How High Performance Modular Instruments Enable Greater Applications and Smaller Form Factors

By Michael Clifford

Following generations of custom benchtop instrumentation, the transition continues toward modular instruments with more flexibility, software control, and smaller form factors. However, lower power consumption in tandem with meeting noise and measurement accuracy targets remains a challenge.

One element of the change away from benchtop instruments is the ability to enable mobility. The large custom and rack-based systems have limitations from a logistical point of view. The breakup of cabinet/desktop equipment into smaller nodes enables custom configuration and optimizes the instruments for the environment and geography of the test site or subject. Improving the mobility of the measurement instruments by breaking them into smaller nodes reduces wiring and installation headaches. Wiring connections to local mobile instruments is easier than tracing long cables back to a central rack or bench instrument. Time spent verifying wiring and fixing miswired connections is recovered. Despite the changing form factors, the need for optimum test performance, certainty, and accuracy remain.

Application Areas

A modular platform instrument with high dynamic range is the 21st century equivalent of the measuring tape. The instrument delivers the measurement capability required to further innovation, research, and development across a broad spectrum of specialties.

- Testing within research and development fields of material science, from the structural analysis of the blades of a windmill to the health, well being, and electrical output of it's turbine.
- Measuring the outputs of strain/piezoelectric transducers, conditioning those voltages and enabling quantitative analysis for structural health and materials development, and providing clear measurement without interference.
- Measurements for automotive cabin noise. Digitizing the output of microphones placed in-cabin during the prototype development, right through to enabling faster, more accurate control loops that increase production throughput on the factory floor.
- Electrical testing:
  - Audio measurement enabling the development of advanced microphone modules and speakers for voice-activated control and operation.
  - Electrical test within ATE for both passive and active electronics where parametric measurement accuracy and speed relate to the cost of the test.
- EEG needs extremely high dynamic range over a specific bandwidth close to dc. Lower power is required to pack many hundreds of simultaneous measurement channels to be packed into a small form factor.

These wide ranging applications have equally wide ranging channel counts. Standard 8-channel modules in industrial applications extend to 512 channels and beyond for an EEG measurement. Scaling the front-end measurement design to a large number of channels, while maintaining simultaneous sampling, is key. It is the basis for the data that guides a generation of research, development, production, and end operation.

Creating smaller form factor housings, whilst holding measurement channel density requires power efficiency. Increasing the dynamic range of the analog-to-digital converter (ADC) and the chain, which precedes it to 110 dB, while keeping current consumption in check is a constant battle. Balancing dynamic range, input bandwidth, and current consumption isn't easy.

A new ADC subsystem supported by the capabilities of the AD7768 and AD7768-4 has emerged. It provides the capability to digitize to wider bandwidths with higher accuracy than before and to do so with fidelity and synchronized sampling across multiple channels. It also provides tools to ease thermal challenges and strike the right balance of dynamic range, input bandwidth, and current consumption in high dynamic range modular system design.

Reconfigurable Thermal Footprint, Software Programmable Measurement Bandwidth

The AD7768 can adapt to the measurement situation. Heat, decreasing air space, and the absence of active cooling are all constraints of modular instruments, which the AD7768 eases using built-in operating modes for fast, median, and eco power scaling. For a given input bandwidth, the user may decide to expend more or less power, reducing heat within the module. An example would be digitizing over an input bandwidth of 51.2 kHz. Such a bandwidth is popular for FFT-based analysis as it provides an integer bin size within the FFT output. The AD7768 features a brick wall digital filter frames that required input bandwidth. A low ripple pass band and a steep transition band combine with full attenuation at frequencies just beyond 51.2 kHz, meaning there is no fold back from around the Nyquist frequency. For the AD7768, the user can choose to operate in either fast or median mode. The decision is between current consumption and dynamic range depending on which is most constrained for the system. Let's take a look:

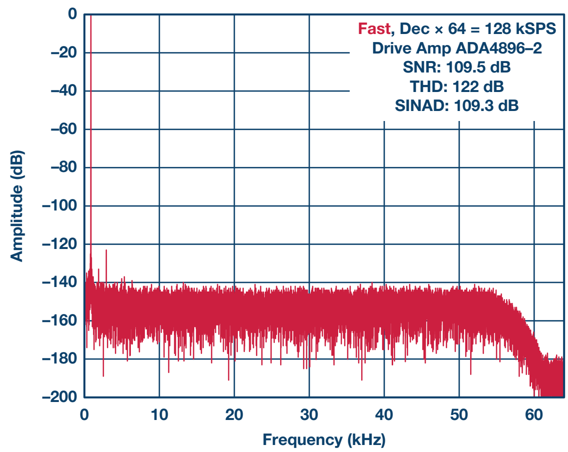

Figure 1. Digitizing 50 kHz input bandwidth. Fast mode performance, FFT showing performance with ADA4896-2 driving. (AD7768 in fast mode with dec × 64 gives an output rate of 128 kSPS) precharge analog input buffer ON.

