Application Note:

Using the SX1280/SX1281 in Low Power Applications

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1. Introduction: The Drive for Low Power

The need for low power consumption is often driven by the requirement for an application to run from a battery for a long period of time, possibly without ever being replaced by the user. However, low power designs may be motivated by objectives beyond simple longevity.

A brief survey of lithium primary cells reveals that the capacity of a cell is proportional to its size, or more specifically volume, as illustrated below (some battery types were tested from two suppliers).

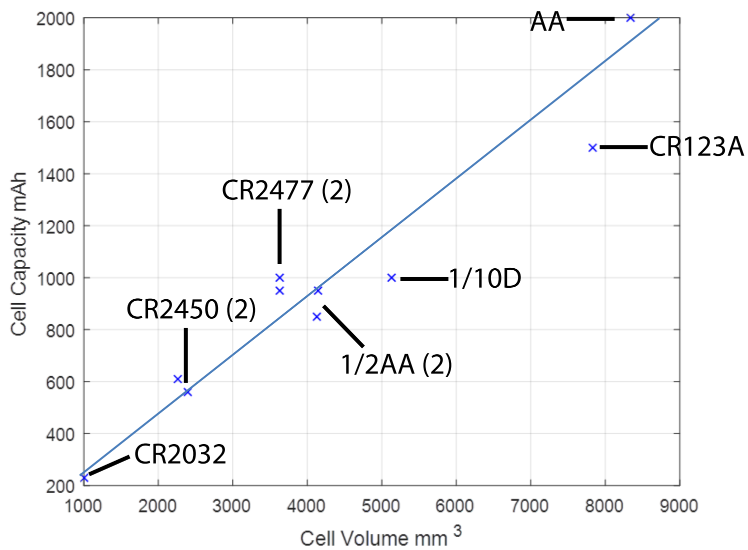

Figure 1: Cell Capacity versus Cell Volume for Different Lithium Primary Cells

In fact, the fixed specific energy and density of lithium manganese oxide (LiMn2O4) used in these batteries. With the exception of the CR123, the capacity of a cell is proportional to its cost:

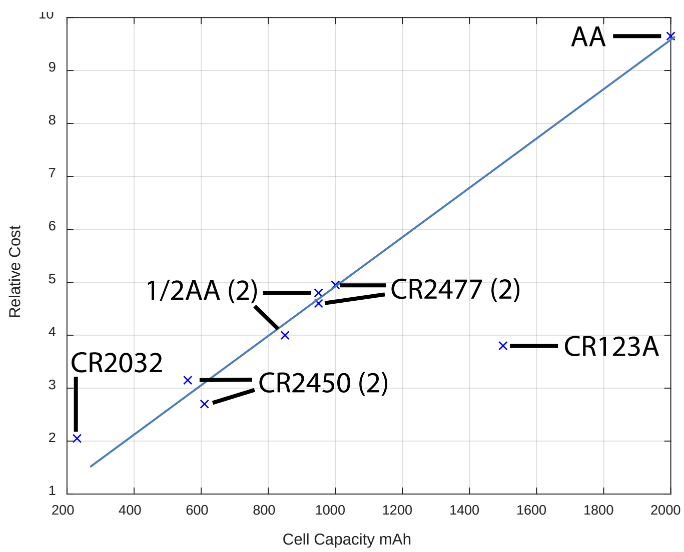

Figure 2: Relative Cost versus Cell Capacity for Different Lithium Primary Cells

So the motivation for low power comes, potentially not only from the need to increase battery life, but also from the potential to reduce both the cost and size of a given design.

2. Peak Current

For completeness in our brief survey, we also look at the peak current load that a battery is capable of supplying. Battery manufacturers typically stipulate a minimum resistive load that the battery is capable of supplying, this is equivalent to the peak current that the battery can deliver at the supply voltage (following Ohm's law). For our small survey of batteries, the minimum load, i.e. peak current, is unrelated to cost and so physical volume of the battery. Although there is no clear link between the peak current and battery size, it is an important design consideration that might exclude some battery types from your design.

