Calibration Methods for Silego GreenCLKs

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Background

Most Notebooks and Desktops have a ±25 ppm or 2 sec/day at 25°C over 5 years system error allowance for the Real Time Clock (RTC). However, actual end-user usage of the computer and the surrounding environment and age can greatly compromise the performance of the internal RTC accuracy.

RTC accuracy is determined by a 32.768 kHz tuning fork crystal in most Notebook and Desktop PCs. The crystal ages at ±3 ppm or 0.25 secs/day/year. So in order to achieve a ±25 ppm or 2 sec/day spec at 25°C over 5 years a ±10 ppm 32.768 kHz crystal is often specified.

It only takes a quick search of the internet and the PC support forums to see that many customers are quite unhappy with the existing RTC 32.768 kHz tuning fork solution. Many complaints are based on the clock being inaccurate because 25°C does not accurately represent the notebook or desktop in its environment. A gamer for example, will often run their PC very hot, a businessman in Canada may store their laptop in the trunk of the car in the middle of winter, a PC designer may place the crystal too close to a hot processor. During these extreme conditions the time accuracy of the crystal only goes one direction – it slows down and the RTC loses time.

In order to compensate for these errors many manufacturers have built in automatic adjustment software to correct the clock when the computer has access to the internet and this capability is built directly into the Windows Operating System. Because the internet is based on atomic clocks with incredible accuracy the PC RTC time can be corrected periodically.

The GreenCLK product from Silego is able to replace these 32.768kHz crystals saving money, PCB space, component count, and improve over-temperature accuracy.

The GreenCLK product is a very consistent time accurate product which is much better than 32.768 kHz tuning fork crystals. However, GreenCLK technology does come with an offset that is 3x or 4x higher and therefore, the PC hardware and firmware designers need to build a very simple one-time in-system adjustment (OTA mode) to create a Real Time Clock with 2x better accuracy at room temperature and 8x to 10x better over temperature. The following sections describe in detail what the expected time performance of GreenCLK RTC system should be with the no-adjustment, one time adjustment, and dynamic adjustment.

Introduction

GreenCLK technology is a silicon circuit which allows a 32.768 kHz clock to be produced with good accuracy and low power. The technology avoids the poor over-temperature and aging characteristics of 32.768kHz tuning fork crystals, by leveraging high accuracy sources such as AT-cut crystals and TCXO's to generate the 32.768kHz clock. For example, it can replace the 32.768 kHz crystals in the notebook computer by using the high-accuracy (typically 25MHz) crystal already present in such systems. High accuracy frequency sources can consume significant power, but GreenCLK technology can eliminate this issue with an ultra-low power Hibernate Mode which only turns on the frequency source periodically at very low duty cycle while still accomplishing internal calibration of the 32.768kHz clock. So even if a high power (mA) MHz TCXO is used, the effective average overall current consumption can be reduced to sub-uA levels. Note that a 32.768KHz TCXO, though it initially compensates for temperature variation, still has a 32.768kHz tuning fork crystal at it's core with their inherent aging issues. GreenCLK being based on low-aging sources thus allows for calibration methods to be effective.

The benefits of GreenCLK are:

- Smaller size than a comparable standard 32.768 kHz crystal.
- Over-temperature time accuracy is much better.
- Over age time accuracy is better (1 ppm/year vs. 3 ppm/year).

(This is summarized below in Table 1.)

- Integrated Solution allows up to 3 crystals to be removed from the notebook or desktop computer, saving money and component count.
- Some versions also include a simple ML coin cell charger and the equivalent of a BAT54 diode switch for power control from the coin cell or always on 3.3V power supply.
- Highly consistent time accuracy allows for easy calibration methods (OTA and DAT).