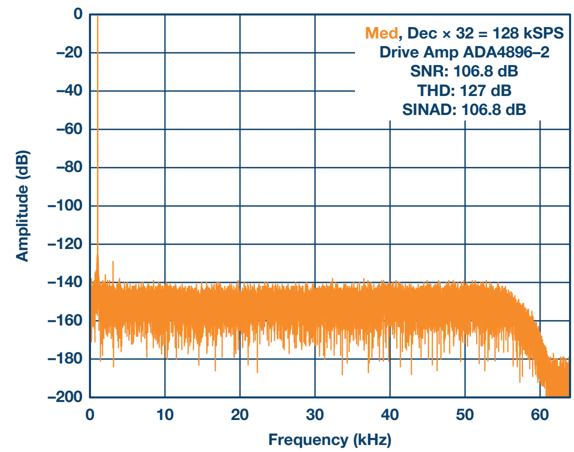

Figure 2. Digitizing 50 kHz input bandwidth. Median mode performance, FFT showing performance with ADA4896-2 driving. (AD7768 in median mode with dec × 32 gives an output rate of 128 kSPS) precharge analog input buffer ON.

The trade off of dynamic range vs. current consumption is demonstrated here using the following base settings: MCLK = 32.768 MHz, low ripple pass-band filter ("brick wall"), 128 kSPS data rate for each mode, digitizing 50 kHz of input bandwidth with a 1 kHz input sine wave at –0.5 dB down from full scale. Figure 1 and Figure 2 show the comparison for the ADC performance: an outstanding low distortion digital version of the analog input sine wave. Moving to median mode allows reduced current consumption in return for compromising on noise and dynamic range by 3 dB.

Table 1. Digitizing and Creating an FFT for 51.2 kHz Bandwidth. Choose Highest Dynamic Range or Lowest Current Consumption

Power Mode	±0.005 dB Bandwidth (kHz)	Dynamic Range[1] (Shorted Input) dB	SNR (dB) 1 kHz –0.5 dB Sine Wave	THD (dB)	Current Consumption ADCs all 8-Ch[2] (mA)
Fast	51.2	111	109.5	<–120 dB	113
Median	51.2	108	107.8	<–120 dB	70

[1] Note, some vendors express this number as SNR (shorted input noise). AD7768 tests with a full sine wave, exercising full reference range required for true SNR.
[2] Includes precharge analog input buffers. Precharge buffers reduce the analog input current vs. input amplitude and make the analog inputs easier to drive for the preceding driver amplifier. The AD7768 delivers a distinct benefit in distortion with precharge buffers on.

In the instance of a classical 51.2 kHz measurement bandwidth, the user can choose to reduce current or maximize dynamic range of the ADC. Not only does the power scaling apply to the ADC, but there is also a knock-on effect to the driver amplifier circuit prior to the ADC. As shown in Figure 3, the subsystem also includes a driver amplifier, typically including signal conditioning for antialiasing.

A selection of amplifiers with differing power consumption can be paired with each of the power modes. The table illustrates that an initial design for fast mode can be scaled later for use in either the median or eco modes with the same base footprint, but repurposed for lower current consumption.

