Building a reliable magnetic card reader (Part 1 of 2)

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A good magnetic card reader requires reliable and accurate performance across a variety of different environments and card swipe speeds, as well as regardless of the physical condition of the card. There are three essential elements of a magnetic card that must be implemented in order to ensure this performance:

1. Automatic gain control (AGC) to continuously adjust the amplitude of the input waveform to maximize dynamic range;
2. Accurate peak detection and raw data decoding; and
3. Preventing noise in the system from causing erroneous readings.

Using a programmable gain amplifier (PGA) and an analog/digital converter (ADC), the input waveform can be measured and scaled to maximize the dynamic range of the system which will allow a wide range of input waveforms to be detected. This article will also show what techniques can be used to accurately detect peaks in the input waveform to read the essential information from the magnetic card. Lastly, creative techniques on how to eliminate false readings due to noise in the system will be discussed.

Magnetic card waveform primer
To understand the concepts described in this article, it is best to first understand the basics behind the magnetic card waveform we are trying to decode. A magnetic strip is composed of a string of magnetic domains, each oriented in a way such that opposite poles are adjacent. In the areas where two magnets with like poles are touching, there is a concentration of magnetic flux which induces a current spike as they pass a magnetic read head.

Each bit of information has the same physical length on the strip. The presence or absence of an additional peak in the middle of the bit determines whether it is a one or a zero. On a magnetic stripe, a one is comprised of a single magnet that is two units long and a zero is comprised of two magnets that are each one unit long. This encoding scheme is known as F2F encoding (or Aiken BiPhase) and is illustrated in **Figure 1**.

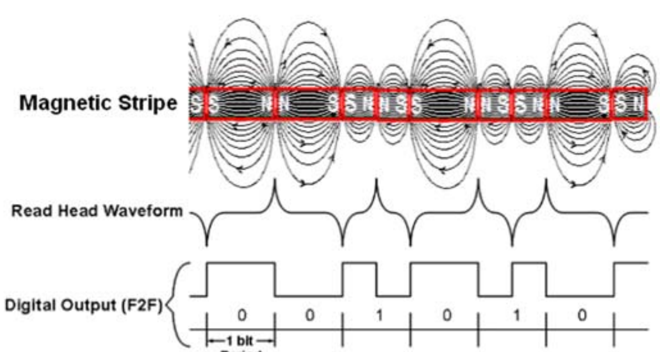


Figure 1: Magnetic card waveform
(Click on image to enlarge)

Automatic gain control
The first essential element of a magnetic card reader is the automatic gain control (AGC), which automatically and

continuously adjusts the amplitude of the input waveform to maximize the dynamic range of the system. The amplitude of the waveform is highly dependent on the card swipe speed. Faster swipe speeds produce waveforms with peaks of greater amplitude, and slower swipe speeds produce waveforms with peaks of smaller amplitude.

The voltage produced by the magnetic read head is small, but can vary by more than 25 dB across all swipe speeds. A fixed gain can be used to bring this voltage to a usable level, but to ensure the signal is at the optimum level at all swipe speeds, AGC is a necessity. During a given swipe, a user will inadvertently change swipe speed several times. As such, the gain of the circuit should be adjusted throughout the swipe to be sure any changes in signal amplitude are accounted for.

There are two essential components required to implement AGC: an ADC and a PGA. In order to know what gain should be applied to the PGA at any given time, we must know the current amplitude of our input waveform. The ADC can be used to monitor the input signal level and adjust the PGA when needed. If the input signal passes below a set minimum threshold, the gain is increased. If the input signal passes above a set maximum threshold and approaches saturation, the gain is decreased.

Since the peaks of a magnetic card signal are very pronounced, it can be difficult for an ADC to sample the input signal at a high enough rate to ensure the amplitude of the peaks in the waveform are accurately measured. To help reduce the load on the ADC, a peak and hold circuit can be used to hold the amplitude of each peak. The exact time at which the amplitude is sampled is not important, as long as the sampling and updating of the PGA occur regularly.

Peak detection

In order to decode the data contained within the waveform, the peaks of the input waveform must be detected. This can be done in a multitude of ways, each way having benefits and drawbacks. Constructing a basic peak detection circuit is relatively easy, but creating a peak detector for a magnetic card reader can be difficult for several reasons:

- The rate of the incoming peaks can vary anywhere from a few hundred bits per second to over 10 kb/s, depending on the swipe speed, card, and card channel.
- The amplitude of the peaks can vary greatly. This can be partially remedied with the use of AGC, but still needs to be considered for precise peak detection.
- The peaks of the magnetic card waveform are pronounced, but the regions between each peak can be very flat – which can cause noise issues in comparator or differentiator based designs.

Comparator-based peak detection

One method for performing peak detection involves the use of a comparator and a delay circuit. The basis for this method is simple: compare the input signal to a delayed version of itself to determine when the signal has changed direction – e.g. when a positive or negative peak has occurred. The nice thing about this method is it detects both positive and negative peaks of the input waveform, both of which are needed to decode the raw data.