	Calibration Method	Time Accuracy at 25°C in sec/day	Frequency Accuracy at 25°C in ppm	Time Accuracy from -10 to 40°C	Frequency Accuracy from -10 to 40°C	Time Accuracy at 25°C after 5 years	Frequency Accuracy at 25°C after 5 years
32.768 kHz Quartz Crystal (±10 ppm)	None	±1	±10	-6	-74	±2	-5 to -25
25 MHz Quartz Crystal (±10 ppm) + GreenCLK	None	±3.3	±40	±4.1	±50	±4	+37 to -47
26 MHz TCXO (±2 ppm) + GreenCLK	None	±1.3	±15	±2.2	±25	±2	±16
25 MHz Quartz Crystal or TCXO + GreenCLK	OTA (One Time Adjustment)	±0.5	±6	±0.75	±9	-1	1 to -11
25 MHz Quartz Crystal or TCXO + GreenCLK	DAT (Dynamically Adjusted Time)	±0.25	±3	±0.25	±3	±0.25	±3

Table 1. Quick comparison table

The negatives of GreenCLK are:

- The power consumption is about 2.0 mA higher (5 mA vs. 3mA) for the complete Intel-based RTC solution.
- Room temperature performance is equivalent to a ±20 ppm 32.768 kHz crystal and worse than a ±10 ppm 32.768 kHz crystal – but a GreenCLK timing system can easily be calibrated to much better performance.

There are three methods of using GreenCLK technology to achieve the most accurate time keeping. These methods are called: Basic Time Keeping (BTK); One Time Adjusted time keeping (OTA); and Dynamically Adjusted Time keeping (DAT).

Using these methods the following frequency ppm performance is possible, assuming a ±10 ppm 25 MHz crystal as the input to the GreenCLK. (see Tables 2, 3, Fig 1.)

Note that AT-cut MHz crystal accuracy from -10 to 70 C doesn't degrade compared to -10 to 40 C due to their "S-curve" temperature characteristic, unlike 32.768 kHz tuning fork crystals which degrade rapidly at temperature extremes. The difference would be even more pronounced at more extreme temperature ranges such as Industrial or Military.

Basic Time Keeping

Basic Time Keeping mode or BTK is the simplest configuration mode and results in performance that engineers will quickly experience by hooking up a 25 MHz crystal correctly and measuring the time accuracy over 1 day at 25°C with no further calibration or adjustment. Please note: The GreenCLK IC derives its accuracy from the 25 MHz AT-CUT quartz crystal. It cannot be MORE accurate than this crystal in the BTK mode.

Method	Temperature	Frequency error in ppm	Time error in sec/day
Basic Time Keeping (BTK)	25°C	±40 ppm	~±3.3 sec/day
One Time Adjusted (OTA)	25°C	±6 ppm	~±0.5 sec/day
Dynamically Adjusted Time (DAT)	25°C	±3 ppm	~±0.25 sec/day

Table 2. Calibration methods at 25C

Method	Temperature	Frequency error in ppm	Time error in sec/day
Basic Time Keeping (BTK)	-10 to 70°C	±50 ppm	~±4.1sec/day
One Time Adjusted (OTA)	-10 to 70°C	±9 ppm	~±0.75 sec/day
Dynamically Adjusted Time (DAT)	-10 to 70°C	±3 ppm	~±0.25 sec/day

