The New Digitally Controlled Programmable Gain Amplifier (PGA)

My name is Kuman Blake. I work at Microchip Technology in our Amplifier Linear Products Group. I am the applications engineer doing analog, amplifiers, comparators and now the programmable gain amplifier (PGA).

As you look at this first slide you will see the title is: The “New Digitally Controlled Programmable Gain Amplifier.” Hopefully no one looked at this and thought we were talking about a programmable Gate Array, right? This is about an analog part that you can control using some kind of microcontroller joining SPI interface. We are real excited about this part. We would like to share with you how we see it fitting into the world of sensor detection.
This next slide (#2) shows one possible way of hooking up our PGA and sensors in order to process the information from the sensors. You will notice on the left, that we have several sensors, as shown by this arrow I just drew. These sensors can be of many different types. You will notice that our PGA accepts the inputs from multiple sensors at several different input channels. This is very powerful because many times when you have to process information from a sensor you have more than one sensor involved. Possibly one of your sensors needs temperature corrections, using the PGA, you can measure temperature and also whatever you are doing elsewhere and that will help out. That is one feature that the PGA has that will help you. Also you will notice on the bottom left here shown by the arrow, there is what I have labeled a reference voltage coming into the input. We will talk about this a little more later. This basic function is to sensor the voltage coming out of the PGA. Shown here with the next arrow at the output. That way if your sensor is different voltage we can adjust the PGA output to compensate.

Down here on the bottom right, you will notice that there is a SPI digital bus connecting the PGA and the PIC® microcontroller, or any other microcontroller for that matter. This SPI bus makes it very easy for the controller to change the PGA whether it is gain, the input channel or even has a shut-down mode. To complete this picture, we have an anti-aliasing filter and a 12-bit A-to-D converter over here on the right, which converts the analog signal into digital so you can do further processing. This is the basic picture. As we go through this, what I am going to point out several times is that the PGA’s combination of being able to select a different input and change the gain is what we bring to your design.
Let’s talk a little more about the sensors. This is probably something that you are familiar with, so I really don’t need to go into great detail about it. I just wanted to show it to remind you of what we are talking about.

One example is shown here on the left. You have a negative temperature coefficient thermistor with the resistor and you get a voltage out with temperature in. This is fairly linearized over a reasonably wide range of temperature on the order of 60°C (Centigrade or Celsius).

Another possible sensor would be a light sensor. We are showing a combination in the second diagram that would put a voltage out with light in. Obviously, this would not be a high-sensitivity or high-precision type circuit, if we have a voltage out like this. It is going to be more for position sensors - just on-off type applications.

Another possible sensor would be a silicon temperature sensor (third diagram). We show one of our devices here (TC1047A). It detects the ambient temperature and produces a 10mV/°C change as the temperature rate changes. Very simple sensors. These will comfortably work with our PGA.
I show a couple more sensors here, these may not be quite as good a fit depending on your requirements for the PGA.

On the left, I show a Wheatstone bridge; you will notice that we say that this can be pressure or load. Also strain-gauges, whatever it is. Typically these put out a very small voltage, and usually you have to reject a strong common noise. We show a thermocouple.

The last example is a Thermocouple. The PGA is not going to get great resolution on a thermocouple. We will talk about that in a little bit. But it could handle a very wide range of temperatures quite well. That basically covers the background information, and is what we are trying to achieve in this presentation.
Sensors

- Single-Ended Sensors
  - Resolution at sensor > 1 mV (typ.)
  - Close to amplifier
  - Small Common-mode noise

- Differential Sensors
  - Resolution at sensor < 1 mV (typ.)
  - Far from amplifier
  - Large Common-mode noise

Now, for this presentation, I have arbitrarily lumped all of these sensors into two broad categories. You will notice I have called one set the Single-Ended Sensors. The resolution does not need to be great, somewhere on the order of 1 mV or better is all you need. They are typically close to the amplifier in the signal processing chain. Typically, you do not see a lot of noise on this type of sensor, and they are not as difficult to work with.

