Senior Project Guide to Texas Instruments Components

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C O N N E X I O N S

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Table of Contents

Introduction[1]

The senior project is an important experience for engineering students preparing for a career. The reason for its importance is that virtually all product development today is done by teams. These teams will have amazingly diverse personalities and training backgrounds. You will find that project teams can have as few as five or 10 people to hundreds of people. On these teams will be engineers with different training from different universities; they will not all specialize in the same thing. There will also be a large assortment of nontechnical people who are experts in areas that up until now may have been of little interest to you, such as marketing, program management, sales and market communications. As you grow in your career, you'll find each of these roles valuable to the success of a product.

Some of the best advice I received as a brand-new engineer out of college was from a senior government employee to whom I reported. I was in the army, serving two years as a draftee. After about a year under his command, he asked me into his office. The topic of our meeting was mentoring, and he asked if I had thought of becoming a manager. My response was a firm "no," as I enjoyed being an engineer and turning ideas into reality. His reply was interesting. He said, "Gene, some day you'll have an idea that will take more than two hands to develop. At that point, you will become a manager."

At this point, you may be trying to tie this story into useful information. Let me attempt to do that.

The purpose of a senior project is to gain experience working on a team. Fortunately, it will be with several other students whom you have known for three or four years and are comfortable working with. Or whom you **think** you are comfortable working with. If your team is like many teams you will encounter in an industrial setting, it will probably have one or two hard-driving individuals. It will also have one or two "lazy, not in a hurry, a C is good enough" individuals. It is with this team that you will have to complete your senior project. As with any team, you will also need a leader; one of your members will become that leader, either by election or by default. The success of your project will depend heavily on the choice of leader.

As the team begins to function, an important question will come to your mind: How do I get graded on this project? Over the years, I have asked professors how they determine the grade for each individual and received responses like, "we watch them closely" and "we ask the team members to rate each other." I see neither as satisfactory answers. Simply put, teams should be graded as teams and not as individuals.

The purpose of a team is to become greater than the sum of its individuals. This effect has happened on several teams to which I've belonged. As we teamed up, two began to look like five and five began to look like 10 and 10 began to look like 30. I call it "jelling." Somehow we became significantly more productive as a team than as a group of individuals. The team was never made up of all hard-driving, passionate individuals; this effect is possible even with a random mix of people.

If you are still reading, you are probably waiting for me to provide the secret as to how this can happen on your team. Unfortunately, I don't know. For just as the team "jelled," it fell apart – rather mysteriously in both cases. But while we were jelling, we did have a few common traits:

- A leader emerged whom everyone was willing to follow. Notice I said leader and not manager. There is a difference between the two.
- A cheerleader emerged – someone who was around to encourage, excite and give credit to the individuals on the team and the team itself.

[1]This content is available online at <http://cnx.org/content/m44269/1.3/>.

- No one was left sitting. Everyone was engaged and working toward the goal.
- We all liked each other.

Let me tie this all together. TI wants to be part of your team, but we don't want to be the leader, cheerleader or lazy member. We want to do whatever we can to make your senior project experience one that you can be proud of, where you will remember TI as an extended member that made the whole project fun. We want you to be ready to have TI as an extended member on your next project – the first one at whichever company you join after graduation.

This leads me to explain how can you get the most out of TI as an extended team member.

Purpose of this book

Use this book as a reference to pick the best TI parts for your project. As you will see later, TI has more than 40,000 components that you could use in your project. Narrowing that number down to one or two (or nine or 10) parts will be daunting. We hope to simplify that task by giving you some hints and shortcuts in this collection of topics to help you get what you need.

How to interact with Texas Instruments

Before we get to the quick overviews of each of our component families, let me introduce you to TI. Although we are generally known as the "calculator company," and that division is a small part of TI, our major business is integrated circuits. As I said earlier, we have more than 40,000 components in our catalog. That is where we can become a valuable member of your team.

There are many ways to get TI to join your project team:

- Use our components.
- Use our many application reports and white papers.
- Use our technical support.
- Use our evaluation modules (EVMs) to prototype.

But before I tell you about all of the resources we have available to you, let me give you the URL for the university program at Texas Instruments: http://www.ti.com/lsds/ti/university_program/ti_university_program.page. [2]

This is a great place to start if you're just getting to know us. Now here are some resources that will help you with your senior project.