Table 3. Calibration methods over extended temperature range

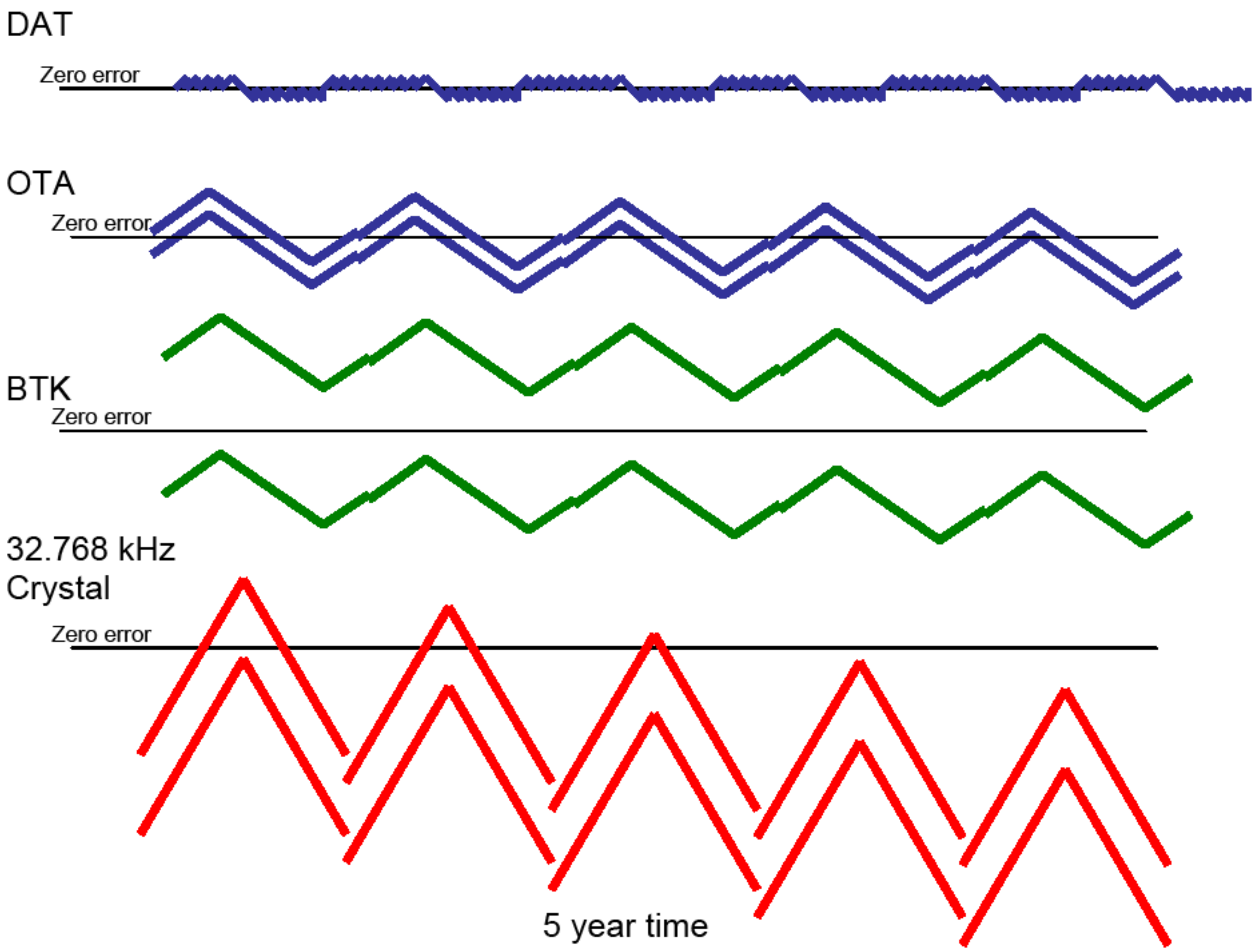


Figure 1. Time error graph up to 5 years

If a ±50 ppm 25 MHz crystal is used, then the RTC clock will not be better than ±50 ppm unless the One Time Adjusted (OTA) or Dynamically Adjusted Time (DAT) techniques are employed.

A notebook computer has 3 different power modes for the real time clock function. The three modes are: VBAT or coin cell powered RTC, +V3.3A always on powered RTC, and +3.3V Active Mode power RTC.

Over temperature performance in the 3 different power modes for the BTK mode are shown in Tables 4,5. To achieve the numbers listed in these tables, the following components and techniques should be followed:

- A 25 MHz quartz crystal specified with 8 or 12 pF load crystals should be used.

Power Mode for RTC	Temp	Frequency error in ppm (assumes ±10 ppm MHz crystal source)	Time error in sec/day	When does this power mode occur
VBAT or Coin cell	25°C	±48 ppm	~4 sec/day	When Notebook main battery is fully discharged or missing and computer is OFF
+V3.3A Always On	25°C	±40 ppm	~3.3 sec/day	When Notebook is sleeping, hibernating, or OFF but with charged main battery
+3.3V Active Mode	25°C	±40 ppm	~3.3 sec/day	When Notebook is operating