Table 2. Mapping ADC Power Modes to Effective Driver Amplifier Solutions

Power Mode	Amplifier	Amplifier Current 8-Ch Diff Input (mA)	Comment
Fast	ADA4896-2	48	Best balance of noise and distortion
	ADA4807-2	16	Lower the current consumption, trade off distortion (fast)
Median	ADA4807-2	16	Extra slew and GBW vs. ADA4805, low current consumption, increased noise; see Figure 4 for FFT performance
	ADA4940-1	10	Fully differential amplifier, single-ended to diff or diff in/out; see Figure 5 for FFT performance
	ADA4805-2	10	Reduced current, slew rate and GBW vs. ADA4807-2
Eco	ADA4940-1	10	Fully differential amplifier, single-ended to diff or diff in/out
	ADA4807-2	16	Extra slew and GBW, low current consumption
	ADA4805-2	10	Reduced current, slew rate and GBW vs. ADA4807-2
	ADA4084	9	Use with precharge on—high performance, low current consumption combination

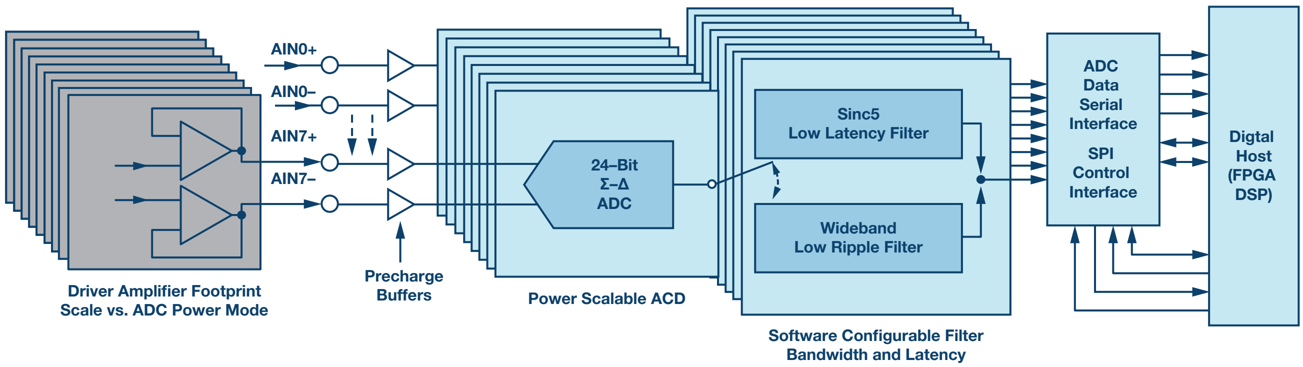

Figure 3. ADC subsystem power scaling: the driver amp footprint can be repopulated with lower current amplifiers in conjunction with power scaling the ADC.

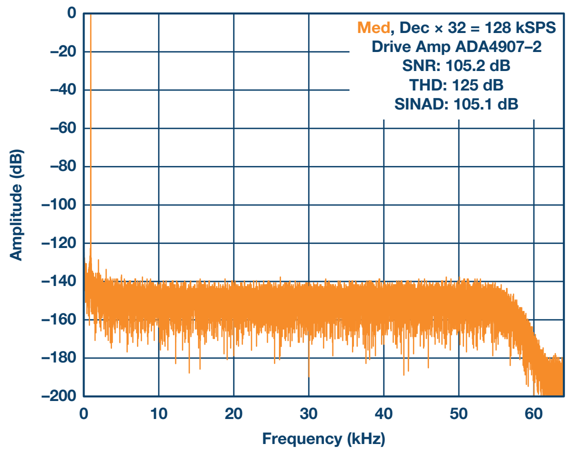

Figure 4. Median mode performance, FFT showing performance with ADA4807-2 driving the ADC precharge analog input buffer ON.

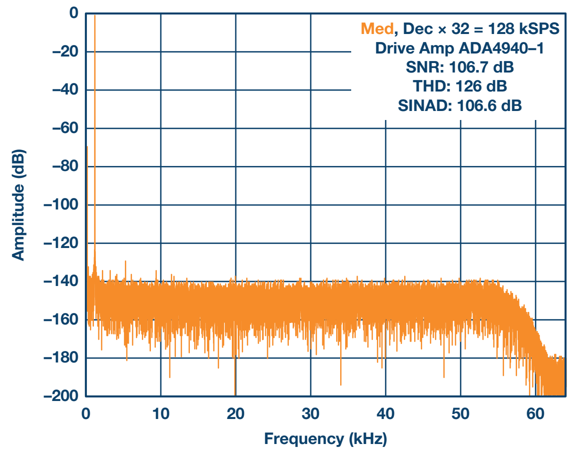

Figure 5. Median mode performance, FFT showing performance with ADA4940-1 driving the ADC precharge analog input buffer ON.