Use our components.http://www.ti.com/[3] is the best place to start your interaction with us. From this URL, you can find all you need to know about every product TI makes available. You can even get free samples shipped to you (if you don't already have them in your senior projects lab). We have just about everything you will need for your project. And if we don't have it, our partner Digi-Key will certainly have it (http://www.digikey.com/[4]).

Use our many application reports and white papers. At http://www.ti.com/,[5] you will find a tab for Applications. Here you will find a gold mine of application material. From the Applications page, look for your area of interest, and from there click the Application Notes tab.

Use our technical support. We have several ways for you to get technical support. Here are a few:

- Technical support line: You can find local support no matter where you are in the world or what language you are most comfortable using at http://www-k.ext.ti.com/sc/technical-support/product-information-centers.htm?DCMP=TIHomeTracking&HQS=Oth
.
- E2E Community: This not only connects you to TI's top applications engineers, but to others like you who have used our parts and may have already solved the same problem you are facing. Give it a try at http://e2e.ti.com/.[7]

[2]http://www.ti.com/lsds/ti/university_program/ti_university_program.page
[3]http://www.ti.com/
[4]http://www.digikey.com/
[5]http://www.ti.com/
[6]http://www-k.ext.ti.com/sc/technical-support/product-information-centers.htm?DCMP=TIHomeTracking&HQS=Other+OT+home_d_cont
[7]http://e2e.ti.com/

Videos that might be helpful:

- www.ti.com/universityvideos. [8]
- TI's YouTube channel. [9]

Use our evaluation modules to prototype. We have EVMs for virtually all of our embeddeed processors. They also include the analog and other interface circuits that work best with the processors. You will find TI EVMs by clicking Tools and Software at http://www.ti.com/[10] .

In fact, you can find many sources of available software by clicking Tools and Software at http://www.ti.com/[11] .

Engibous Prize entry requirements

One way that we recognize the effort that you and your team have put into your senior project is with the Engibous Prize. It is named after Tom Engibous, our now-retired president and CEO. Engibous spent his career at TI, starting as a design engineer in our analog circuit business unit. He was promoted from there to a management role, finally becoming president and CEO in the late 1990s until his retirement in the mid-2000s. We are very proud of him and his career at TI, so we designated this prize in his honor to recognize top senior design projects.

Eligibility for entry is relatively simple:

- You must have used at least three TI analog components, or one of TI's digital components plus two analog components.
- You must have completed the project with a working prototype.
- You must submit a project report to TI discussing the problem, solution and results, and include a list of TI components and how they were used.

There is a chapter in this book that goes into further detail about how to write an Engibous Prize entry.

With that, I will offer a biased hint: It is okay to use more than three TI devices. With more than 40,000 parts available to you, you should be able to find more than three that fit your needs.

Book organization

It's time to get started picking the best TI parts for your project. Here is a quick list of chapters:

- Analog:
  - Amplifiers.
  - Data converters.
  - Power management.
  - Wireless conductivity.
  - System components.
  - Interface components.
- Embedded processors:
  - MSP430™ ULP microcontrollers.
  - TMS320C2000™ microcontrollers.
  - ARM M3/M4 microcontrollers.
  - DSP and ARM microprocessors.
- Writing the project summary.

Each chapter will cover three topics:

- Technical overview.

[8] http://www.ti.com/universityvideos
[9] http://www.youtube.com/user/texasinstruments?ob=0&feature=results_main
[10] http://www.ti.com/
[11] http://www.ti.com/

- How to read the data sheet.
- How to pick the right part.

The last chapter will discuss the Engibous Prize in more detail. It will also introduce you to Tom Engibous and his career at TI and provide the official rules.

Chapter 1

Analog

1.1 Analog[1]

Introduction

Your senior project will require a lot of analog circuits. The goal of this section of the book is to help you find the right parts for your design. Texas Instruments has tens of thousands of unique part numbers covering this broad area of IC technology.

Reading the chapters that follow will help you remember the theory behind selecting the parts you will need. Our goal is to help you think through the process of selecting the right parts, and then actually finding them.

Here are the topics of the chapters in this section, with the authors' names in parentheses:

- Operational amplifiers (Bruce Trump).
- Data converters (Rick Downs and Tom Hendricks).
- Wireless communication devices (Thomas Almholt and Farrukh Inam).
- Interface devices (Thomas Kugelstadt).
- System devices (Charles Hefner).
- Power management (Upal Sengupta).

