Interfacing op amps and analog-to-digital converters

By Bruce Carter (Email: r-carter5@ti.com)
Advanced Linear Products, Op Amp Applications

Introduction

One of the most common questions asked of the TI High-Speed Amplifiers Applications team is what op amp to use with a given analog-to-digital converter (ADC). The ADC is often from a competitor. Answering this question is a challenging task—and there is no absolute answer, only a list of gray areas and trade-offs.

It would be handy to have a table with ADCs on one side and recommended op amps on the other. But this table will never exist; there are too many variables in system design that affect op amp selection. This article does not contain answers, but questions. The questions will help the designer organize his thoughts and define exactly what the op amp needs to do. He should be prepared to answer these questions before committing to a design.

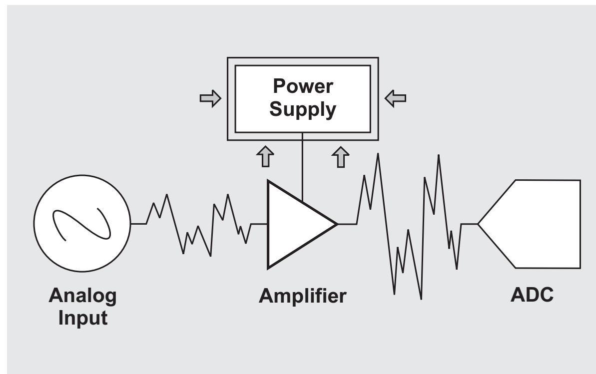
The list of questions may look daunting at first, but it is divided into sections that break up the system into component parts: system, power supply, input signal, ADC, operational amplifier, and other considerations. The completion of each section is a piece of the puzzle, and by the end of the process the designer should have weeded out op amps that are unsuitable for the job.

System information

The overall characteristics of the system often yield valuable information. A clear understanding of the product and its function is imperative to design success.

- Exactly what is the end equipment and its application? Different systems have different requirements. For example, key concerns in a video system are completely different from those in a wireless communication system.
- In general terms, what is the function of this signal-acquisition chain in the system? Where does the input signal come from and what happens to it once it is digitized?
- How many signal-acquisition chains are used in the product? Channel density can influence system design in numerous ways, including space constraints, thermal requirements, and amplifier channel density per package.
- Will this signal chain be duplicated in other products? Is flexibility an advantage, or can the design be narrowly focused on the task at hand?
- Is the design forced to adhere to a particular standard?
- In what temperature conditions will the system operate (for example, –40°C to +85°C, 0°C to +70°C, or +45°C to +55°C)?
- Does the system have forced air flow from a fan to help with thermal dissipation?
- Is automatic gain control (AGC) functionality required? If so, is it digital or analog control? What is the gain range, etc.?
- Is a current solution unsatisfactory in some way? Why is the current solution unsatisfactory?

Figure 1. Focusing on power supply characteristics



Power supply information

Power supply rails can quickly rule out amplifier solutions. This is similar to clothing shopping—the style may be desirable; but if the size doesn't fit, the style is useless. So a wise shopper finds the options in the size first, before becoming attached to a style. Similarly, an op amp with fantastic specifications at ±15 V may not operate at all from a +3.3-V power supply. Power supply information is collected first, because it will simply and unequivocally narrow choices. See Figure 1.

- What is the power budget for the overall system? Is power a concern, or is performance the ultimate goal?
- What power supply voltages are available in the design?
- Is there a preferred power supply voltage for the amplifier circuitry?
- Can an additional supply voltage be added if performance could be improved? Often, the best amplifier performance can be obtained with split supplies.
- Is a precision reference available in the system? In single-supply systems, it is important to supply a virtual ground to the op amp circuitry. If the system contains a reference, it would be advantageous to utilize it.
- Are there any special characteristics of the power supply? For example, is the power supply a switching power supply? Although op amps usually have excellent power supply rejection, it could be a concern in a high-resolution system. Any widely varying loads could also affect the op amp supply voltage.

Input signal characteristics

Understanding the input source is key to proper design of the interface circuitry between the source and the ADC (see Figure 2).

- What is used for the signal source to the amplifier block in front of the ADC? Is it another amplifier, a sensor, etc.?
- Describe the input signal. For example, is it continuous or discontinuous (i.e., pulsed)? The signal might be a QAM signal, an NTSC signal, a non-standard continuous wave signal, a random analog signal, etc.
- Are there any unusual characteristics of the signal source? Some sources have characteristics that will affect the performance of the amplifier circuit. For example, photodiodes have an associated capacitance, and the value of this capacitance plays an important role in how the associated amplifier circuit is designed.
- What is the output amplitude range of the source?
- Does the source produce a voltage or a current output?
- Is the signal source output single-ended or differential?
- What is the output impedance of the signal source?
- Is the input signal dc-referenced? If so, to what dc voltage is it referenced?
- What are the frequency characteristics of the input signal? For example, the signal might have a 10-MHz bandwidth centered around 25 MHz, or it might be a signal with frequency content from dc up to 20 MHz. If low frequency isn't important, this opens the possibility of ac coupling the input signal.
- What level of rejection is required out-of-band? Some applications have very strict requirements for out-of-band rejection, while others are less strict. The filter interface between the amplifier network and the ADC is dictated by this sort of information.
- Is there a known interfering frequency (system clock, sample clock, etc.) that must be filtered out? Are other large signals expected outside of the band of interest? A simple low-pass filter often may not have sufficient rejection of a particular interfering signal, forcing additional circuitry to produce a high Q notch filter.
- Is there a requirement for gain or phase flatness or error? This is a concern in video systems.
- Is there a matching requirement on the input impedance of the amplifier circuit? Some circuits require that the load be matched to a particular value for optimal performance (e.g., 50 Ω).