Positive peaks are represented with a falling edge on the output of the comparator and negative peaks are represented with a rising edge on the output comparator. The digital comparator output can then be used for decoding. **Figure 2** illustrates this peak detection method. The black trace is the original signal from the output of the AGC circuit and the blue trace is the delayed version of the same signal. Both of these signals are fed into a comparator, which produces the decoded digital output (red trace).

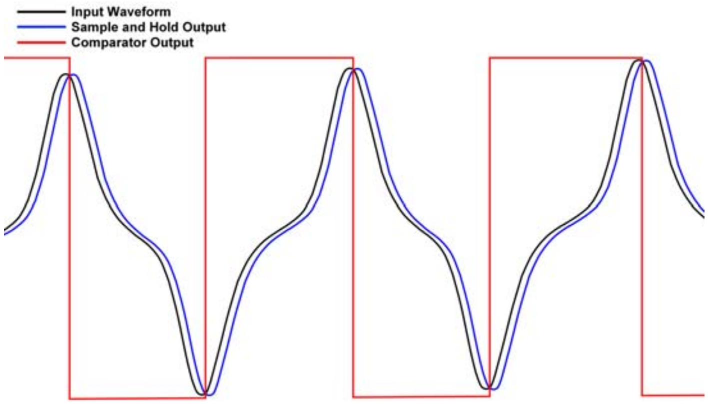


Figure 2: Comparator-based peak detection
(Click on image to enlarge)

The amount of delay introduced into the system affects both the noise immunity of the system and the accuracy of the peak detection. With less delay, the peaks of the input waveform will be detected with more precision. However, the reduced delay will also make the circuit more susceptible to false peak detections due to noise. As the delay is increased, the precision of the peak detection will be reduced but the circuit will be less susceptible to erroneous peak detections due to noise.

Sample and hold circuit
A sample and hold circuit can be used to create the necessary delay on the input waveform. A sample and hold circuit will not continuously delay the waveform, but a clocked comparator can be used to sample the output of the comparator when the sample and hold is holding the voltage. This technique is illustrated **Figure 3**.

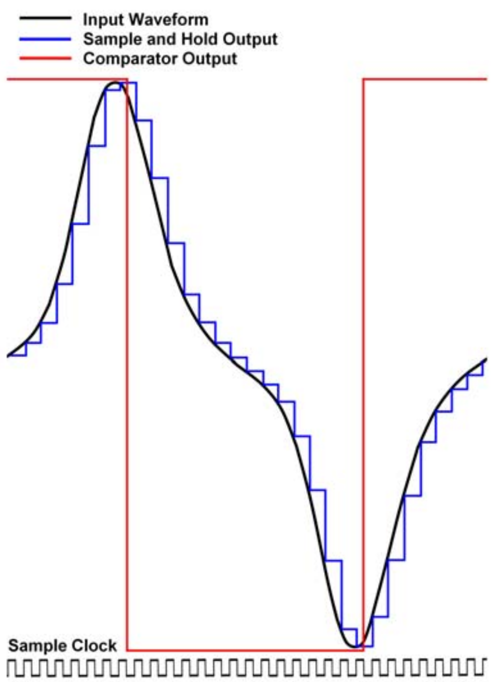


Figure 3: Sample-and-hold peak detection
(Click on image to enlarge)

The sample and hold is clocked on the rising edge of the input clock, and the comparator is clocked on the falling edge of the same clock. This ensures the held voltage is stable and adequately delayed from the original input signal. The sample clock can be adjusted to optimize the performance of the system.

In low-noise systems, the sample clock can be increased so the output of the comparator matches the input peaks closely. In noisy systems, the clock can be slowed to increase the delay between the signals and therefore increase noise immunity. If the system has dynamically adjustable clocks, the sample clock can also be adjusted to match the current swipe speed. As the swipe speed increases or decreases, the sample rate can also be increased or decreased to optimize the sample rate at all swipe speeds.

Using the ADC for peak detection

Since a magnetic card reader system will likely already have an ADC available, the ADC can also be leveraged to perform peak detection. The peaks in the magnetic card waveform can be narrow during a fast swipe, which means the ADC needs to be high speed in order to accurately resolve the peaks of the waveform. The ADC sample speed should be in the range of 100 ksps to 1 Msps per channel, depending on the accuracy and precision needed for the application.

Once the ADC has sampled the data, there are a couple of ways to determine where the peaks occurred. The obvious option is to implement a firmware algorithm that analyzes the ADC data to determine where the peaks occurred. This method requires a fast and efficient CPU in order to keep up with the incoming samples; especially if multiple tracks are being sampled.

However, this method is extremely flexible since the chosen algorithm can be adjusted to fit the needs of the system. Unwanted noise can be ignored to prevent erroneous detections and the AGC can be directly controlled from the data that has been collected. Since the waveform is already sampled in its entirety, there is no need for an additional peak and hold circuit for the AGC.