Packages

You may notice that many of the devices you would like to use from TI will not be easy to insert into your printed circuit board. And because they are not dual inline packaged (DIP), they don't plug into a prototyping board. This is an issue we discussed at length when we were selecting parts for the Senior Project Cabinet. We decided to go this route because when you get to your first post-collegiate project, these difficult-to-solder parts will be what you'll design with, as they take up less board space and are easier to use in automated production lines. It is also less expensive to use these smaller devices. So we chose to give you a bit of experience using these devices and prepare you for the future.

But the news isn't all bad. There are adaptor boards available that will convert the quad flat package (QFP) to a DIP. One of them is shown in Figure 1.

[1] This content is available online at <http://cnx.org/content/m44384/1.2/>.

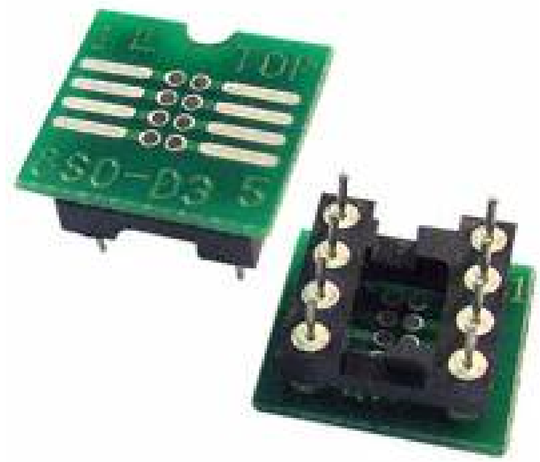

Figure 1.1

Figure 2 shows an alternate solution that allows you to build your own adaptor boards. It has multiple adaptor circuits on one board that split apart easily.

Figure 1.2

Enough about adaptors. It's time for you to jump into the chapters on analog circuits. Each was written by an expert on TI's application staff. Learn to enjoy the task of revisiting material you forgot right after the test. This will not be the first time you will relearn material, or in some cases learn it for the first time. It will be a career-long exercise as you grow with the technology.

1.2 Operational Amplifiers[2]

Operational amplifiers and other analog components

The op amp is perhaps the most versatile building block for analog circuits. With an op amp and a few passive components, you can make amplifiers of all sorts with inverting and noninverting gains. You can make integrators, differentiators, filters and voltage-level shifters. You can perform signal rectification, convert

[2]This content is available online at <http://cnx.org/content/m44275/1.2/>.

voltages to currents and vice versa. Applications information is widely available on Texas Instruments' website and across the Internet by searching with a few keywords.

Op Amps for Everyone[3] is an excellent general reference. This section of the book will also briefly cover special amplifiers and related component types such as instrumentation amps, comparators and difference amps.

Let's start with some basics. If you recall the ideal op amp assumptions, the most important are infinite gain and infinite input impedance. The infinite gain assumption can be troubling. Think of it this way: When negative feedback is connected from output to input, the output seeks a voltage that creates 0 V between the two input terminals.

In Figure 1, the noninverting input voltage is clearly defined; it's 0 V connected directly to ground. The voltage at the inverting input is determined by the voltage divider formed by R1 and R2. The op amp (with its feedback network) performs a balancing act, driving the output to a voltage that will make $V_X = 0$ V. Any small deviation of V_X away from zero will nudge the output in the direction to regain balance at 0 V. Some simple nodal equations involving V_{IN}, V_O and $V_X = 0$ will yield the transfer function of this circuit.

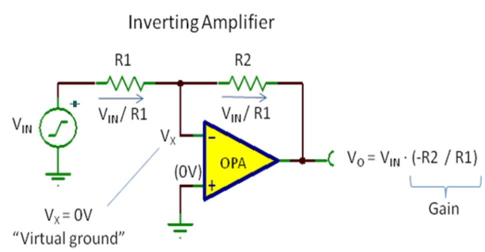

Figure 1.

Figure 1.3

The noninverting amplifier shown in Figure 2 is essentially the same circuit, with the input signal applied at a different node. The "input" side of R1 is now connected to ground and the noninverting input of the op amp is now the signal input terminal. Through feedback, the output seeks a voltage that causes the inverting input terminal voltage to be equal to V_{IN}. Again, simple nodal analysis will yield the transfer function and gain. Note that the gain is different in this case with a "+1" term added.