Table 4. BTK mode- various notebook power modes at 25C

Power Mode for RTC	Temp	Frequency error in ppm (assumes ±10 ppm MHz crystal source)	Time error in sec/day	When does this power mode occur
VBAT or Coin cell	-10°C to 70°C	±60 ppm	~5 sec/day	When Notebook main battery is fully discharged or missing and computer is OFF
+3.3V Always On	-10°C to 70°C	±50 ppm	~4.1 sec/day	When Notebook is sleeping, hibernating, or OFF but with charged on main battery
+3.3V Active Mode	-10°C to 70°C	±50 ppm	~4.1 sec/day	Notebook is operating

Table 5. BTK mode- various notebook power modes over extended temperature range

- The crystal load capacitors should have a tolerance of ±5%.
- The 1kΩ safety resistor in series with the coin cell should be set to 301Ω.
- A 22μF capacitor should be connected to the 301Ω to ground.
- Measure the time accuracy for one day.

One Time Adjusted (OTA) Time Keeping

Most of the time, error in a GreenCLK timing system is offset error that is built into the system and does not change much with manufacturing processes, temperature, or supply voltages. Thus it is quite simple to adjust for much better accuracy. A very simple technique creates a notebook timing system that is much more accurate as compared to today's 32.768 kHz crystal based systems.

The technique is to build into firmware the ability to measure the internet time when the computer is turned on and then about 1 week later when the computer is turned on again measure the time. Internet time is based on atomic clocks and is very accurate and excellent timing source to synchronize with. After determining the total time error for this period and calculating for the seconds/day of error, a continuous adjustment to the time can be made every minute or hour to maintain a clock with excellent accuracy. The time error after one week will be a very good representation of the total error of the MHz crystal offset + GreenCLK offset.

Consistent time performance of (±0.25 sec/day) is a key feature of GreenCLK – this allows for calibration techniques to be used with good success.

Standard tuning fork 32.768 kHz crystals change their frequency and thus their time accuracy significantly over temperature, voltage, manufacturing process variation, and, age and are therefore more difficult to calibrate post-manufacturing.

Power Mode for RTC	Temp	Frequency error in ppm (assumes ±10 ppm MHz crystal source)	Time error in sec/day	When does this power mode occur
VBAT or Coin cell, +V3.3A Always On, and +3.3V Active Mode	25°C	± 6 ppm (measured over 1 month)	~0.5 sec/day	Standard use condition
VBAT or Coin cell, +V3.3A Always On, and +3.3V Active Mode	-10°C to 70°C	±9 ppm (measured over 1 month)	~0.75 sec/day	Outdoor computers, automotive, or extreme CPU users

Table 6. Enhanced accuracy using OTA mode

Because the time error adjustment period will be one week, it is a reasonable assumption that the typical usage of the end user will be represented and thus time error offset that is a result of different use conditions will also be cancelled out. For example, a computer frequently used for graphics intense gaming will run much hotter than a computer used for word processing. **It is NOT recommended to use a time error measurement period shorter than 1 week**

Dynamically Adjusted Time (DAT) Keeping

As stated in the OTA section: most of the time error in a GreenCLK timing system is offset error that is built into the system and does not change much with manufacturing processes, temperature, or supply voltages.

However, there are a few time error sources that can be removed by re-running the OTA mode once per week and then averaging the last 4 measurement over the period of a month through the seasons of the year and the life of the system. If the system is not turned on in over a week, then re-run the OTA when possible but only average the results that occurred in whatever is close to a one month period.

For example, MHz crystals age nearly linearly at a rate of -1 ppm per year, after 10 years there will be a -1 sec/day error not present when the computer was manufactured.

Keep in mind, GreenCLK technology aging error is 3x lower than a standard 32.768 kHz tuning fork crystal which is -3ppm/year or nearly -2.5 seconds/day of un-calibrated error after 10 years.

Please compare BTK and 32.768 kHz crystal charts in Table 1, and notice how the 32.768 kHz crystal's ppm error graphs shift down dramatically in ten years' time (up to five years shown in Fig 1.).

