100G Single-Battery ERT® Modules: Achieving a 20-Year Battery Life

Fixed Network AMI Solutions

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INTRODUCTION

For natural gas and combination utilities deploying automated meter reading (AMR) or advanced metering infrastructure (AMI) technology, battery longevity and frequency of required battery change-outs in radio frequency (RF)-based endpoints can make a dramatic difference in the cost of system deployment and operation.

Given these variables, the difference between having to do multiple battery change-outs over a 20-year product life is nothing short of dramatic. Add in the customer inconvenience and the implications of a battery change-out become clear. After all, the purpose of AMR and AMI is to eliminate the need to visit the meter.

This white paper is meant to address the battery life of Itron's 100G, 100G DL and 100G DLN, and 100G DLS ERT® modules. It will provide a high-level technical overview of battery life determination for the module predecessor, the 100G Gas ERT. It serves to provide technical insight in determining allowable current levels for 20-year operation and variances between the first release of the 100G which contained two cells, and the subsequent release of the 100G DL, 100G DLN, and 100G DLS which contain one cell. It will speak to several major and minor design improvements in the 100G DL, 100G DLN, and 100G DLS that make a one-cell solution realizable while maintaining a 20-year battery life.

Itron will be implementing a 100G series battery field monitoring program. Customers can use data presented in this white paper along with future field data to manage their AMR and AMI systems more cost-effectively, and time the change-outs of their modules.

ABOUT 100G DL, 100G DLN, AND 100G DLS ERT MODULES

The 100G DL, 100G DLN, and 100G DLS automatically store 40 days of hourly data on the hour. Mathematically that is 960 intervals (40 days x 24 hours/day), with the oldest interval dropping off as a new interval is collected. As with the 100G, the 100G DL, 100G DLN, and 100G DLS are equipped with programmable output power and can be optimized for handheld, mobile or fixed network reading all without the need for a license from the Federal Communications Commission.

Used in conjunction with mobile reading, the 100G DL, 100G DLN, and 100G DLS module provides functionality very near that of a fixed network. The module enables move in and move out functionality to minimize off cycle reads reducing the cost of special reads and/or truck rolls. The daily data can be used to settle customer service and billing disputes. For monthly gas balancing, the module allows utilities to assess penalties for transportation customers and meet the accountability requirements set forth by Sarbanes Oxley. The hourly data can also be used to facilitate load studies and projections. When the 100G DL, 100G DLN, or 100GDLN is read by Itron's new Fixed Network AMI solution, benefits such as remote disconnect, time synchronized interval data, and time-based billing can now also be realized.

The 100G DL, 100G DLN, and 100G DLS build upon the field-proven design of the 40G, 40GB and 100G Gas ERT modules to deliver an industry leading 99.999 percent read accuracy rate. Like the 100G module, the 100G DL module offers up to 250 milliwatts of output power, the 100G DLN and 100G DLS offer up to 500 milliwatts and can operate in a bubble-up mode. Regardless of data collection solution, the module offers a 20-year battery life to ensure low cost of ownership.

DETERMINING ALLOWABLE CURRENT LEVELS FOR 20-YEAR BATTERY LIFE

Itron uses a Li-$SOCl_2$ (lithium thionyl chloride) battery in 100G DL, 100G DLN, and 100G DLS ERT modules. An important characteristic of this battery is the flat voltage profile. The battery life is a function of the current seen by the battery. For this type of chemistry, self-discharge of the battery is also critical in determining its life.

Itron uses a twofold approach to determine battery life. The first being theoretical/lab experimental data and the second being field data.

The theoretical approach is based on models to simulate the failure mechanism. In a typical battery, the various failure mechanisms are as follows:

- Exhaustion of battery capacity, relative self-discharge and voltage drop due to the operating conditions
- Integrity of the mechanical can (i.e. battery packaging)

Battery life models based on battery chemistry are developed to simulate the above failure mechanisms. Itron also conducts accelerated lab tests to simulate the above failure modes. These experiments include discharge under various conditions as well as micro-calorimetry to determine the pertinent model parameters.