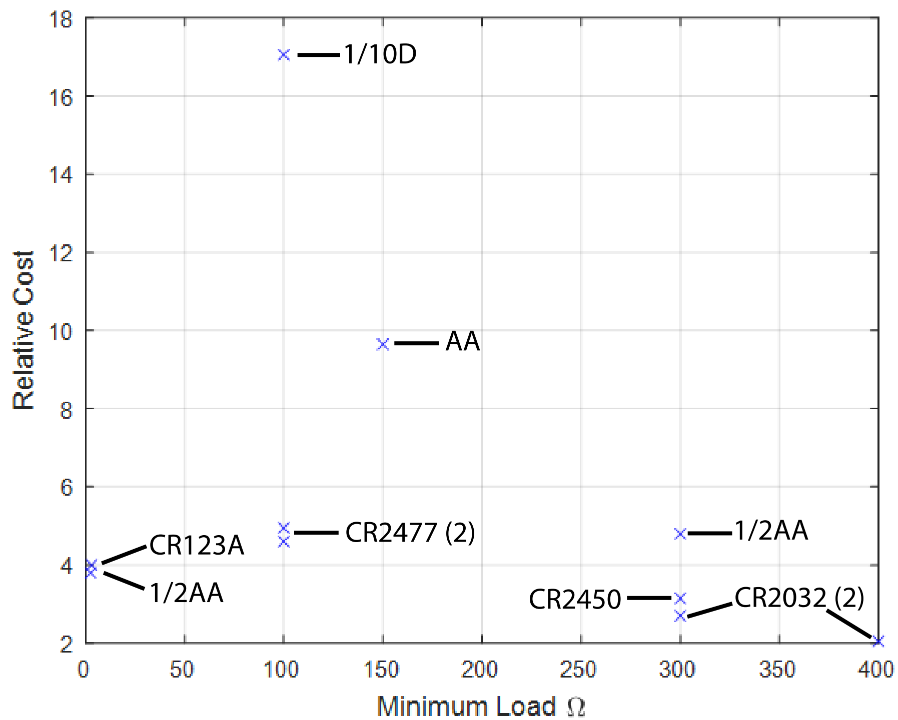

Figure 3. Minimum Load (Maximum Current) of Lithium Primary Cells as a Function of Cost

3. How to Design for Low Power?

Given the various benefits of low power design, how do we start the process of radio and battery selection in a wireless design? And what guidance should we use? There are three important considerations:

1. A part to select must have the lowest possible consumption in each mode of operation.
2. The amount of time spent in each of these modes also determines the charge consumed from the battery, we should seek to reduce the time spent in each mode, especially in the high current consumption modes
3. Any peaks in current consumption should be minimized, noting that the battery must be dimensioned to deliver them and have adequate charge capacity for the intended lifetime of the device.

The SX1280/SX1281 transceiver Is built with low power operation in mind and has the corresponding features to assist the designer in the pursuit of low power operation:

1. The SX1280/SX1281 features a DC-DC converter, which reduces the current consumption substantially in the highest consuming modes of operation, namely transmit and receive modes.
2. The SX1280/SX1281 is designed to automatically transition between modes of operation as quickly as possible. In addition to this, the designer has access to bitrates up to 2 Mbps, allowing for very low time-on-air to reduce the charge consumed from the battery[1].
3. Powering radio devices can lead to in-rush currents. An in-rush current consists of a transient current-peak which is higher than the steady-state consumption. The SX1280/SX1281 has built-in current limiters to ensure that the peak consumption never exceeds the peak transmitter consumption of 24 mA.

With this understanding, let's examine the overall consumption of an SX1280-based design. In this application note, we show how to calculate and measure the charge consumption of the SX1280/SX1281 for some example modem configurations.

[1] Although beyond the scope of this document, keep in mind that high data rates mean a reduced range, so the trade-off between data rate, energy consumption and long range is left at the designer's discretion.

4. Computing Charge Consumption

We can consider the cell, or battery of cells, as a chemical store of electrical charge. Battery capacities are often stated in ampere-hours [Ah]; here we'll use the equivalent unit of charge, coulombs [C]. The current I is defined as a flow of charge Q per unit of time t:

$$I = Q/t$$

Because a current of 1 ampere equals to a flow of a charge of 1 coulomb per second, the conversion from ampere-hour units of charge storage to coulombs of charge is trivial; there are 3600 seconds in one hour, so:

1 Ah = 3600 C

When it comes to evaluating the charge consumption of each use of the transceiver we simply need to know the current consumption associated with each phase of operation and its duration, the product of which is the charge consumed by that activity as shown below, where we'll use the subscript *mode* to show which radio operating mode we're talking about:

$$C_{mode} = t_{mode}\, I_{mode}$$

Ordinarily, the radio will periodically embark on some activity – such as wake from sleep and transmit a packet. To predict the lifetime of an application running from a given battery we first sum the total charge consumption, C_{cycle}, and duration, t_{cycle}, for one cycle of that periodic activity:

$$C_{cycle} = C_{mode1} + C_{mode2} + \ldots$$

$$t_{cycle} = t_{mode1} + t_{mode2} + \ldots$$

Armed with knowledge of the total charge consumption for the periodic operation of the transceiver, it is very simple to evaluate either the lifetime, $t_{lifetime}$, afforded by a specific battery or cell of capacity $C_{battery}$ based upon the number of times we can repeat our periodic activity:

$$t_{lifetime} = (C_{battery} / C_{cycle})\, t_{cycle}$$

Alternatively, we can specify the battery capacity required for a given battery lifetime:

$$C_{battery} = (t_{lifetime} / t_{cycle})\, C_{cycle}$$

Finally, it is important to note that the actual charge available from the battery over its lifetime depends upon the impact of peak currents, self-discharge currents and temperature on the battery, such highly detailed modelling is application-specific and is not within the scope of this application note. Certainly the most reliable way to determine the capacity is by measurement. For details on how to measure the capacity of a cell for your application see [1, 2].