[3]http://www.ti.com/lit/an/slod006b/slod006b.pdf

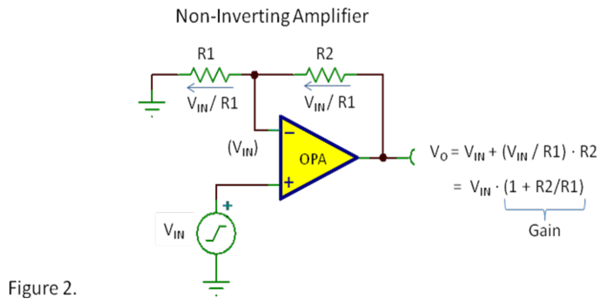

Figure 1.4

Although many complexities exist involving the nonideal behavior of op amps, understanding an application circuit always starts with a firm understanding of how the ideal circuit is meant to operate.

Finding your op amp

You've probably used a prescribed op amp in your labs, and your professors have designed assignments to suit the characteristics of the op amp you are using. When you need to select an op amp that meets the needs of your project, you will find that there are hundreds to choose from. Where do you start?

These key specifications are generally the most important selection criteria.

Operating voltage

- Battery-operated projects generally use CMOS op amps operating from 5 V or less.
  - Often use CMOS op amps operating from 5 V or less.
  - Rail-to-rail op amps allow wider input and output voltage with limited supply voltage.
- Higher voltages are often used for higher accuracy and special performance characteristics.
  - ±15-V supplies are commonly used for instrumentation and measurement applications.
  - Dual (±) supplies are easier when accurate positive/negative signals are important.

Gain bandwidth (GBW)

Determines the signal bandwidth that you can achieve with a given closed-loop gain (G).

- Maximum usable signal bandwidth = GBW / G.
- Op amps meeting minimum requirements will use less power.
- Op amps with unnecessarily high GBW (>50 MHz) may be more difficult to use.

Offset voltage (V_{OS} or V_{IO})

- The voltage between the two input terminals of the op amp (ideally zero).
  - Ranges from a few microvolts to a few millivolts.
  - Can be very important in processing accurate DC signal values.
  - Generally unimportant with AC signals such as audio.
- Offset at the output is amplified by the closed-loop gain.

Input bias current (I_B)

- The current that flows in the input terminals of an op amp.
  - Ranges from picoamps to microamps.

  - CMOS and JFET op amps have the lowest I_B.
- Contributes to offset voltage by I_B x Input Resistance.

Quiescent current (I_Q)

- The current drawn from the power supply with no load current.
- Ranges from approximately 1 microamp to several milliamps.
- Low I_Q op amps are "slow" for low-bandwidth signals, battery-powered circuits.

Input common-mode voltage range and output voltage range

Among the most common difficulties users encounter are the limitations to input voltage range and output voltage swing.[4] So-called "rail-to-rail" types have an input voltage range that extends to, or slightly beyond, the power supply rails. Those featuring a rail-to-rail output can swing close to the power supply rails. Rail-to-rail amplifiers are particularly useful in battery-operated circuits with low-voltage supplies.

Dual and quad versions, package types

Many op amps are available in single, dual and quad package versions. Dual and quad versions can save space (and money, if you are concerned about high-volume production). In a prototype development, however, single op amps make circuit board or prototyping easier.

There are many different package types. Newer, tiny surface-mount types may be difficult to handle in prototyping. Some new op amp types may not be available in the dual-inline (DIP) packages that are most convenient for prototyping.

Reading the data sheet

An op amp data sheet can be a bit overwhelming – so much information for a device with only five pins. The summary of features and suggested applications on the front page tell you much about the intended uses of the device. You should have a clear idea of the key specifications that will drive your selection. Be aware of the conditions that apply to each parameter. Ones that apply to all parameters may be listed at the top of the specification table. Others for individual parameters may be listed in the "conditions" column. Understand that these conditions may be a formal way of defining how we measure a parameter, but may not preclude use in other conditions.

Typical performance graphs can tell you much about the basic nature of a device. This information is not generally assured by production testing and may vary from device to device. You will find some graphs, such as open-loop gain vs. frequency, in virtually every op amp data sheet. Other graphs will vary according to the behavior of that particular device and its expected uses.

The applications discussion can be quite helpful. It provides cautions and advice on how to best use the device. Application figures and diagrams can help explain best practices and how to get the most out of a particular op amp. Much of an op amp users' design knowledge comes from careful reading of data sheets.

