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# Application Note

# AL100 Sample Errors and Error Correction

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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, lets 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.

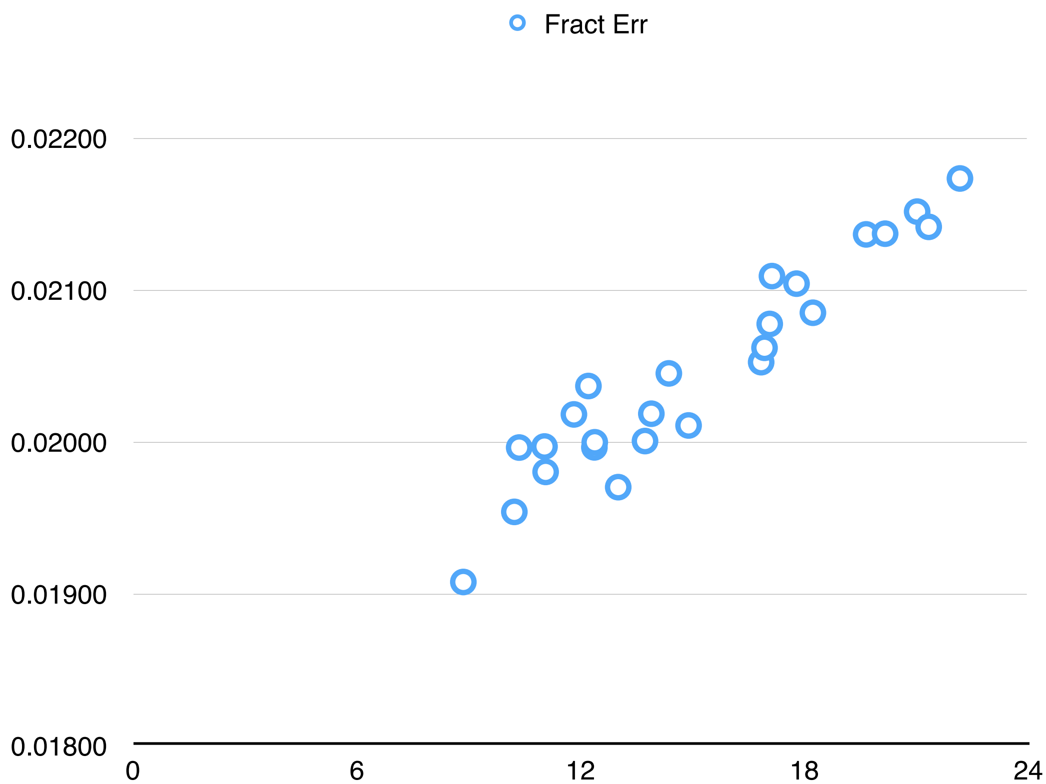
The observed error is not constant. The following table shows the error in the sample rate (relative to the RTC) over a 24 day period for one AL100. It shows the excess number of

| 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, is 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*60*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 houir, 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, lets 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 the best resolution. If Fu 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:

$$C = N / Fu*3600 \quad \text{EQN-2}$$

Then, suppose that you determine an FFT from this same data at Ff, where Ff is the FFT input sample rate. Ff will be less than, or the same as, Fu. 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, Fb, will be

$$Fb = C * Ff/M \quad \text{EQN-3}$$

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.