5. SX1280/SX1281 in Low Power Applications

The SX1280/SX1281 transceiver features two regulators: a low drop-out regulator (LDO) and a DC-DC converter. The integrated DC-DC buck converter steps down an input voltage directly from the battery to a lower output voltage. A full description of buck converter operation is given in the SX280/SX1281 datasheet [3]. In the case of SX1280/SX1281 it's sufficient to know that the conversion process produces a current consumption reduction proportional to the ratio of the input and output voltages.

In the case of operation from a lithium battery, the converter reduces the input current consumption to almost half of the consumption in a given mode as it is regulating the internal output voltage to 1.5 V from the 3.0 V of the lithium battery voltage.

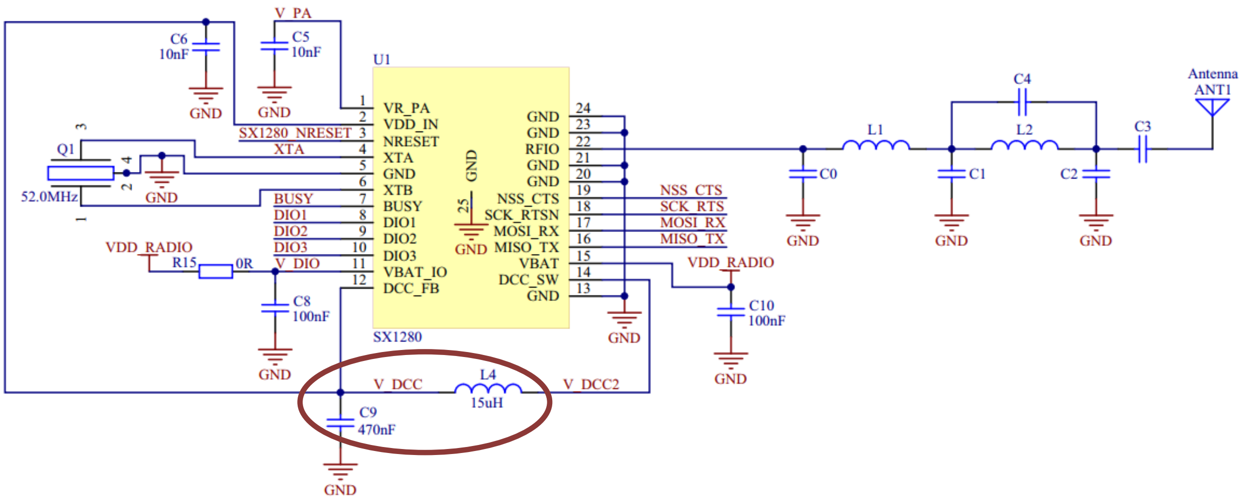

Figure 4: SX1280/SX1281 Application Design Schematic

The only cost of this reduced current consumption to the designer is the external LC low pass filter required to filter and smooth the 4.7 MHz switching frequency of the regulator. This comes in the form of an external 15 µH inductor and a 470 nF capacitor, as illustrated in the figure above.

We assume that the transceiver will operate in this favorable, low-current consumption mode, exploiting the DC-DC buck converter where possible. In practical terms, not all modes of operation need to employ the DC-DC converter [3], specifically standby and sleep modes use conventional linear (LDO) regulation instead of the DC-DC converter because the currents in those modes are already very low. Therefore, only the higher consumption modes, such as XOSC, FS, Tx and Rx where reducing current consumption really matters, make use of the DC-DC.

Table 1: Regulation Type versus Circuit Mode

Circuit Mode	Sleep	STDBY_RC	STDBY_XOSC	FS	Rx	Tx
Regulator Type = 0	-	LDO	LDO	LDO	LDO	LDO
Regulator Type = 1	-	LDO	DC-DC	DC-DC	DC-DC	DC-DC

6. SX1280/SX1281 Consumption

As explained above, it's enough to know the amount of time that the transceiver will spend in each mode and the associated current consumption of that mode, to calculate the charge consumed by each phase of activity and the lifetime of the transceiver. The start-up of the transceiver, whether into transmit or receive mode, implies a sequential progression through the intermediate modes. The ideal current consumption and duration of this sequence is shown in the following figure.

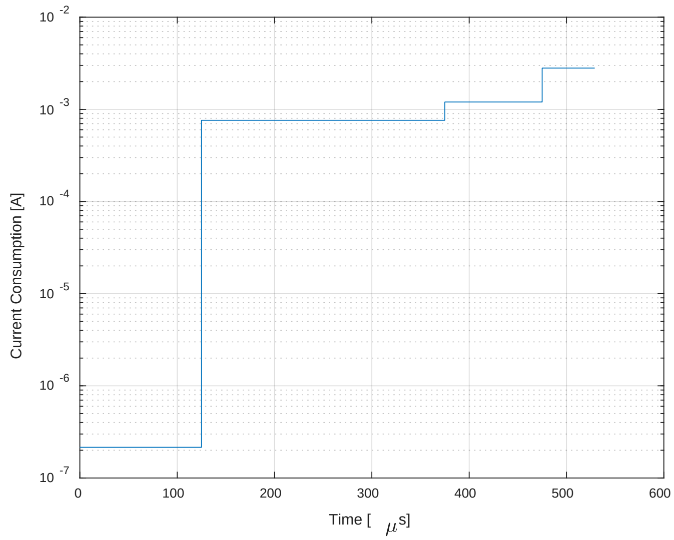

Figure 5: Idealized Sleep to FS Trajectory

The total integrated charge consumption required for the start-up process, exploiting the efficiencies of the DC-DC is a mere 0.595 µC and a total wake-up time of just of 530 µs. Note that we also add a precautionary 0.8 µC of charge consumption for every transition from sleep mode to standby mode.