Finding your op amp

Consider the op amps on the recommended list first. These devices cover a wide range of needs and have proven to be easy-to-use, capable performers. A variety of package types is available. DIP packages are easy for prototypes. Surface-mount types can be awkward for manual construction but do save space. You are not limited to these devices if you have special needs. There is a selection tool on our website that provides slider-bar tuning specifications. Go to http://www.ti.com/[5] and select Amplifiers and Linear.[6]

Simulating with SPICE

You can download SPICE macromodels from http://www.ti.com/.[7] They are found in the product folder for each device. Although you cannot simulate all components, such as data converters and controllers, simulating the critical analog portion of the signal chain does help solve basic problems and optimize your circuits. TI offers a free, easy-to-use SPICE simulation program with installed macromodels. Download it at http://www.ti.com/tina-ti.[8]

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[4]http://e2e.ti.com/blogs_/b/thesignal/archive/2012/05/08/op-amp-voltage-ranges-input-and-output-clearing-some-confusion.aspx

[5]http://www.ti.com/

[6]http://www.ti.com/lsds/ti/analog/amplifier_and_linear.page

[7]http://www.ti.com/

[8]http://www.ti.com/tina-ti

Other amplifier types

There are a few other special amplifier types that deserve a brief introduction. You will find some of these devices in the TI recommended parts list.

Buffer amplifier.[9] Increases the current output of an op amp to drive small speakers, motors, etc.

Difference amplifier.[10] An op amp with four accurately matched resistors to measure voltage differences.

Comparators. Provide a binary output comparison of two analog voltages. Though some op amps can perform this function, comparators provide better features and performance.

Instrumentation amplifier.[11] Three op amps and resistors to accurately acquire small-difference voltages in noisy environments.

Current shunt monitor.[12] A special amplifier intended to measure current flowing in a shunt resistor, often used to measure current in a battery or power supply.

Programmable gain amplifier.[13] Closed-loop gain is digitally controlled.

Current-feedback amplifier.[14] A wide-bandwidth op amp similar to a standard op amp, with special restrictions on the feedback resistor values and configurations.

Voltage-controlled amplifier.[15] Gain is controlled by an analog voltage signal.

You may also seek help on TI's E2E Community forums.[16] The op amps are handled in the Precision Amplifiers forum.[17] Please read this short primer on submitting questions[18] before posting to ensure prompt and efficient support.

1.3 Data Converters[19]

Technical overview

A data converter is the bridge between the real, physical world of analog signals like voltage or current, and the digital world of numbers represented by ones and zeros. An analog-to-digital converter (ADC) converts a voltage into a number; a digital-to-analog converter (DAC) converts a number into a voltage or current. An ADC might be used to measure a weight or the intensity of light, or allow an audio signal to be captured and stored as a digital file for playback in a media player. Converting that digital file back into sound would require a DAC; a DAC can also control a valve that affects the flow of chemicals into a chemical reaction, or the position of a cutting head on a system that makes mechanical parts.

ADCs

Figure 1 is a general representation of an ADC. An analog-to-digital converter can be represented by the three functional blocks shown here, regardless of architecture.

[9] http://www.ti.com/lit/gpn/buf634
[10] http://e2e.ti.com/blogs_/b/thesignal/archive/2012/04/24/difference-amplifiers-the-need-for-well-matched-resistors.aspx
[11] http://e2e.ti.com/support/amplifiers/precision_amplifiers/w/design_notes/1777.aspx
[12] http://focus.ti.com/paramsearch/docs/parametricsearch.tsp?family=analog&familyId=426&uiTemplateId=NODE_STRY_PGE_T
[13] http://focus.ti.com/paramsearch/docs/parametricsearch.tsp?family=analog&familyId=1614&uiTemplateId=NODE_STRY_PGE_T
[14] http://www.ti.com/lit/an/snoa390a/snoa390a.pdf
[15] http://focus.ti.com/paramsearch/docs/parametricsearch.tsp?family=analog&familyId=1473&uiTemplateId=NODE_STRY_PGE_T
[16] http://e2e.ti.com/support/default.aspx
[17] http://e2e.ti.com/support/amplifiers/precision_amplifiers/default.aspx
[18] http://e2e.ti.com/support/amplifiers/precision_amplifiers/w/design_notes/1769.aspx
[19] This content is available online at <http://cnx.org/content/m44273/1.4/>.