The other category is a Differential Sensor such as the Wheatstone bridge. Usually the resolution on these has to be significantly higher than 1 mV, for example, 10 microvolts would be a good number to throw out. Many times they are a fair distance from the amplifier so you see a lot of common mode noise on your two wires coming into your signal conditioning circuitry.
On this slide there is a little bit of preparation, I hope you will bear with me. We will get a little more into the “meat” as we go. This circuit shows one implementation that you can use to change the reference voltage going into the input of the PGA, depicted there by that arrow I just drew. And, when you change that reference it will be, if you remember, that it all changes the center-point of the output voltages of the PGA. On the left of the diagram, I have drawn the voltage divider that sets two different voltages. Two and half volts (2.50V) and .33 volts. Obviously, you can pick whatever voltage satisfies your requirements. I now come to a CMOS switch and use that switch to choose among the voltages, obviously you would drive that with your microcontroller. Then, at the output of the CMOS switch, I am showing an op amp set-up as a unity gain buffer to drive the VREF pin in the PGA. This unity gain buffer is very important to that pin and the data sheet describes that in detail.

The most important thing about this slide is the idea that it is possible to change that voltage into there and to change the output center point and that can help you process several different sensors. For instance, if you have one sensor that is centered on ground, and another sensor that is centered at mid-supply it could be difficult to do both of them if the VREF pin were tied to ground.
Reference Voltage

- Reference Voltage
  - Used to center output signal
  - Settling time (1%) when changing $V_{REF}$
    \[ t_{settles} \approx \frac{0.35}{BW_{VRef}} \]
    \[ < 0.4 \text{ ms}, \quad \text{for circuit on previous slide} \]
  - Variations
    - Ground PGA’s $V_{REF}$ pin
    - Silicon reference voltage and buffer
    - Digital-pot with MCP6021 buffer

To summarize what we just went through, the reference voltage center is the output voltage of the PGA.

Now you need to worry about the settling time of the reference voltage when you change between two voltages. There are a couple of different ways you can accomplish this. The circuit I showed on the previous slide is only one solution. I have listed three additional ones at the bottom of this slide.

For instance, you can just ground that $V_{REF}$ pin. Just tie it to ground. That is the easiest and cheapest solution. You can use a silicon reference and buffer that. Or, another possibility, is that you can use one of our digital pots and buffer that going into the pin. Obviously, you have many different possibilities here.
We are now to the point in the signal chain where it is time to talk a little more about our PGA, just so you understand what happens later.

At the input of our PGA, we have a MUX. This selects from among the different possible inputs, as many as 8 inputs. Down at the bottom left of the diagram, you will notice that we have a SPI logic/register box. That is what does all of the “digital smarts,” and it tells the MUX and in other parts of the PGA what to do, and when to do it.

Here in the middle we have a block called gain switches. That is the block that tells this resistor, latter at the end, what voltage gets fed back to the op amp. What that basically does is change the gain. That, in a nutshell, is what the PGA does. Here is a little bit more detail.
Our PGA

- SPI™ bus
  - Digital Control (gain, input)
  - Shutdown
  - Daisy chain
- Input MUX
  - Handles multiple sensors
  - 1, 2, 6 or 8 inputs

The SPI bus controls gain and the input channels. We also mentioned before that it has a shut-down feature and is capable of daisy chaining with other SPI parts.

The input MUX handles multiple inputs. You will see that I have listed the possibilities: 1, 2, 6 or 8 channels. These are the possibilities that we offer.
I’ve talked several times about changing the gain. Changing the gain is important because you can either increase or decrease the resolution at your sensor. The gains that we offer are mostly in a binary weighted set as you can see here: 1, 2, 4, 8, 16, and 32.

It is also possible to select from decimal gains, those being: 1, 5, 10. Whatever your choice is we are also looking at future products that will have other gains selection that may fit your application better.