This is to account for the current required to perform the first charge of the 470 nF decoupling capacitor (C9 of *Figure 4: SX1280/SX1281 Application Design Schematic*) as this capacitor is disconnected from the supply upon the transition to sleep mode.

Therefore, the total value for the consumption is 0.8 + 0.595 ≈ 1.4 µC for startup.

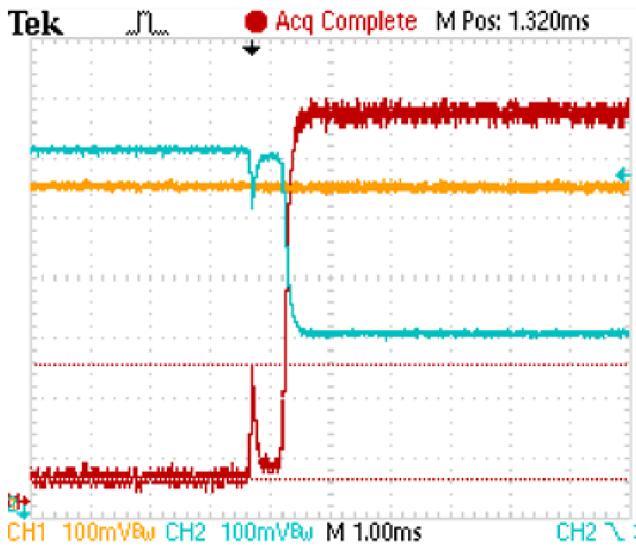

Figure 6: 9 mA Measured In-Rush at the Sleep to Standby Transition

The red curve in Figure 6 above shows a measurement of this in-rush phenomenon for a real transition from sleep to TX. Here the in-rush was measured across a 10 Ω resistance in the supply line, the blue and orange curves showing the supply voltage either side of the resistance. The red curve is hence the voltage difference across the resistor and shows a measured peak of 90 mV, which corresponds to 9 mA.

Note: the peak current will depend upon the impedance of the source (battery) but it can never be higher than 25 mA due to internal current limiters irrespective of the load presented.

Understanding that this is the cost of making the transceiver ready for either reception or transmission, we examine two application cases:

- the first is a duty-cycled transmitter application which we will term "beaconing",
- the second is a duty-cycled receiver application.

We will examine each case with more than one modem.

These two examples do not serve a specific application but can be modified and combined by the user to calculate their own application charge consumption.

7. Duty-Cycled Transmitter Application

For the purpose of demonstration, we need a hypothetical application. Here we consider a simple duty-cycled transmitter application where the radio will communicate in one direction and periodically send a packet of information.

In a simple beacon application, the transceiver wakes from sleep mode periodically to broadcast one of several packets. The general principle is shown below for clarity, the consumption depends on the specific consumption and duration spent in each mode:

Figure 7: Ideal Duty-Cycled Transmitter Operation

For the purposes of our example we assume the following:

Tx Payload size	16 Bytes
Tx Duty cycle	3 packets every 10 minutes
Tx Power	12.5 dBm (maximum output from SX1280)

We will now evaluate the radio consumption for two example modem settings in this scenario:

- LoRa SF8 and bandwidth 1.6 MHz
- GFSK at 1 Mbps

7.1 GFSK Energy Consumption Example

When it comes to determining the duration of a packet to be transmitted, a very useful tool is the SX1280/SX1281 calculator. This can be downloaded from the Semtech website [4] and reveals the packet time-on-air for a given packet format and modem settings.