Another option for ADC-based peak detection is to use a DAC to reproduce the original waveform after it has been sampled by the ADC. At first glance this may seem wasteful, but doing this serves three basic functions:

1. The reproduced DAC waveform is a delayed version of the original waveform, which allows the comparator-based peak detector to be used again.

2. This method reduces the CPU load, since taking a sample and outputting the sample to a DAC is far less CPU intensive than a full peak-detection algorithm.

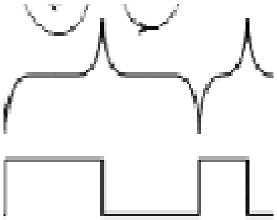
3. The ADC samples can also be used to control the AGC.

Since some SoCs (system on a chip) already have DAC resources available, this method serves as a good option to reduce the load on our CPU, which can be used for other functions in the system.

(*Part 2* will discuss preventing false readings due to noise.)

About the author

Dan Sweet is a PSoC Applications Engineer at Cypress Semiconductor Corp. He graduated from Western Washington University with a BS in Electrical Engineering Technology.



Building a reliable magnetic card reader (Part 2 of 2)

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Understand the challenging nature of the signal, and what must be done to detect and decode it properly (*Part 1* of this article is here; it begins with a magnetic card waveform primer, and then discusses automatic gain control, peak detection including comparator-based peak detection, sample and hold circuits, and using the ADC for peak detection)

Preventing false readings due to noise
Due to the shape of the magnetic card waveform, a comparator- or differentiator-based peak detector can be susceptible to false readings. During each peak, the waveform is changing quickly, which allows the delay imposed on the waveform to create appropriate separation for the comparator to detect the peaks.

However, during the transition between each peak, the waveform changes more slowly, which means very little voltage separation is created between the waveforms. Any noise during this period can cause the comparator to trip and cause an erroneous reading. This noise can (and should) be reduced by proper board layout, bypass capacitor selection, using a low-noise power supply and PGAs, and related techniques; but all noise cannot be completely eliminated.

There are other application-level techniques that can be used to help prevent erroneous readings in the system despite the noise that is present. One technique is to add hysteresis to the comparators. Hysteresis will reduce the likelihood that small noise spikes will cause the comparator to trip. Transitions at the peaks of the waveform will exceed the hysteretic threshold and will still allow the peaks to be detected accurately.

Another useful and effective technique is to employ the use of a window comparator for each channel. The thresholds for the window comparator can be set so the waveform is only checked for peaks when the waveform protrudes outside the set positive and negative thresholds. This prevents any false detection when the waveform is slowly transitioning between peaks.

This method is illustrated in **Figure 4**. For an ADC-based peak detector, this method provides an additional bonus because the ADC does not need to sample the waveform while it is inside the window – which reduces the load on the ADC and CPU.

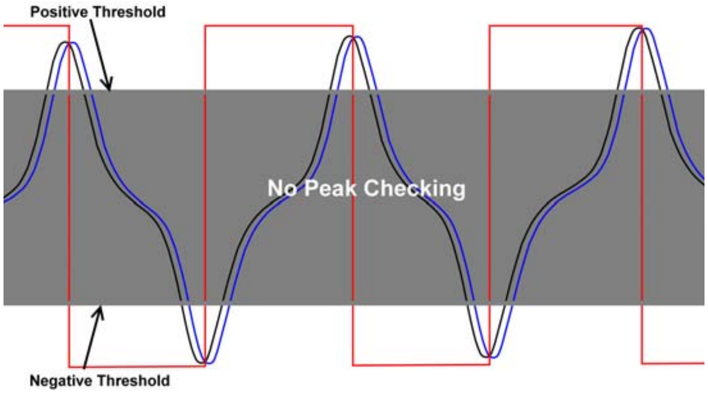

Figure 4: Windowed comparator
(Click on image to enlarge)

Conclusion
A SoC can be a good option for implementing the magnetic card reading methods and techniques discussed in this article if it has all the required resources to implement any of these solutions on a single chip with very few external components. **Table 1** summarizes a range of available resources and the function each resource can fulfill in implementing a multi-channel magnetic card reader that provides accurate performance across a variety of different environments and card swipe speeds.

Resource	Function
Op-Amp	4 built-in, used as initial gain stage
PGA	4 built-in, 1x to 50x gain used for AGC
ADC	2 SAR (1 Msps each @ 12-bits), able to directly sample multiple channels
DAC	4 current or voltage DAC's. Useful for reference generation for window comparators, or waveform recreation in sample and track peak detection method
Comparator	4 low offset comparators with optional 10 mV hysteresis and clocked output. 8 additional low-precision comparators available for up to 4 window comparators.
Sample & Hold	4 clocked sample and hold circuits (if not using PGA)
CPU	ARM Cortex M3, 80 MHz

Table 1: This table shows a range of available resources in SoC devices, in this case the PSoC 5 from Cypress, and the functions each resource can serve in implementing a multi-channel magnetic card reader.
(Click on image to enlarge)

About the author
Dan Sweet is a PSoC Applications Engineer at Cypress Semiconductor Corp. He graduated from Western Washington University with a BS in Electrical Engineering Technology.