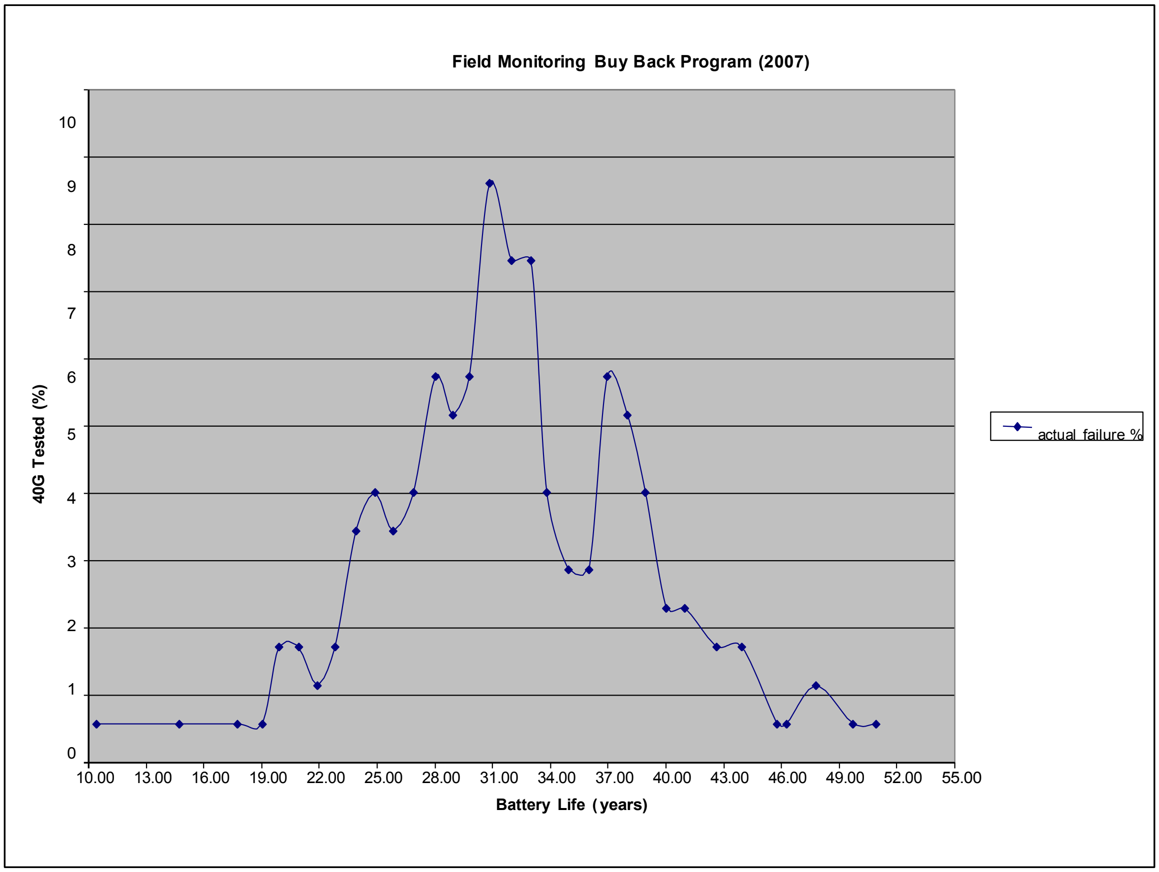
The second phase of this approach is to test the model with field data. Field research has proven to be a primary factor in revising estimates of average battery life for Itron. Rising above its competitors, Itron initiated a Battery Field Monitoring Program in 1997—over fifteen years ago. To date the program is specific to Itron's existing 40 Series Gas ERT module. To carry out testing, functional modules from four to six utilities that have been in the field for more than five years, are returned to Itron each year. Various tests are conducted in-house on the batteries including determination of the remaining battery capacities. This is all done to provide customers with as accurate information as possible in determining overall battery life.

The Battery Field Monitoring Program enables Itron to further check, verify and refine its battery life prediction model against "real-world" data. Itron customers can then use this data to manage their system cost-effectively and time the change-outs of their applicable ERT modules.

Based on the above modeling/lab tests approach and field data we have developed battery life equations as a function of the average current seen by the battery. The model takes into account such variables as product type, battery type, location and climate, and the type of data collection technology used.

As an example, the 2007-2008 field data from six utilities and 174 modules is shown in the Field Monitoring Buy Back Program (2007) chart on the following page.

The mean life is equal to 32.03 years (standard deviation = 10.69 years). Itron has similar curves from previous battery field monitoring programs for 2.75 Ah capacity batteries.