ADC characteristics

Once the power supply and input signal have been defined, it is time to focus on the device that the op amp will drive—the ADC (see Figure 3).

- Has the ADC been selected, or can it be changed to enhance performance?
- What is the desired sampling rate? Designers often assume that a data converter is going to be used at its maximum level of performance, but this typically isn't the case. For example, an 80-megasample-per-second (MSPS) converter might be given a sampling frequency of 60 MSPS.

Figure 2. Focusing on the input signal

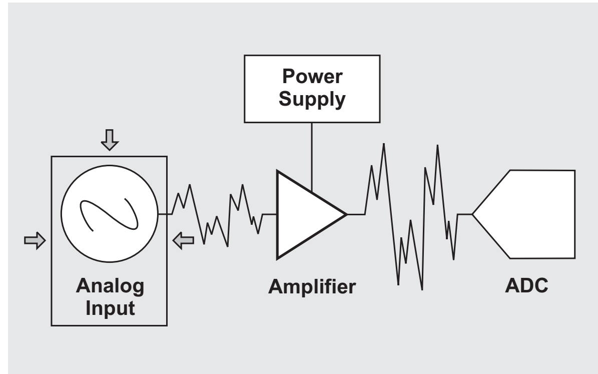
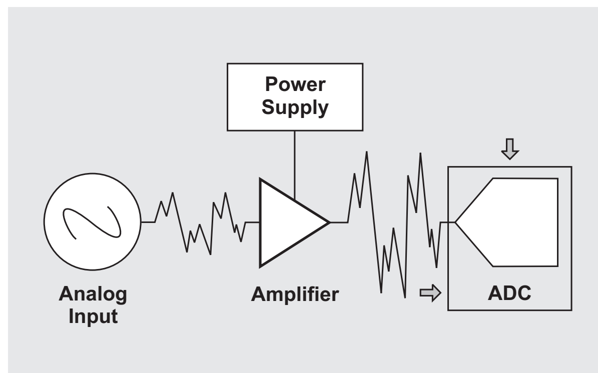


Figure 3. Focusing on the ADC



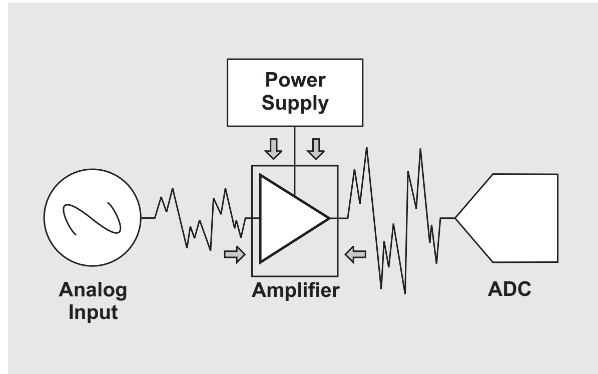
- What is the desired resolution and effective number of bits? A 14-bit converter won't effectively yield 14 bits. The true resolution will probably be closer to 12 or 13.
- What is the full-scale input range of the data converter? Some data converters permit the input to be configured for different ranges.
- Will the data converter be used with single-ended or differential inputs? Typically, most high-performance data converters have differential inputs and require their use for optimal performance.
- Are there any other options on the data converter that could be an advantage? Data converters have lots of options that vary from part to part.
- Are there any compensation requirements for the input of the data converter? Normally, a small RC filter is required at the input of the data converter to compensate for its capacitive input. These components are usually specified in the converter data sheet and should be included as part of the interface. Otherwise, the op amp interface circuit may exhibit instability.

Operational amplifier characteristics

Although this article is intended to aid in the selection of the correct operational amplifier, it is possible that the nature of the system already defines some characteristics. See Figure 4.

- Has the operational amplifier already been selected, or can it be changed to improve system performance?
- Are there specific requirements for the package of the amplifiers? For example, must it be an 8-pin SOIC, or as small as possible, etc.?
- Does the cost of the operational amplifier interface or the physical size of the interface circuitry dictate that as few operational amplifiers as possible be used? Or would it be an advantage for the circuitry to be easily modified in the future, using more operational amplifiers for the flexibility?