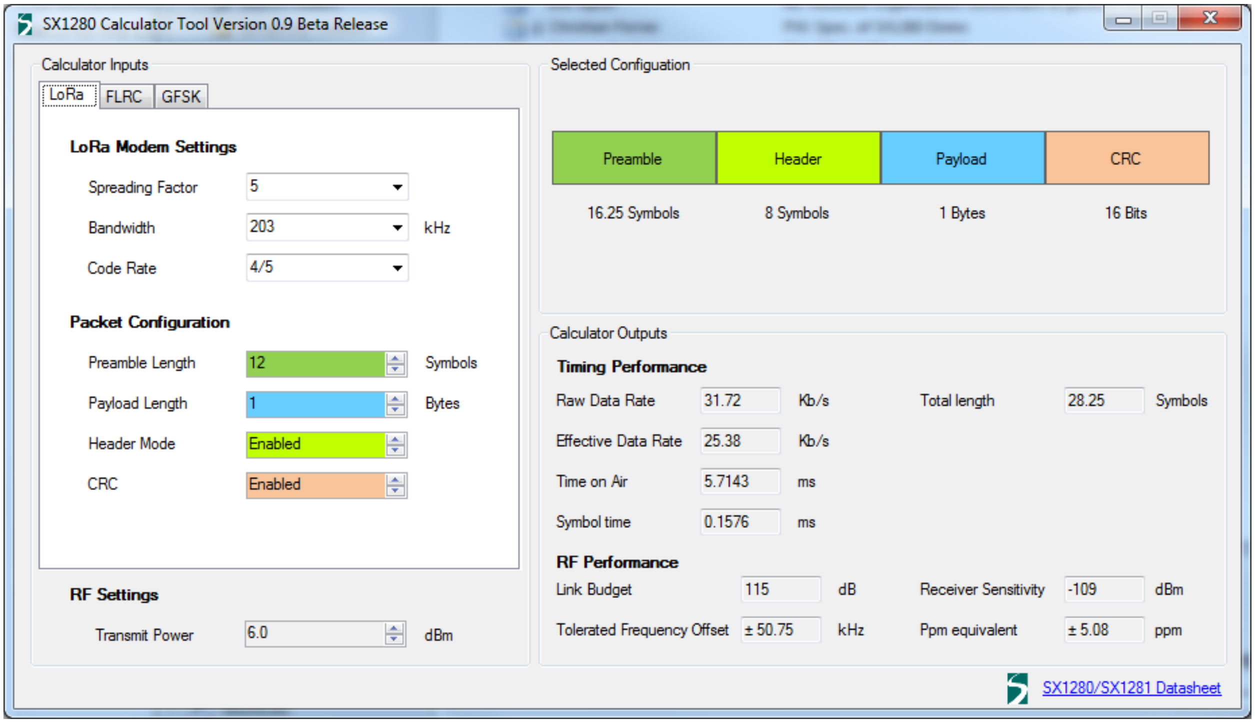

Figure 8: Semtech SX1280/SX1281 Calculator Tool

If we choose a GFSK packet for transmission at 1 Mb/s at a maximum RF output power of 12.5 dBm, in our hypothetical scenario the following format is to be transmitted 3 times every 10 minutes:

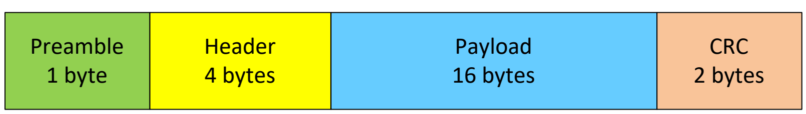

Figure 9: GMSK Packet Sent at 1 Mb/s

When this packet format is entered into the calculator with the raw data rate of 1 Mb/s, the calculated total packet duration is 184 µs. In addition to the packet length we must also add the time for the PA to ramp up and down:

$$t_{transmit} = (2 * T_{RAMP}) + ToA_{Packet}$$

Where

- T_{RAMP} is the programmed PA ramp time, the PA will ramp up and down with this duration.
- ToA_{Packet} is the calculator result

With our default value of 20 µs PA ramping the result is:

$t_{transmit}$ = (2 * 20 µs) + 184 µs = 224 µs

$C_{transmit}$ = 24 mA * 224 µs = 5.15 µC

Note: here we ignore the negligible reduction from having 530 µs of this time in startup mode.

From *Section 6 SX1280/SX1281 Consumption* we know that:

$t_{startup}$ = 530 µs

$C_{startup}$ = 1.4 µC

The timing and ideal consumption for this start-up and transmit phase is shown in the figure below.