The initial less than 1% failures prior to year 15 are due to circuit problems in earlier 40G modules. This problem was resolved in post-July 1999 modules. Due to circuit substrate changes, this problem is nonexistent in 100G DL, 100G DLN, and 100G DLS ERT modules.

The battery used in modules from the field data above has a capacity of 2.75Ah, whereas the battery used in 100G DL, 100G DLN, and 100G DLS modules has a higher capacity of 3.65Ah. As shown in the calculations in the next paragraphs, for a 40 Series gas module, even with a 3.65 Ah battery, the model life estimation is equal to 26.04 years. The above field data with a lower capacity battery (2.75 Ah) show a mean life equal to 32.03 yrs. This data show Itron's model is overwhelmingly conservative.

BATTERY LIFE CALCULATIONS FOR 100G DL, 100G DLN, 100G DLS AND 100G ERT MODULES

The current used by the 100G DL, 100G DLN, and 100G DLS was designed and validated through a series of tests. Self-discharge has been accounted for in the calculations by using micro-calorimetry and field data.

CALCULATION OF BATTERY LIFE FOR 100G DL, 100G DLN, AND 100G DLS ERT MODULES

Failure mechanism (a) viz. capacity, self-discharge and voltage drop

Average current consumed by the circuit during standby as well as transmit =14.86 µA.

Self-discharge of battery (based on the tests mentioned above) = 7.31 µA

Average battery capacity = 3.65 Ah (single cell)

$$\text{Average life}^* = \frac{(3.65\ \text{Ah} \times 10^6)}{(14.86+7.31) \times 0.9} / 8760 = 20.86 \text{ years}$$

Failure mechanism (b) viz. integrity of the mechanical can

Based on accelerated tests done on the product (including the battery), battery life is at least 20 years.

(* Based on field data from 40 Series gas modules using the same battery chemistry, this estimation is conservative by at least 10%, which accounts for 0.9 in the above equation)

CALCULATION OF BATTERY LIFE FOR 100G ERT MODULES

Failure mechanism (a) viz. capacity, self-discharge and voltage drop

Average current consumed by the circuit during standby as well as transmit = 30 µA.

Self-discharge of the 2 pack battery (based on the tests mentioned above) = 14.62 µA

Average battery capacity = 7.3 Ah (2 pack)

$$\text{Average life}^* = \frac{(7.3\ \text{Ah} \times 10^6)}{(30+14.62) \times 0.9} / 8760 = 20.75 \text{ years}$$

Failure mechanism (b) viz. Integrity of the mechanical can

Based on accelerated tests done on the product (including the battery), life is at least 20 years.

(* Based on field data from 40 Series gas modules using the same battery chemistry, this estimation is conservative by at least 10%, which accounts for 0.9 in the above equation)

As an example of the comparison of the model and field data, estimations for 40G and the latest field data are listed here:

Calculation of battery life for 40 Series Gas ERTs used in Wake Up Mode

Failure mechanism (a) viz. capacity, self-discharge and voltage drop

Average current consumed by the circuit during standby as well as wake up (once a month) =10 µA.

Self-discharge of battery (based on the tests mentioned above) = µA Average battery capacity (at present) = 3.65 Ah

Average life = $(3.65 \text{ Ah X } 10^6) / 8760 = 26.04$ years

(10+6)

Failure mechanism (b) viz. Integrity of the mechanical can = 20 years

Based on accelerated tests done on the product (including the battery) life is at least 20 years.

Field Data for 40 Series Gas ERTs (2007-2008 Field Monitoring Program)

Sample Size: 174 ERTs

6 Utilities

2.75 Ah battery

Mean = 32.03 years

Standard deviation = 10.69 years

(Note the model predictions for 40G wake up units are for 3.65Ah battery and the field data are for 2.75Ah battery.) These data show that the model is quite conservative also for 2.75Ah battery in the field.

EFFICIENCY GAINS THAT ALLOW 20-YEAR BATTERY LIFE WITH ONE CELL

Getting 20 years of life out of a battery requires that the electrical circuit draw very low levels of electrical current. This means the circuitry does as little as possible as efficiently as possible between essential functions and sleep.

As with most new products, the period between new releases acts as time to refine and perfect the product. Itron took the time between the release of the initial 100G module and the release of the 100G DL and thereafter the releases of the 100G DLN and 100G DLS modules as an opportunity to optimize battery performance.