Figure 4. Focusing on the operational amplifiers



Other pertinent considerations

This is the point at which the definition of the system should be complete. The wise designer, however, should take a step back. He should be asking, “Are there any other questions I should have asked? If questions were not asked, why not?”

The biggest consideration of all may be cost. This single concern has the potential of forcing a lot of good design work to be thrown on the trash heap. Yet a wise designer seldom goes wrong if he keeps the cost and number of components in mind when creating his design. Whether a million systems are produced, or only one, every manager will be pleased if the cost can be reduced without compromising system performance.

Conclusion

The design of a data acquisition system is a complex and time-consuming task. There are no universal solutions, nor are there any reliable lists of which op amp is matched to which ADC. There are a great number of factors affecting performance, and each design should be approached as if it were a custom design for which no precedent exists.

The designer must first answer the questions presented earlier to gain a good understanding of the true nature of his system and the scope of his design task. The next step is to visit **amplifier.ti.com** and look in the op amp selection guides for op amps that fit the application. As a general rule, the op amp should be much better than the data converter to which it is interfaced; otherwise, the designer is wasting money on the data converter.

In addition to the “Related Web sites” below, TI has a semiconductor technical support knowledge base to assist designers in finding products and services related to their technical questions. The direct link to this knowledge base is **support.ti.com/sc/knowledgebase**

For more general support information, visit **support.ti.com**

Related Web sites

analog.ti.com
amplifier.ti.com
dataconverter.ti.com

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products	
Amplifiers	**amplifier.ti.com**
Data Converters	**dataconverter.ti.com**
DSP	**dsp.ti.com**
Interface	**interface.ti.com**
Logic	**logic.ti.com**
Power Mgmt	**power.ti.com**
Microcontrollers	**microcontroller.ti.com**

Applications	
Audio	**www.ti.com/audio**
Automotive	**www.ti.com/automotive**
Broadband	**www.ti.com/broadband**
Digital control	**www.ti.com/digitalcontrol**
Military	**www.ti.com/military**
Optical Networking	**www.ti.com/opticalnetwork**
Security	**www.ti.com/security**
Telephony	**www.ti.com/telephony**
Video & Imaging	**www.ti.com/video**
Wireless	**www.ti.com/wireless**

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page
support.ti.com

TI Semiconductor KnowledgeBase Home Page
support.ti.com/sc/knowledgebase

Product Information Centers

Americas			
Phone	+1(972) 644-5580	Fax	+1(972) 927-6377
Internet/Email	support.ti.com/sc/pic/americas.htm		
Europe, Middle East, and Africa			
Phone			
Belgium (English)	+32 (0) 27 45 54 32	Netherlands (English)	+31 (0) 546 87 95 45
Finland (English)	+358 (0) 9 25173948	Russia	+7 (0) 95 7850415
France	+33 (0) 1 30 70 11 64	Spain	+34 902 35 40 28
Germany	+49 (0) 8161 80 33 11	Sweden (English)	+46 (0) 8587 555 22
Israel (English)	1800 949 0107	United Kingdom	+44 (0) 1604 66 33 99
Italy	800 79 11 37		
Fax	+(49) (0) 8161 80 2045		
Internet	support.ti.com/sc/pic/euro.htm		
Japan			
Fax			
International	+81-3-3344-5317	Domestic	0120-81-0036
Internet/Email			
International	support.ti.com/sc/pic/japan.htm		
Domestic	www.tij.co.jp/pic		
Asia			
Phone			
International	+886-2-23786800		
Domestic	Toll-Free Number		Toll-Free Number
Australia	1-800-999-084	New Zealand	0800-446-934
China	800-820-8682	Philippines	1-800-765-7404
Hong Kong	800-96-5941	Singapore	800-886-1028
Indonesia	001-803-8861-1006	Taiwan	0800-006800
Korea	080-551-2804	Thailand	001-800-886-0010
Malaysia	1-800-80-3973		
Fax	886-2-2378-6808	Email	tiasia@ti.com
Internet	support.ti.com/sc/pic/asia.htm		ti-china@ti.com

C011905

Safe Harbor Statement: This publication may contain forward-looking statements that involve a number of risks and uncertainties. These “forward-looking statements” are intended to qualify for the safe harbor from liability established by the Private Securities Litigation Reform Act of 1995. These forward-looking statements generally can be identified by phrases such as TI or its management “believes,” “expects,” “anticipates,” “foresees,” “forecasts,” “estimates” or other words or phrases of similar import. Similarly, such statements herein that describe the company's products, business strategy, outlook, objectives, plans, intentions or goals also are forward-looking statements. All such forward-looking statements are subject to certain risks and uncertainties that could cause actual results to differ materially from those in forward-looking statements. Please refer to TI's most recent Form 10-K for more information on the risks and uncertainties that could materially affect future results of operations. We disclaim any intention or obligation to update any forward-looking statements as a result of developments occurring after the date of this publication.

Mailing Address: Texas Instruments
Post Office Box 655303
Dallas, Texas 75265