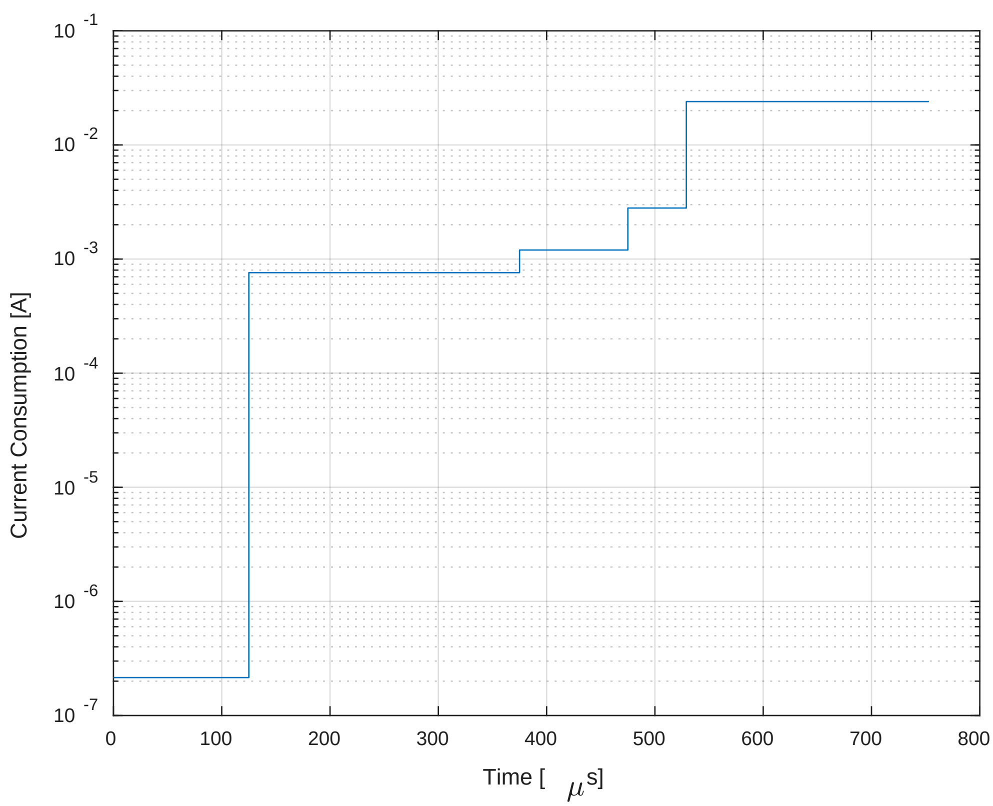

Figure 10: 1 Mb/s FSK Packet Transmission Consumption

The rest of the time we are in sleep mode, from our specification of one packet every 10 minutes, one cycle is therefore 200 seconds. Here also we choose to ignore the negligible reduction from having 530 µs of this time in startup mode:

T_{sleep} = 200 s

C_{sleep} = 215 nA * 200 s = 43 µC

Summing over one full duty-cycle of operation gives us:

$T_{cycle} = 200$ s

$C_{cycle} = 43 + 1.4 + 5.15 = 49.55$ µC

If we take a CR2032 button cell which has a capacity of 240 mAh (864 C):

$t_{lifetime} = (C_{battery} / C_{cycle})\ t_{cycle}$

$= (864 \text{ C} / 49.55\ \mu\text{C}) * 200 \text{ s} = 110.5$ years

A theoretical lifetime in excess of 110 years – well beyond even the shelf life of a lithium button cell! In reality the button cell would self-discharge many years beforehand.

7.2 LoRa® Energy Consumption Example

In a similar vein we can look at the transmission of the same packet payload using the LoRa® packet engine. Here we have selected a notional spreading factor of 8 and a bandwidth of 800 kHz to avail of the -115 dBm sensitivity and increased range of the LoRa® modulation scheme over conventional GMSK modulation. Here we apply the same method, using the SX1280/SX1281 calculator to determine the time-on-air. The packet format is shown below. This yields a packet duration of 14.266 ms.

Preamble 12.5 Symbols	Header 8 Symbols	Payload 16 bytes	CRC 16 bits

Figure 11: LoRa® Packet Sent at SF8 800 kHz

With this time-on-air, for each transmission we will incur the consumption of the full start-up sequence and PA ramp time in addition to the packet time-on-air. The consumption profile for which look like this:

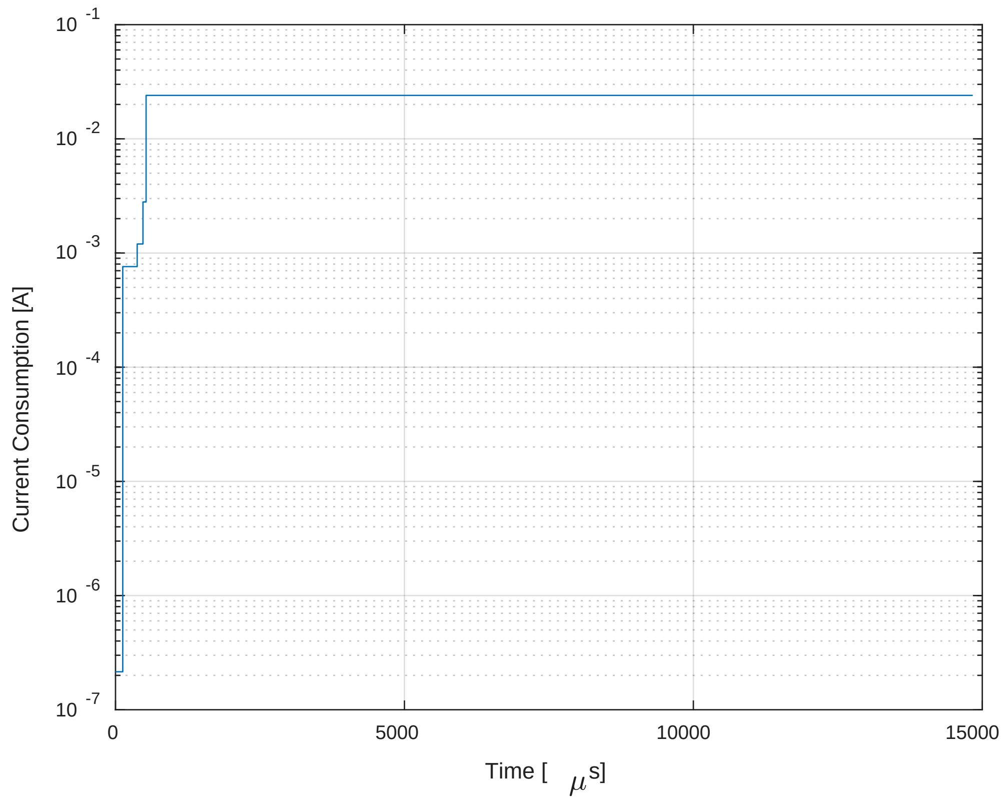

Figure 12: 25.4 kbps LoRa® Packet Transmission Consumption

Using the same method as for the GMSK modem, we calculate a charge consumption per Tx operation as shown below:

$t_{transmit}$ = (2 * 20 μs) + 14.266 ms = 14.306 ms

$C_{transmit}$ = 24 mA * 14.306 ms = 343.34 μC

Again, from *Section 6 SX1280/SX1281 Consumption* we know that:

$t_{startup}$ = 530 μs

$C_{startup}$ = 1.4 μC

This time we subtract the operating time from the sleep mode time:

T_{sleep} = 200 s - (14.3 ms + 530 μs) = 199.98 s

C_{sleep} = 215 nA * 199.98 s = 42.997 μC

Summing over one full duty cycle of operation gives us:

T_{cycle} = 200 s

C_{cycle} = 343.34 + 1.4 + 42.997 μC = 344.74 μC

If we take a CR2032 button cell which has a capacity of 240 mAh (864 C):

$t_{lifetime} = (C_{battery} / C_{cycle})\ t_{cycle}$

= (864 C / 344.74 μC) * 200 s ≡ 15.89 years

This again results in a predicted lifetime that exceeds the shelf life of a consumer lithium button cell.

8. Duty-Cycled Receiver Application

One of the other main types of application is duty-cycled receiver operation. The image below illustrates the basic principle. The vertical scale represents an exaggerated view of the consumption in each mode of operation and the horizontal axis shows the passage of time. In a duty-cycled application, the receiver passes as much time in sleep mode as possible. It then wakes periodically to check for the presence of a valid signal (normally preamble) before returning to sleep mode.

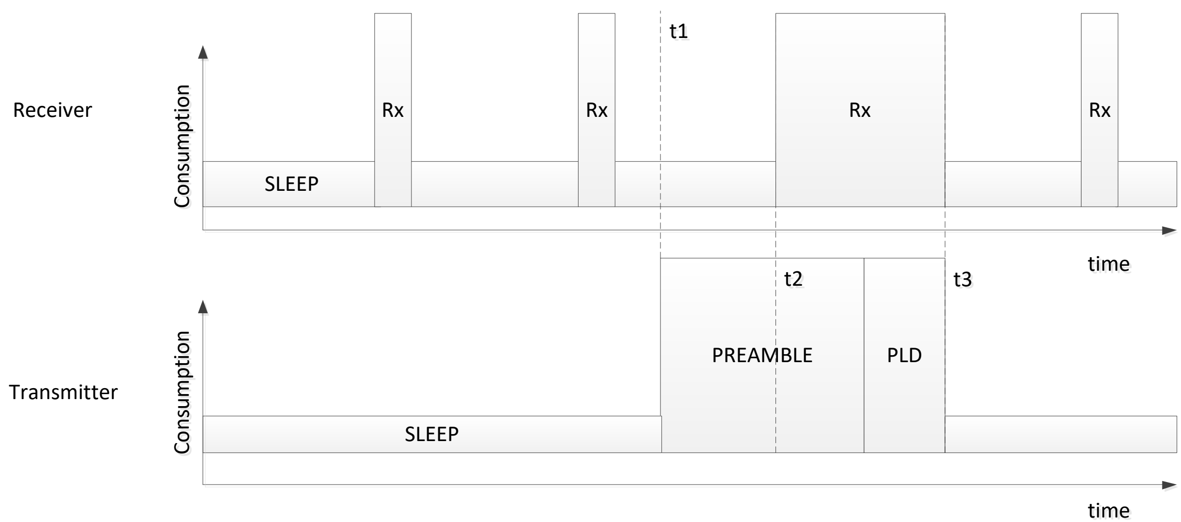

Figure 13: Basic Principle of Duty-Cycled Transmission and Reception

If a device begins transmitting at time t1, the preamble length and wake-up period of the receiver are dimensioned so that the waking receiver is guaranteed to detect the transmitted preamble, here at time t2. At this point the receiver recognizes the validity of the incoming preamble signal and remains in receive mode until the end of the payload of the packet has been received (t3) or a defined time-out has expired.

The utility of this approach is that we can spend the main part of the radio's operating cycle in sleep mode thus reducing the consumption. Here we work through an example of duty-cycled receiver operation for both the GFSK and LoRa modems of SX1280/SX1281.

For the purposes of our example we assume the following:

Rx Duty-Cycle Period	500 ms	
GFSK Listen Duration	2 Bytes	(1 Mbps)
LoRa® Listen Duration	5 LoRa® symbols	(SF8 800 kHz)

Note:
We only calculate only the duty-cycle receive portion (no estimation of consumption due to successful Rx operation).