Scaling to a lower power amplifier with median mode helps reduce current consumption further. The performance using either ADA4807-2 or ADA4940-1 in median mode is illustrated by Figure 4 and Figure 5 when digitizing for ac and dc over 50 kHz input bandwidth.

Having the ability to tune and scale the power consumption of the measurement subsystem enables two benefits. Firstly, the embedded power scaling flexibility allows on-the-fly flexibility to improve either measurement range or the duration of the measurement (for example, if the module was powered from a battery). Secondly, it allows the ability to create a base platform design that can be set and adapted for specific measurement bandwidths and performance points so that a custom instrument is developed to meet the exact end customer measurement challenge.

Software Configurable Input Bandwidth and Latency—Applying it to Groups of Channels

As well as using the AD7768 to scale current consumption and dynamic range of the ADC, there also exists configurable filtering, which can be adapted to the measurement situation. Brick wall, low ripple filters are great for providing gain accuracy over a wide frequency range. Their drawback is a long integration/averaging time. As a result, group delay is relatively large for the AD7768, in the range of 34 data cycles before you see the digitized version of the analog input. To give a relative timescale, running in fast mode at 250 kSPS, each data conversion cycle is 4 µs so the group delay is 136 µs. This may not be tolerable in control loops or in applications that may value fast response above gain accuracy over frequency. To enable these high dynamic range measurements for control loops, the sinc5 filter can be used. This path reduces the group delay by a factor of 10 relative to the wideband filter.

A useful capability of the AD7768 is that it can allow a user to mix the type of filters among the channels. Each ADC may be assigned to one of two groupings of channels. Each group can then be assigned to one of the two filters and its speed set via one of six available decimation rates. This functionality enables different measurement types to be completed within the eight ADCs and allows them to be configured via software setting similar to the scenario where each of the ADCs were discrete. An example scenario is when monitoring a significant industrial asset, the user may wish to measure dc output from a 4 mA to 20 mA transmitter or voltage output transmitter at the same time as measuring the vibration sensor on another analog input channel. The dc response can be read from the transmitter and fed to the control loop while the vibration is being measured on a separate, but simultaneous channel. The mix of input bandwidth and latency capabilities are the basis for creating a custom, high value instrument for industrial settings: one instrument doing the dual functions of running the process variables and integrating plant vibration information, all on one system, and all simultaneously.

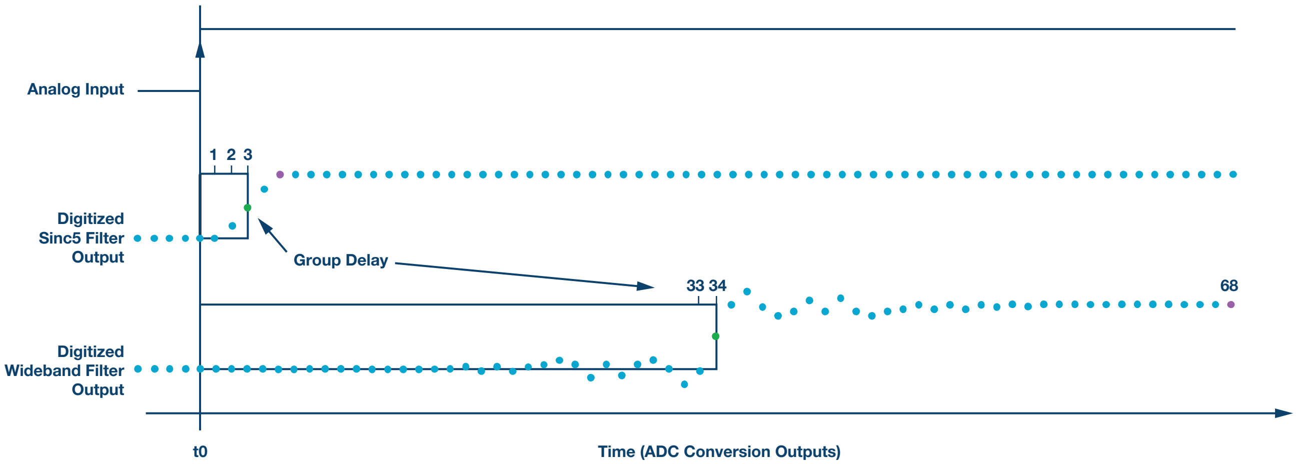

Figure 6. Comparing the group delay of the sinc5 filter with the wideband filter. Sinc5 provides a fast response to input changes on analog input, suited to control loop applications where minimizing the loop latency is key. The green dot represents the sample at the group delay time, the pink dot indicates a final settled value from each filter.