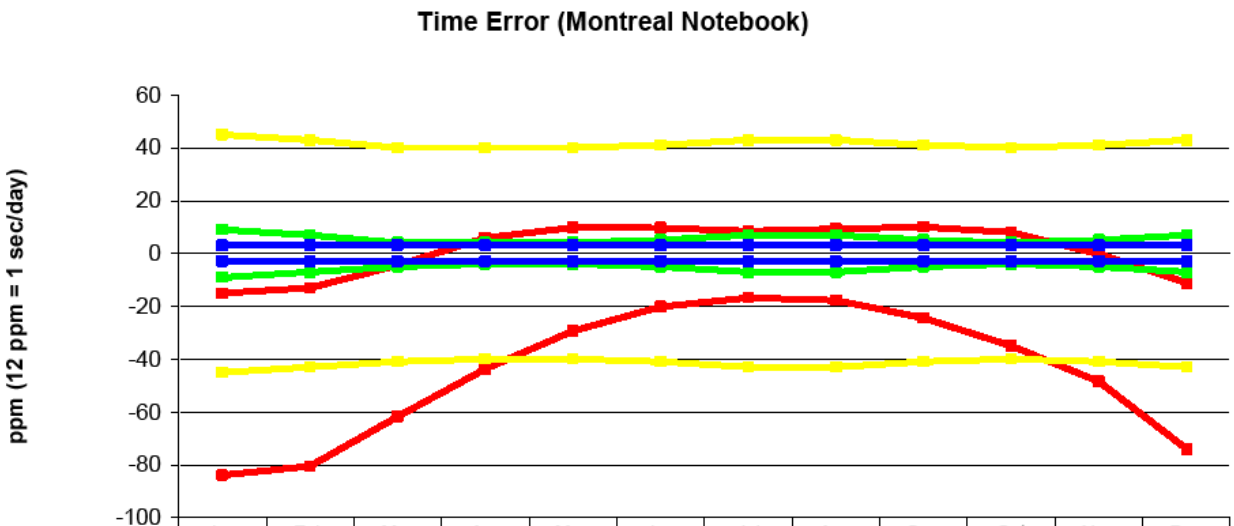
Power mode for RTC	Temp	Frequency error in ppm (assumes ±10 ppm MHz crystal source)	Time error in sec/day	When does this power mode occur
VBAT or Coin cell, +V3.3A Always On, and +3.3V Active Mode	25°C	± 3 ppm (measured over 1 month)	~0.25 sec/day	Standard use condition
VBAT or Coin cell, +V3.3A Always On, and +3.3V Active Mode	-10°C to 70°C	±3 ppm (measured over 1 month)	~0.25 sec/day	Outdoor computers, automotive, or extreme CPU users

Table 7. Enhanced accuracy using DAT mode

For example, notebook computers in the northern regions of North America will experience extreme temperature variation in winter and summer periods. Temperatures as low as -20°C and as hot as 45°C will regularly be experienced by a notebook computer in the trunk of a car in Chicago. A -20°C temperature will result in up to about ±1 sec/day of additional error for GreenCLK vs. -10 seconds per day for a standard 32.768 kHz crystal.

By using the DAT technique of re-running the OTA mode and averaging, a computer user can experience excellent time accuracy through the most extreme seasonal temperatures.

Fig 2. shows a typical time error graph for a notebook exposed to the Montreal, Canada climate comparing the standard 32.768kHz crystal with the three different GreenCLK calibration methods



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
32k Xtal H	-15	-13	-4	6	10	10	9	9	10	8	0	-11
32k Xtal L	-84	-81	-62	-44	-29	-20	-17	-18	-24	-35	-48	-74
BTK H	45	43	40	40	40	41	43	43	41	40	41	43
BTK L	-45	-43	-41	-40	-40	-41	-43	-43	-41	-40	-41	-43
OTA H	9	7	4	4	4	5	7	7	5	4	5	7
OTA L	-9	-7	-5	-4	-4	-5	-7	-7	-5	-4	-5	-7
DAT H	3	3	3	3	3	3	3	3	3	3	3	3
DAT L	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3

