

Signals-From-Noise Single-Bit ADCs in a Nutshell - Part I

by Dave Van Ess, Principal Application Engineer, Cypress Semiconductor

Many embedded applications require sensing analog inputs under processor control. It may be an amplified signal from a microphone or an ECG signal from a body; it may be to monitor the output voltage on a potentiometer to determine a particular position or volume level; it can be to read the voltage response from a resistor stimulated with a current to measure resistance. The applications are endless. This function requires an analog-to-digital Converter or ADC.

Unlike DACs, no one knows how to say ADC. So it usually comes out as A D C. It could have been named analog-to-digital-domain or ADD. This rolls nicely off the tongue but ADCs have been around too long now to change their name. Now if DACs are a precious resource, ADCs are even more so. Usually there is only one ADC for a single chip system and in some cases none. One solution is to build your own using onboard digital resources and firmware, along with external circuitry. This article will explain the concept of single-bit ADCs, different techniques to construct them, and the benefits and consequences of each type. Even if you do not build your own ADC, these concepts will help in selecting what sort of ADC you want.

As explained in my previous column http://www.analogzone.com/iot_0904.pdf, a single-bit DAC is a digital stream that can be converted to the desired analog value. This on-versus-total-time ratio was defined as the duty cycle. Well, duty cycle was not the best term to use, as it is most commonly associated with PWMs. A better term to define this ratio would be to call it a density. A single-bit ADC converts an analog signal to a digital signal in the density domain.

A Single Bit ADC In It Simplest Form

If you have a DAC, a comparator and some logic, you can build an ADC (Fig. 1).

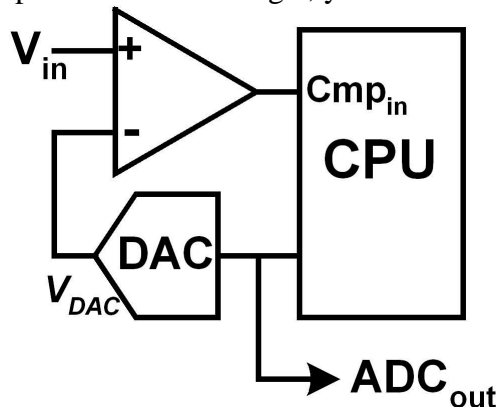


Fig. 1: ADC Constructed From A DAC

The CPU uses the DAC to generate an analog value. A comparator is used to determine if this value is larger or smaller than the input voltage. The CPU has some algorithm that determines the new density value to be tried. The algorithm can be as easy or complicated as desired and is dependent on the system's particular design requirements. A common algorithm is to perform a binary search or successive approximation and register (SAR). Other algorithms assume that the ADC value is most likely close to the last calculated value and limits its search range. The simplest algorithm to implement is to start the DAC at its most negative value and increment its value till the DAC output is just greater than the input voltage. The only real advantage this technique has is that it does not require much sophistication and can easily be implemented with the simplest hardware. For lack of a better term this technique is called stupid approximation and increment SAI. There is some debate whether such a simplistic technique deserves its own three-letter acronym. I say what the heck, this is America and any algorithm can aspire to have a TLA no matter how humble its beginnings or its lack of polish.

My last column finished a two-part series on constructing single bit-DACs. One of these can be used to generate the DAC value needed for comparison (see Fig. 2).

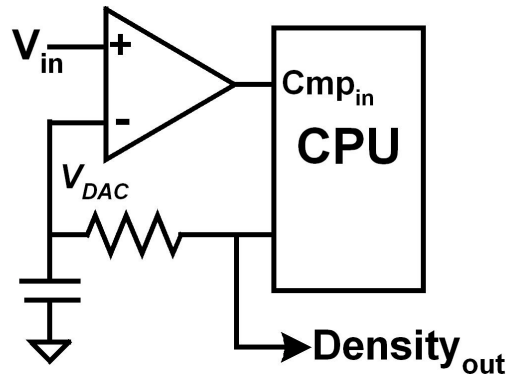


Fig. 2: Basic Single-Bit ADC

The CPU generates some density value that is filtered to become an analog value. A comparator is used to determine if this DAC voltage is larger or smaller than the input voltage. The CPU algorithmically determines the new density to generate. Since the CPU generated the density signal, it can calculate what V_{in} must be using the equation:

$$V_{in} = V_{DAC} = V_{ref} (2 \cdot Density_{out} - 1) \quad (1)$$

Generating A Digital Density Without Using A CPU

Suppose a triangle wave is fed into the negative input of the comparator and the voltage to be measured is fed into the other. The comparator output will be high only when the triangle wave is less than the input voltage. It is a pulse width modulated output where the ratio of the pulse width and period is the density value.

