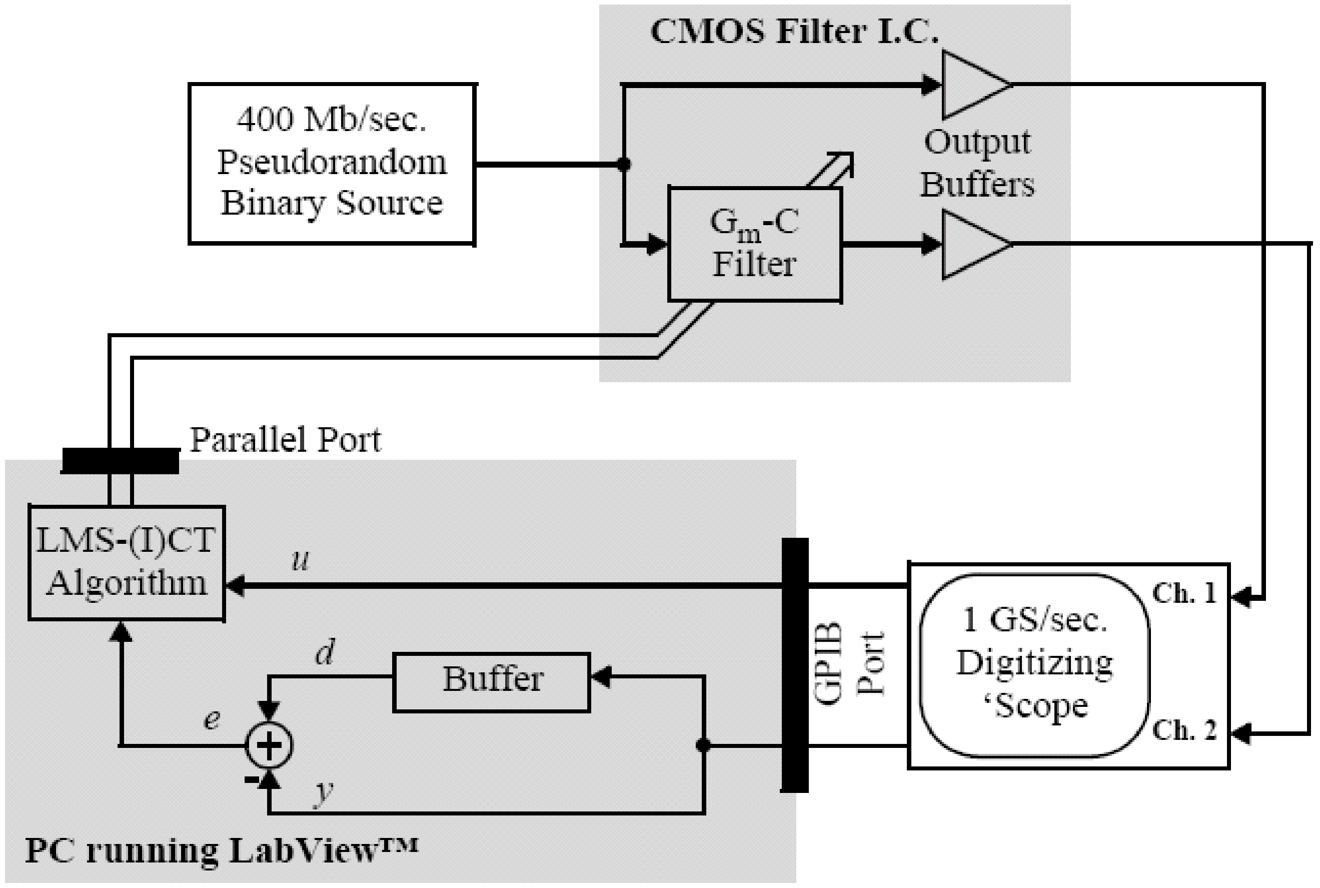


Examples

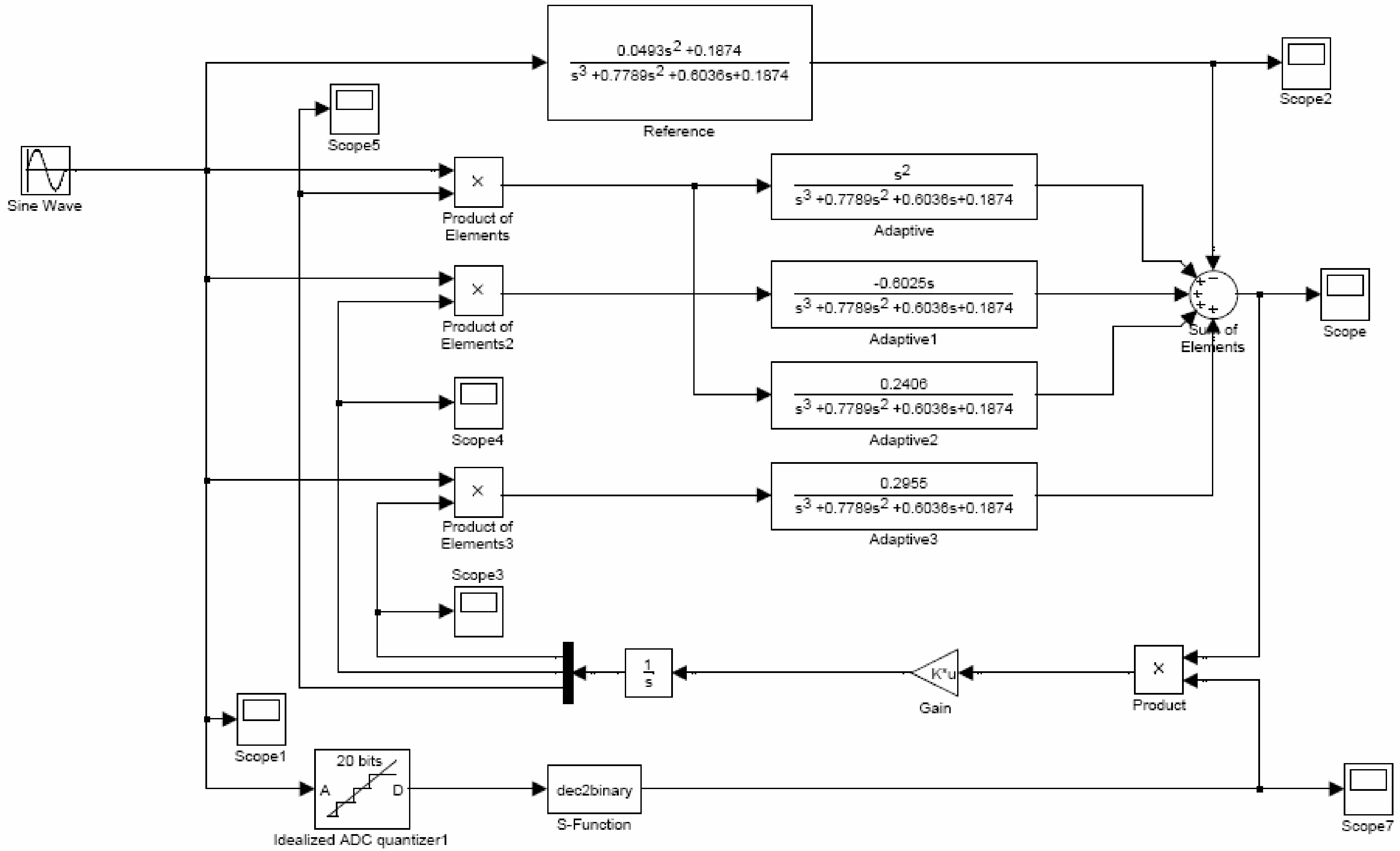
Examples


White Noise Source
u
Reference Filter
α, p*
d
n
e
Ideal A/D
Adaptive Filter
α, p
y
p
μ∫
Matrix Gain
K
Adaptive Algorithm
Ideal A/D
Shift Register