In the 100G ERT module, the circuits operate in current-consuming-modes too long and draw excess average current for a one-cell, 20-year solution. Consuming a higher average current required the initial 100G module to have a two-cell battery pack to maintain a 20-year battery life. Additionally, its radio frequency integrated circuit (RFIC) limitations forced tradeoffs that kept the design from achieving a single-cell battery existence. These limitations were to the point that there was no benefit in optimizing small details for improved efficiency since a one- cell design was not possible.

With a more efficient RFIC, as is used with the 100G DL, 100G DLN and 100G DLS, fewer tradeoffs were required and near single-battery performance was readily obtained. With a few additional small improvements, current consumption was reduced by slightly more than a factor of two and, as a result, a one-cell solution was realizable. In actuality, the battery-life is improved over that of the initial 100G ERT module. This is of ultimate benefit to customers as designing a more efficient product allows Itron to be more price competitive. There are three major design improvements and several small improvements in the 100G DL, 100G DLN, and 100G DLS that reduce average current. They follow in order of significance.

Limited isolation in the RFIC between On/Off Keying (OOK) modulation circuits and the internal power amplifier

Due to this internal coupling, the RFIC used in the original 100G ERT is not able to modulate the transmitted message. Instead, the power amp (PA), external to the RFIC, is modulated. As a result, the RFIC is active throughout the transmitted message which approximately doubles transmit current. In mobile mode (+10 dBm) this requires the PA to be active for transmit operation. The reason the RFIC cannot be modulated in the original 100G ERT is because the internal coupling causes pulling of the “on” bits, resulting in a spectrum that is not sufficiently clean. With 100G DL, 100G DLN, and 100GDLS, the RFIC (same for both series) performs the modulation and the device is off during the “off” bits of the transmitted message. In addition, the PA is not active when the endpoint is operated in mobile mode.

Time allotment for settling of the RFIC

The RFIC used in the 100G ERT module requires more time than that used in the 100G DL, 100G DLN, and 100G DLS ERT modules to prepare for transmit or receive functions. There is more delay required:

- from the point that the device is powered until it is reading for commands.
- for the crystal oscillator of the RFIC to stabilize
- for the phase-locked loop of the RFIC to settle on frequency.

All this means that the RFIC for the original 100G ERT module is powered longer, consuming more electrical current from the battery.

Receive current

The 100G ERT module consumes more current in receive mode.

Fixed Network Messages

The 100G DL supports “advanced” fixed network messages; specifically the network interval message (NIM) and the network consumption message (NCM). These messages contain more information that the standard 96-bit consumption message (SCM) and are intended for fixed network support. While the SCM is 96 bits, the fixed network messages are approximately 200 and 375 bits for the NCM and the NIM respectively. The fixed network messages transmit at the high power setting (+24 dBm or 250 mW). The occurrence of these messages is low enough that these longer messages at high power do not reduce battery life below the 20-year mark. Since the NIM and NCM messages bubble up less frequently, average current remains less than that of the average current of a 100G DL in mobile mode (+10 dBm every 15 seconds). A typical scenario may be a NCM transmission every 2 minutes with a +10 dBM SCM transmission one minute after, or a NIM transmission every 5 minutes with a +10 dBM SCM transmission each minute on the four minutes in between. Even at these rates the 100G DL will consume less average current than a unit programmed to mobile mode.

The 100G DLN and 100G DLS were further enhanced with a higher power higher data rate fixed network FM transmission that enabled the addition of a 500 mW fixed network mode that operates with the same duty cycle as the 100G DL for fixed network mode.

SUMMARY

At a time when utilities continually search for innovative ways to drive out costs, the 100G DL and specifically the latest models—the 100G DLN and 100G DLS—ERT modules provide a sensible pathway from handhelds to mobile to fixed network. The module brings value to customers with its increased output power—mobile AMR users can collect RF reads from a greater distance.

The 100G DL, 100G DLN, and 100G DLS ERT modules use Li-$SOCl_2$ technology for their power source/battery. These modules will operate for 20 years on a single 'A' cell (3.65Ah), while the 100G ERT module required two cells for a 20-year battery life. Many efficiency gains were made to accomplish this, most notably changing the RFIC. The technology inherent to the 100G DLN and 100G DLS ERT modules bring with them added messaging for fixed network support. When these messages are used, the endpoint will maintain a 20-year battery life.

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