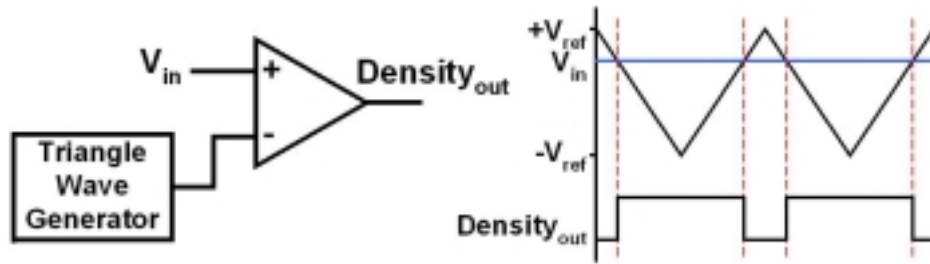


Fig. 3: Triangle Waveform Single-Bit ADC

Digital hardware can be used to measure both the period and pulse-width values. Knowing the values of the reference voltages, it is possible to calculate what the input value must have been.

It is not necessary to digitally measure the values; a single-bit output ADC is useful by itself. Shown below (Fig. 4) is a block diagram for a power supply or battery charger.

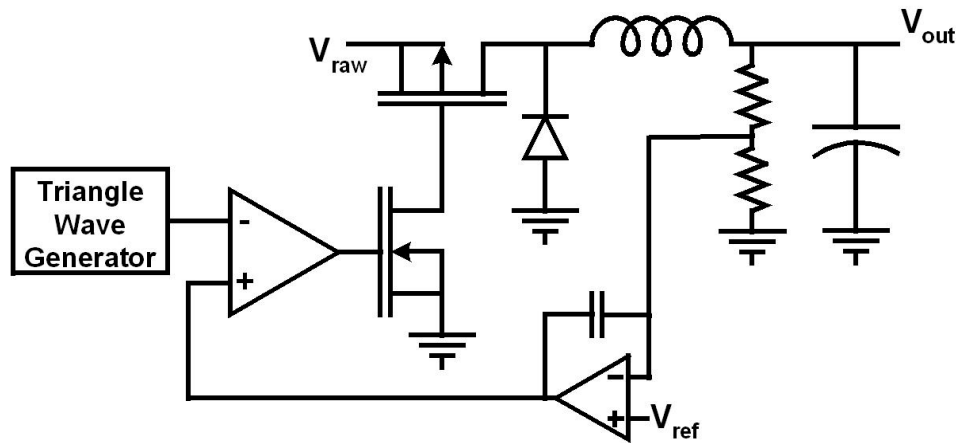


Fig. 4: Single-Bit ADC Power Supply

The transistors, inductor, and capacitor form a buck converter. The output voltage is proportional to the supply voltage and the duty cycle that controls it. It is a single-bit DAC. The output is compared to some reference. If the output becomes larger than the desired value, the integrator swings in the negative direction. This voltage level is fed to the comparator where this pulse width is decreased, causing the buck converter to generate a lower output voltage. It works oppositely for a decreasing output voltage.

Power supply designer have been using this trick for at least 50 years; however, I have never found any reference where they have ever called this feedback element a single-bit ADC. I guess they think of ADCs as data conversion devices and that they don't apply to their particular field of design.

We'll discuss more about ADCs, starting with self-modulation, in the next installment of this column.

Postscript

It was really great to receive so many e-mails from so many readers in response to my first column *DACs in a Nutshell* http://www.analogzone.com/iot_0904.pdf. While your letters mostly involved kind words, there was enough diversity of opinion that they can be partitioned into four different groups.

The first group is guys thanking me for my article. The underling theme is that they are mostly firmware designers that are finding they really need to know more about the total system to build the best product they can. Thank you, I appreciate your e-mails. You are the group for whom I am writing this column. If you have ideas of things you want me to cover in future installments, please send them in.

The next group is those letting me know that my work is simplistic and that they know more than me. Way more. For some reason they seem to still be in grad school and like to ask me questions guaranteed to validate their proposition. It is true, you are most likely way smarter than me and, if you like, I will send you a certificate stating so. I am long past having my self worth depend on me being the smartest one in the room. Still, go ahead and write. It reminds me of me, at your age.

The next group is those inquiring about jobs and usually have a résumé attached. I'll see what I can do but I can't make any promises.

The last group is those offering to sell me little blue pills or penny stocks. Stop it! I wish the government's anti spam and witness relocation programs would work together and hire those relocated thugs to "talk" to those spammers and convince them to change their ways. They got my uncle to stop gambling.

Keep writing! I will try to answer e-mail from three of the four groups. - Dave

About The Author

Dave Van Ess is a Principal Application Engineer at Cypress Semiconductor. He is an electrical engineer with experience in hardware, software, and analog design. Dave joined Cypress in 2000. He has nine patents for medical systems, signal processing design, and PSoC digital block enhancements. He has written numerous User Modules, application notes, and articles. He graduated sigma cum barely with his BSEE from the University of California, Berkeley, 1977.

An engineer by training, a poet by temperament, an outlaw in Nebraska, and a heck of a nice guy, Dave has worked in many different industries. His work experience includes test and measurement equipment, measurement and control systems for high energy physics research, and underwater acoustic transmitters and receivers deployed in open sea and arctic ice fields. Electrons fear him! Women revere him!

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