8.1 GFSK Energy Consumption Example

The packet format that we would attempt to receive in a duty-cycled receiver application is shown below. The principle is to wake-up within the 500 ms preamble to ensure detection of any such packet on the air.

Preamble 0.5 s	Header 4 bytes	Payload 16 bytes	CRC 2 bytes

Figure 14: GMSK Packet Received at 1 Mb/s

To estimate the charge consumption and battery lifetime we follow the same process as in the transmit examples, however, here we replace the transmit time with the time spent in receive mode at our bit rate, R_b, of 1 Mbps:

$$t_{receive} = 16 \text{ bits} * 1/R_b = 16\ \mu s$$

$$C_{receive} = 5.3 \text{ mA} * 16\ \mu s = 84.8 \text{ nC}$$

From *Section 6 SX1280/SX1281 Consumption* we know that to wake the receiver costs the following:

$$t_{startup} = 530\ \mu s$$

$$C_{startup} = 1.4\ \mu C$$

The radio must sample once every 500 ms to receive the long preamble

$$T_{sleep} = 500 \text{ ms} - (16\ \mu s + 530\ \mu s) = 499.5 \text{ ms}$$

$$C_{sleep} = 215 \text{ nA} * 499.5 \text{ ms} = 107.38 \text{ nC}$$

Summing over one full duty cycle of operation gives us:

$$T_{cycle} = 500 \text{ ms}$$

$$C_{cycle} = 84.8 \text{ nC} + 1.4\ \mu C + 107.38 \text{ nC} = 1.59\ \mu C$$

If we take a CR2032 button cell which has a capacity of 240 mAh (864 C):

$$t_{lifetime} = (C_{battery} / C_{cycle})\ t_{cycle}$$

$$= (864 \text{ C} / 1.59\ \mu C) * 0.5 \text{ s} = 8.6 \text{ years}$$

8.2 LoRa® Energy Consumption Example

What is the impact of changing this to a LoRa® packet?

As we saw in the preceding section, although we achieve higher sensitivity with the LoRa® modem, we do so at the expense of longer time-on-air. In this next example, we replace the FSK modulation of the first receiver example with LoRa® modulation at SF8 with a bandwidth of 800 kHz.

The preamble sequence (wake period) of 0.5 seconds stays the same and we append the packet structure of the Tx example as shown below.

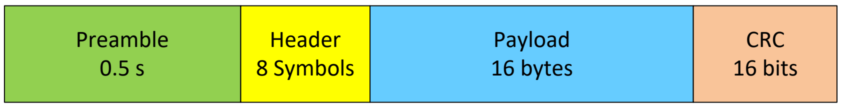

Figure 15: LoRa® Packet Received at SF8, 800 kHz

In LoRa® mode at 800 kHz the modem consumes 7.0 mA and must remain in full receive mode for 5 symbol periods, T_s, (each of 317.27 µs at this modem setting).

$$t_{receive} = 5 \text{ symbols} * T_s = 1.6 \text{ ms}$$

$$C_{receive} = 7.0 \text{ mA} * 1.6 \text{ ms} = 11.03 \text{ µC}$$

From *Section 6 SX1280/SX1281 Consumption* we know that to wake the receiver costs the following:

$$t_{startup} = 530 \text{ µs}$$

$$C_{startup} = 1.4 \text{ µC}$$

The radio must sample once every 500 ms to receive the long preamble

$$T_{sleep} = 500 \text{ ms} - (1.6 \text{ ms} + 530 \text{ µs}) = 497.9 \text{ ms}$$

$$C_{sleep} = 215 \text{ nA} * 497.9 \text{ ms} = 107.05 \text{ nC}$$

Summing over one full duty cycle of operation gives us:

$$T_{cycle} = 500 \text{ ms}$$

$$C_{cycle} = 11.03 \text{ uC} + 1.4 \text{ µC} + 107.05 \text{ nC} = 12.54 \text{ µC}$$

If we take a CR2032 button cell which has a capacity of 240 mAh (864 C):

$$t_{lifetime} = (C_{battery} / C_{cycle})\, t_{cycle}$$

$$= (864 \text{ C} / 12.54 \text{ uC}) * 0.5 \text{ s} = 1.09 \text{ years}$$

With a CR2032 we can expect a year of battery life from a LoRa® modem based application with 0.5 s reactivity.

9. Conclusion

In conclusion we reaffirm that the increased time-on-air required by the LoRa® modem is still compatible with some of the smallest consumer battery technologies currently in use today, providing years of battery life in the cases we examined. Moreover, legacy FSK use at very high data rates can be used to compliment the LoRa® modem to provide either high throughput or very low energy communications thanks to the SX1280/SX1281 DC-DC converter which halves the charge consumption relative to a conventional design.

10. Revision History

Version	Date	Modifications
1.0	August 2018	First Release

11. References

[1] Measuring Cell Capacity
https://www.electronicdesign.com/test-measurement/measuring-cell-capacity

[2] Park *et al.* Battery Capacity Measurement And Analysis Using Lithium Coin Cell Battery
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