We have talked about the VREF pin before, but I should probably emphasize here that we do externally set that voltage; it is not an internal reference voltage.
The next block in the signal chain is an anti-aliasing filter, or a low pass filter. You will notice they go between our PGA (which is an amplifier) and A/D converter that converts that analog signal into a digital one. This is a fairly important function. It also does a little bit of noise filtering. We will talk about that later.

I would like to point out that we do offer as a free download from our website a package called FilterLab® Active Filter Design software. It will help you design this type of filter.

One of the design requirements that you will need to think about when you are selecting the bandwidth of that filter is the settling time. As you switch between sensors, by changing the input channel of the PGA, you will need to wait a certain amount of time for the output of the filter to settle. So, the slower the filter, the longer you will have to wait for it to settle. It is a design trade-off you can play with.
At the end, I am showing an A/D converter. If you remember the original block diagram, it showed the A/D converter contained within a microcontroller, that is one possibility. You can also choose to have an external A/D converter, an independent one, the decision is relatively minor. What is important is that you have some kind of converter that has reasonable resolution. For most of the applications, that we have shown, the 12-bit converter is probably good enough. Obviously you can do a finer resolution if you need it. For this example that I am showing on this slide, I chose to set the reference voltage for the A/D converter at high voltage VDD so we could do a ratio metric measurement. That is an arbitrary choice, you can do something else. But the most important thing to notice here is the least significant bit (LSB) of the converter I have chosen is 1.2mV. That is your step size between codes in the A/D converter. Now, that’s if you go back to the sensor, you can resolve that 1.2mV at the sensor if your PGA gain is 1. What if you change the gain to 32, instead, the highest gain in this PGA. Now your sensor resolution is going to be 38µV, a much finer resolution and it is just because you changed the gain in the PGA. This is one of the strengths of our PGA. You can choose whether you want the fine resolution or the coarse resolution depending on the sensor that you are trying to deal with. Obviously you would set the sampling rate of your converter depending on what you would need in your application.
Summary

- Single PGA
  - Simplifies multiple sensor circuits
  - Integrates MUX and gain control
  - Gives good resolution at sensor
  - Works well with many micro-controllers
  - Reduces parts count
  - Easy to use

This has been a fairly quick overview of what we can do; obviously, there is more that we can discuss. Unfortunately, we have 20 minutes, and I apologize that we cannot cover everything that you may have wanted to see. To summarize what we did in this presentation, we showed you some simplified circuit diagrams from multiple sensors. If you think about many of the systems that you deal with, you will have multiple amplifiers and possibly multiple converters. MUX, whatever, many parts are replaced by this one part. This part not only does that, but it combines the digital control of which input channel and the gain so that you customize the PGA performance for that particular sensor. We also achieve good resolution at the sensor by changing the gain.

For your information, I have included some extra references at the back of this presentation. On the next slide I have listed several different documents that are available on our web site to download that will give you background information and should cover a lot of the additional questions you may have.
First of all, information specific on the PGA. I have listed the data sheet and an Application Note on how to make any PIC microcontroller interface to this part even though it doesn't have an SPI interface. It talks about creating a similar version SPI interface for it.

There are some other Applications Notes listed as well as Analog Design Note, ADN002, which that discusses using the PGA with different types of sensors. These go into a little more detail than we have time for in this presentation.

Just for your information, there was also an article in *Electronic Design*, back in March, of this year (2003) that discussed Microchip’s PGA.
References

- Sensors and Op Amps
  - Temperature (AN684, AN685, AN687)
  - Pressure (AN695)
  - Bridge (AN717)

- FilterLab Active Filter Design Software
  - Free
  - Downloadable
  - Active, op amp filters

We have also listed some more Application Notes on sensors using op amps. Although they are not written for the PGA, they provide good background material on this topic.

And last of all, we have the FilterLab® software package available. It's free, you can download it from our web site and it will help you design many active op amp filters.
Thank you for learning about our new digitally controlled Programmable Gain Amplifiers and watch our web site for additional Web Seminar topics in the months ahead.