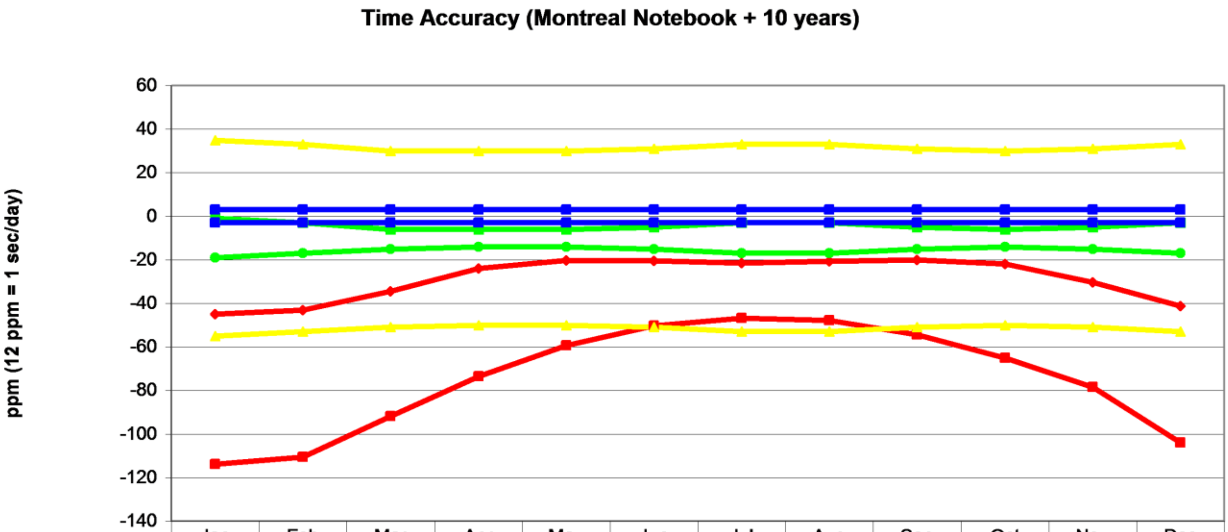
Months

Figure 2. Time error graph – New notebook

Fig 3. Shows a typical time error graph for a notebook exposed to the Montreal, Canada climate after 10 years comparing the standard 32.768 kHz crystal with the three different GreenCLK calibration methods after 10 years. Please note: In the worst case condition, the 32.768 kHz crystal is off by nearly 10 secs/day in the winter time in Montreal.

Conclusion

It has been shown that the GreenCLK can utilize the performance advantages of MHz crystals, providing a more accurate and long term stable timekeeping compared to standard 32kHz crystal implementations. The level of accuracy is determined by the calibration method used.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
32k Xtal H	-45	-43	-34	-24	-20	-20	-21	-21	-20	-22	-30	-41
32k Xtal L	-114	-111	-92	-74	-59	-50	-47	-48	-54	-65	-78	-104
BTK H	35	33	30	30	30	31	33	33	31	30	31	33
BTK L	-55	-53	-51	-50	-50	-51	-53	-53	-51	-50	-51	-53
OTA H	-1	-3	-6	-6	-6	-5	-3	-3	-5	-6	-5	-3
OTA L	-19	-17	-15	-14	-14	-15	-17	-17	-15	-14	-15	-17
DAT H	3	3	3	3	3	3	3	3	3	3	3	3
DAT L	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3

Months

Figure 3. Time error graph – after 10Yrs

About the Author

Name: John McDonald

Background: John McDonald came to Silego from SiTime ('05 – '08), a MEMS resonator start up. As VP of Sales and Marketing, the SiTime team introduced the world's first and only production MEMS oscillators, achieved numerous design wins shipping 100's K of units in the first production quarter. Prior to SiTime, John was working for Cypress MicroSystems (CMS), a Cypress Semiconductor funded startup and makers of the popular PSoC microcontroller family. As VP of Marketing ('01 to '05), he led a great worldwide marketing and applications team that grew the PSoC product family to be the fast growing and high margin success it is today. Prior to CMS, Mr. McDonald worked for Cypress Semiconductor and was part of the general purpose and programmable clock marketing group ('98 - '01) during a period in which non acquisition sales grew by more than 5x of which more than 50% was Japan designed in revenue.

Mr. McDonald has also worked for Analog Devices in the Precision Op Amp group and as an advanced analog design engineer for 6 years in Washington State. John has his BSEE from the University of Washington, and has authored numerous technical articles.

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A	John McDonald	12/04/2014	New application note

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