

Oregon
Research
Electronics



Application Note

AL100 Sample Errors and Error Correction



31677 N. Lake Creek Drive, Tangent, OR 97389 USA
+1-541-928-7869 ORElectronics@comcast.net

Copyright 2016, Oregon Research Electronics

July 4, 2016

Application Note

AL100 Sample Rate Errors and Error Correction

INTRODUCTION: This application note discusses the accuracy of the sample rate, some of the consequences, and methods for dealing with sample rate errors.

Error Amplitudes

Before discussing the sources of the various timing variances, let's consider what the sizes of sample rate errors mean in real life.

The accuracy of a real-time clock is often quoted in "parts per million" (ppm) - that is 1 part in $10^6 = 1E6$. Since there are 86400 seconds in one day, one ppm error in the RTC tick rate (frequency) is equivalent to an error of .086 seconds per day. Over a month, this amounts to about 2.5 seconds. Then, 10ppm is then equivalent to 25 seconds a month and 50ppm is equivalent to 125 seconds (just over 2 minutes) per month.

At a sample rate of 10Hz, there are 865400 samples in one day. An error of 1 ppm translates, here, to 0.864 samples per day, too fast or too slow. That is, a sample rate that is 10ppm fast will have about 8.6 extra samples each day. 1 part per thousand (ppt, or 0.1percent) then results in 860 too few or too many samples per day.

AL100 Sample Rates

The AL100 internally samples at a fixed rate of 100Hz (1 sample every 10ms). In this note, the internal sample rate will be called "Raw Sample Rate" to distinguish it from the sample rate that is specified by the user, which is raw rate divided by an integer in the range of 4 to 255.

The Raw Sample Rate is not exact. The accelerometer's manufacturer has no specification on the accuracy of the sample rate. Errors of a few percent plus or minus, have been seen relative to the real-time clock in several units. It is likely that some units may exhibit errors greater than this.

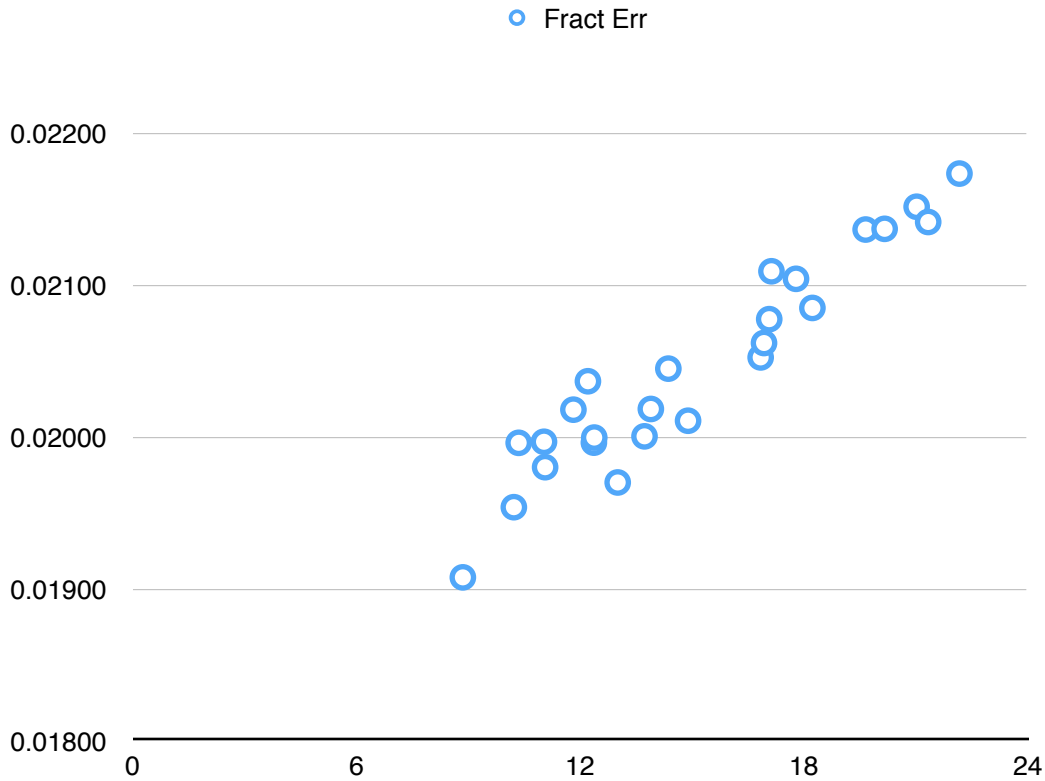
The observed error is not constant. The following table shows the error in the sample rate (relative to the RTC) over a 24 day period for one AL100. It shows the excess number of

