

# Recent Advances in High-Resolution Hybrid Discrete-Time Noise-Shaping ADCs

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**ABSTRACT** High precision data acquisition requires very-high-resolution Analog-to-digital converters (ADC) for kHz speed or to keep a relatively high resolution for wider bandwidth (BW) around the MHz range. Although widely used, noise-shaping (NS) in ADCs offers a high-resolution characteristic, but obtaining good power efficiency and compact die area is still challenging. Recent literature showed promising progress by utilizing hybrid Discrete-Time (DT) NS-ADCs with measured silicon results. This paper focuses its analysis and discussion on two important trending classes: hybrid Incremental ADCs (I-ADC) and hybrid Time-interleaved (TI) NS-ADCs. Furthermore, this paper presents a review and addresses the benefits of those hybrid architectures.

**INDEX TERMS** ADC, analog-to-digital converter, DAC, digital-to-analog-converter, hybrid ADC, incremental ADC (I-ADC), delta-sigma modulator, time-interleaving, extrapolating, noise shaping, successive approximation register, SAR.

## I. INTRODUCTION

HIGH resolution ADCs are crucial building blocks in consumer electronics, especially for high precision sensors in the Internet of everything (IoT), audio codecs, and wearable healthcare applications. Such ADCs usually process signals around tens of kHz [1]. However, with the rapid development of modern industry, some wide bandwidth applications also raise the need for high-precision ADCs, including ultrasound imaging systems, radars, and emerging communications [2], [3].

The combination of oversampling and noise-shaping (NS) techniques is traditionally a promising approach to implement high-resolution ADCs. Based on the circuit characteristics, designers could divide NS-ADCs into two main types: continuous-time (CT) or discrete-time (DT). As the names suggest, the CT structure takes a continuous-time loop

filter, whereas the DT structure operates based on switched capacitor circuits.

If high resolution is the primary consideration, Fig. 1 lists a detailed comparison between CT/DT NS-ADCs. The CT structure generally operates faster than the DT, leading to a possible larger oversampling ratio (OSR). Besides, the CT structure simplifies the analog front end by bringing along the inherent alias rejection property and providing an easy-driven resistive input. In this way, lower BW, smaller slew rate amplifiers can be the interface between the frontier stages and a CT-ADC. Similarly, the CT case doesn't need a reference buffer to fight against the large switching current in the DT. However, the CT case limits the linearity. Since CT's DACs' outputs error is directly injected into the loop in continuous time without the help of any noise shaping, the CT structure suffers from

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### **Table of Contents Experimental High Resolution Hybrid Auto**

1. Understanding the eBook Experimental High Resolution Hybrid Auto
  - The Rise of Digital Reading Experimental High Resolution Hybrid Auto
  - Advantages of eBooks Over Traditional Books
2. Identifying Experimental High Resolution Hybrid Auto
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Experimental High Resolution Hybrid Auto
  - User-Friendly Interface
4. Exploring eBook Recommendations from Experimental High Resolution Hybrid Auto
  - Personalized Recommendations
  - Experimental High Resolution Hybrid Auto User Reviews and Ratings
  - Experimental High Resolution Hybrid Auto and Bestseller Lists

5. Accessing Experimental High Resolution Hybrid Auto Free and Paid eBooks
  - Experimental High Resolution Hybrid Auto Public Domain eBooks
  - Experimental High Resolution Hybrid Auto eBook Subscription Services
  - Experimental High Resolution Hybrid Auto Budget-Friendly Options
6. Navigating Experimental High Resolution Hybrid Auto eBook Formats
  - ePub, PDF, MOBI, and More
  - Experimental High Resolution Hybrid Auto Compatibility with Devices
  - Experimental High Resolution Hybrid Auto Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Experimental High Resolution Hybrid Auto
  - Highlighting and Note-Taking Experimental High Resolution Hybrid Auto
  - Interactive Elements Experimental High Resolution Hybrid Auto
8. Staying Engaged with Experimental High Resolution Hybrid Auto
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Experimental High Resolution Hybrid Auto
9. Balancing eBooks and Physical Books Experimental High Resolution Hybrid Auto
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Experimental High Resolution Hybrid Auto
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Experimental High Resolution Hybrid Auto
  - Setting Reading Goals Experimental High Resolution Hybrid Auto
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Experimental High Resolution Hybrid Auto
  - Fact-Checking eBook Content of Experimental High Resolution Hybrid Auto
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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