Examples

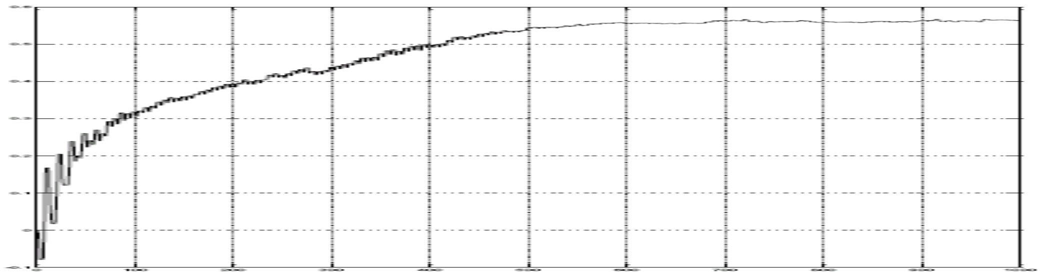

CMOS Filter I.C.
400 Mb/sec. Pseudorandom Binary Source
Output Buffers
Gm-C Filter
Parallel Port
LMS-(I)CT Algorithm
u
d
Buffer
e
y
GPIB Port
1 GS/sec. Digitizing 'Scope
Ch. 1
Ch. 2
PC running LabView™

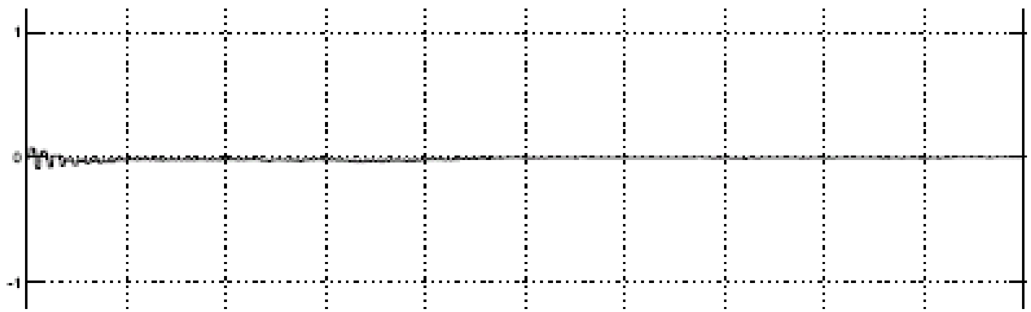
Examples

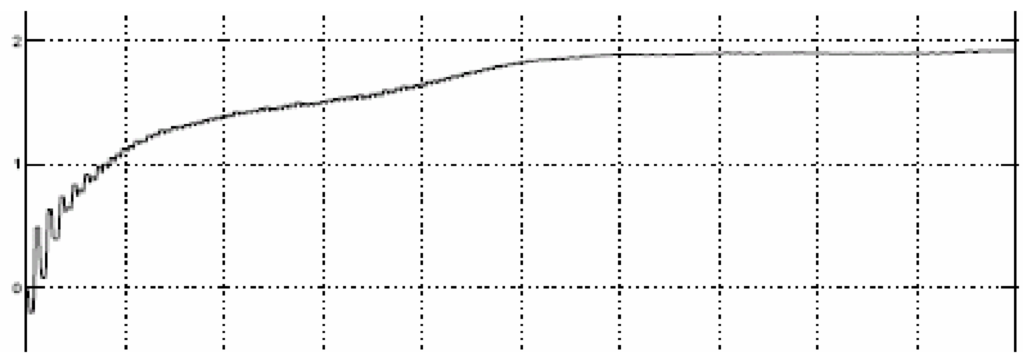


0.0493s^2 +0.1874
s^3 +0.7789s^2 +0.6036s+0.1874
Reference
Scope2
Scope5
Sine Wave
Product of Elements
s^2
s^3 +0.7789s^2 +0.6036s+0.1874
Adaptive
-0.6025s
s^3 +0.7789s^2 +0.6036s+0.1874
Adaptive1
Product of Elements2
Sum of Elements
Scope
Scope4
0.2406
s^3 +0.7789s^2 +0.6036s+0.1874
Adaptive2
Product of Elements3
0.2955
s^3 +0.7789s^2 +0.6036s+0.1874
Adaptive3
Scope3
1/s
K*u
Gain
Product
Scope1
20 bits
A
D
Idealized ADC quantizer1
dec2binary
S-Function
Scope7

Examples







References

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- A Top-Down Mixed-Signal Design Methodology Using a Mixed-Signal Simulator and Analog HDL
- Analogue adaptive filters: past and present, A. Carusone and D.A. Johns
- Digital LMS Adaptation of Analog Filters Without Gradient Information, Anthony Carusone, David Johns

- Questions?
- Thank you!