Date/Time	First Sample	Last Sample	# of Samples	Expected #	Difference	Fractional Err	AvgTemp
2016-04-13	1	880479	880479	864000	16479	0.01907	8.85
2016-04-14	880480	1761726	881247	864000	17247	0.01996	12.37
2016-04-15	1761727	2643165	881439	864000	17439	0.02018	13.90
2016-04-16	2643166	3525346	882181	864000	18181	0.02104	17.80
2016-04-17	3525347	4407938	882592	864000	18592	0.02152	21.04
2016-04-18	4407939	5290719	882781	864000	18781	0.02174	22.19
2016-04-19	5290720	6173181	882462	864000	18462	0.02137	19.67
2016-04-20	6173182	7055132	881951	864000	17951	0.02078	17.08
2016-04-21	7055133	7936801	881669	864000	17669	0.02045	14.37
2016-04-22	7936802	8818077	881276	864000	17276	0.02000	12.38
2016-04-23	8818078	9699323	881246	864000	17246	0.01996	10.35
2016-04-24	9699324	10580430	881107	864000	17107	0.01980	11.06
2016-04-25	10580431	11461309	880879	864000	16879	0.01954	10.22
2016-04-26	11461310	12342561	881252	864000	17252	0.01997	11.03
2016-04-27	12342562	13224158	881597	864000	17597	0.02037	12.21
2016-04-28	13224159	14105593	881435	864000	17435	0.02018	11.82
2016-04-29	14105594	14986613	881020	864000	17020	0.01970	13.01
2016-04-30	14986614	15868837	882224	864000	18224	0.02109	17.14
2016-05-01	15868838	16751303	882466	864000	18466	0.02137	20.18
2016-05-02	16751304	17633036	881733	864000	17733	0.02052	16.85
2016-05-03	17633037	18514319	881283	864000	17283	0.02000	13.73
2016-05-04	18514320	19395691	881372	864000	17372	0.02011	14.90
2016-05-05	19395692	20277506	881815	864000	17815	0.02062	16.94
2016-05-06	20277507	21160011	882505	864000	18505	0.02142	21.35
2016-05-07	21160012	22042026	882015	864000	18015	0.02085	18.24

samples compared to the expected number over each 24 hour day. The fractional error is relative to the expected 864000 samples. The average temperature for each day is also shown.

Table 1 - Sample Rate Errors & Variation for AL100 sn 1050

It appears that this variation is somewhat correlated with the mean temperature for each 24



hour period. Table 2 shows daily fractional error plotted against daily mean temperature.

Table 2 - Sample Rate Error vs Temperature for AL100 sn 1050

In fact, a linear least-squares fit shows the relationship

$$\text{Fractional Error} = 0.0001702 * \text{Temperature} + 0.01788 \quad \text{EQN-1}$$

It is likely that other units will have different fit coefficients.

Because the changes are relatively large (around +/- 0.15%), the origin is not likely to be the RTC, since its maximum error should be in the 10s of ppm and observed error variation is around 100 times larger. This leaves the accelerometer, itself, as the likely source. And, this, in turn, means that the RTC can be used as a reference for sample rate timing.

Implications of Sample Rate Inaccuracies

There are a number of possible implications of the inaccuracy (and the variation) of the sample rate. Some of these implications are not very obvious.

- A. Sway Frequency: If you have N samples (where N is an integer power of 2) taken at a rate of F (samples per second) then an FFT gives you a spectrum with bin size of F/N. As a result, if the actual sample frequency varies, then the location of spectrum peaks will vary by exactly in proportion. Thus, if you are looking for very small changes in frequency, then the actual sample rate must be taken into account.
- B. Time Reckoning: If you want to view short sections of a daily data record, it is convenient to simply count samples to determine the start and end of the section. But, if the sample rate is lower than expected, there will be fewer than the expected samples in a given time interval. And, if the sample rate is higher than expected, there will be more than the expected samples in a given time interval.

Dealing With Sample Rate Inaccuracies

One possible solution for both problems is to rely on time stamps rather than sample rate.

Hour intervals are relatively convenient for an FFT. A 10Hz sample rate averaged down to 2.5Hz gives (about) $2.5 \times 60 \times 60 = 9000$ samples in an hour. 8192 samples meets the FFT criterion of a block of $2^{**}N$ samples. Using the original nominal sample rate of 10Hz gives 36000 samples in 720 5-second time stamps. Assuming the use of 10Hz samples over an hour, the sample rate can be determined to 1 part in 36000 or .0002777 (about 0.028%). This is about 100 times better than the error shown in Tab;e 1.

So, let's determine a correction factor based on the user sample rate, for 1 hour blocks of samples. The user sample rate is the one that you set in the AL100's configurations. The user sample rate is used because it is the highest frequency available within the data and results in the best resolution. If F_u is this sample rate and N is the number of samples counted in one hour, based on timestamps, then the correction factor, C, is given by:

$$C = N / F_u \times 3600 \quad \text{EQN-2}$$

Then, suppose that you determine an FFT from this same data at F_f , where F_f is the FFT input sample rate. F_f will be less than, or the same as, F_u . Suppose that the sample block on which the FFT is executed contains M samples (M might not contain the full hour of data). Then the output bin size, F_b , will be

$$F_b = C * F_f / M \quad \text{EQN-3}$$

For time reckoning, it is important to use the time stamps (and the header time) rather than to count samples. If necessary, samples can be used to interpolate between the time stamps.

A Reminder for Programmers

Counting timestamps and sample events needs a little thought. For example, If you want a time interval of an hour based on 5 second timestamps and the first one is indexed as zero, then the last will have an index of 720 such that there are 721 timestamps.

Counting sample events to determine frequency is subject to slightly different logic. If you have an interval, T , and there are N events within that time interval, then the nominal frequency is N/T . There is a possible error, however, of up to one period at each end of the interval. That is, the first sample may occur up to 99.999...% of a sample period after the beginning of the interval and the last sample may occur 99.999...% of a sample period before the end of the interval. Thus, the observed sample interval can vary ± 1 count over a given interval, just from the counting process.

Conclusion

It is now apparent that the AL100 sample rates may not be accurate enough for precision tree sway determination without correction. Time stamps can be used fairly easily to correct sample rates in the sense that the output spectrum from an FFT can be rescaled with a correction factor. The correction factor can be easily determined by counting samples between timestamps.

Further, time stamps should be used for time reckoning rather than sample counts.