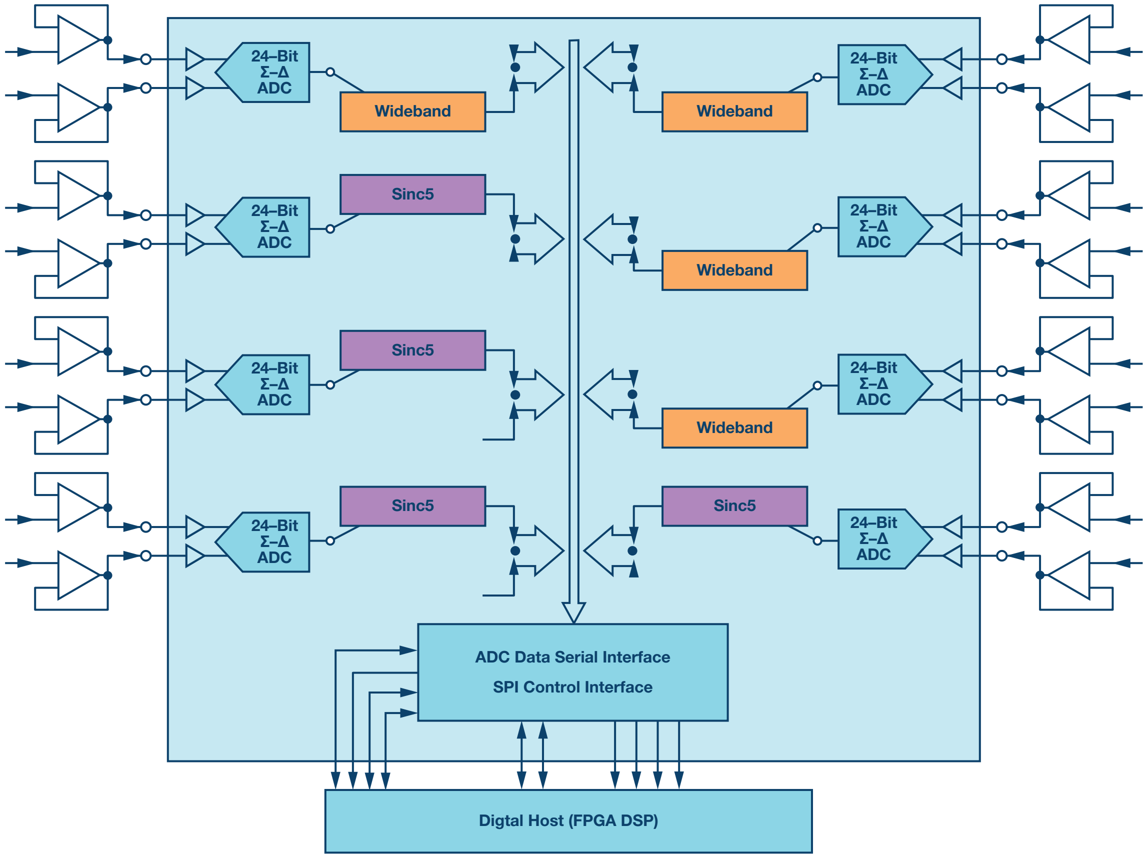

Figure 7. Configure different ADC channels for different filter types. Two groups: A is using wideband, B sinc. The decimation rate for each group may also be configured over SPI.

High Performance with Scalable High Speed and Low Power Enable Modern Form Factors and Use Cases

The move from larger stationary instrumentation to more mobile and flexible devices continues to gain popularity. They offer valuable potential for advanced development and innovation in a wide range of industries, markets, and applications. While challenges such dynamic range, input bandwidth, and current consumption exist, advanced ADCs are helping to mitigate them and give designers a tool with greater capabilities than before.

About the Author

Michael Clifford is a member of the Linear and Precision Technology Applications Team at Analog Devices (Limerick, Ireland). He has worked for Analog Devices since 2004 and is focused on precision analog-to-digital converter products, in particular those using the Σ-Δ topology for both precision dc and ac measurement. He holds a bachelor's degree in electrical and electronic engineering (B.E.E.) from University College Cork (UCC).

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