



User Guide for the Calculators Version 0.9

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1. Introduction

The simple calculator spreadsheet you have downloaded from the LearnZigBee.com website is developed based on the materials discussed in the ZigBee Wireless Networks and Transceivers book. This document explains different tabs in the spreadsheet and walks you through a number of examples. In the spreadsheet, the cells that contain calculation results have yellow shading and should not be modified. You can change the value of the cells that have no shading.

For the latest version of this document and the calculator spreadsheet please visit LearnZigBee.com. You can send your comments to ShahinFarahani@ieee.org

2. Range Calculation

Click on the “Range Calculation” tab of the spreadsheet. This calculator is based on the materials discussed in section 5.8 of the book and allows you to answer the following question:

How far can we separate two nodes from each other and still expecting the nodes to communicate properly?

Assume node A is transmitting and node B is receiving. There are five parameters that we use to calculate the range:

P_o (dBm): This is the transmitted power from node A. You need to include the antenna gain (if present).

P_r (dBm): This is the receiver sensitivity of node A.

n : The path loss exponent (Table 5.1, chapter five). The value of n depends on the environment.

F_m (dB): This is the fade margin (section 5.5.3)

f (MHz): The transmitted signal frequency

The range in cell D24 is calculated from the equation 5.9. For instance, if the transmitted power from node A is -3dBm, node B sensitivity is -85dBm, the path loss exponent is 2.5, the fade margin is estimated at 8dB, and the signal frequency is 2405MHz signal, then node B can be as far as 19 meters and receives the packets from node A with PER of 1% or less.

Similarly, you can calculate the range when node B is transmitting and node A is receiving. The practical range for two-way communication is the smaller of these two range calculations.

3. Range Extension

Click on the “Range Extension” tab of the spreadsheet. This calculator provides three range extension estimates based on the materials discussed in section 5.8.1 of the book. In all three

scenarios, it is assumed that the transmitted output power of node A and node B are the same. Furthermore, node A and node B are assumed to have the same receiver sensitivities.

The first section of this sheet calculates the extended range if an external LNA is inserted in the receiver path of each node as it is shown in figure 5.10.b of the book. The sensitivity value in cell D4 is the sensitivity of each node before the external LNA is added to the node. In order to calculate the extended range, we need to have either one of the following information:

1. The receiver Noise Figure (NF)
2. The minimum SNR (dB) that is required by the receiver demodulator to successfully recover the data

Unfortunately, neither of the above information is typically provided in a transceiver datasheets. But you may ask the manufacturer to provide you with an estimate for either of these values. If you have the receiver NF, enter its value in cell D7. If you do not have the receiver NF, but you know the minimum SNR value, you can calculate the receiver NF by entering the minimum SNR value in cell D5. If none of these values are available, the minimum SNR may be estimated as a number between 0dB and 4dB. The higher the value of the minimum SNR is, the less range extension you will get. Therefore, as a conservative choice, you may set the value of the minimum SNR to 4dB if the actual value is unknown.

The next input value is the signal bandwidth. You can use the value of the chip rate provided in table 1.1 of the book as an estimate for the bandwidth. For example, for 2.4GHz mode of operation, you can use 2MHz as the bandwidth. In practical implementation, however, the actual signal bandwidth is slightly less than the chip rate. For instance, in 2.4GHz mode of operation, the actual signal bandwidth may be as low as 1.6MHz instead of 2MHz. The smaller the signal bandwidth is, the more range extension you will get. If you do not have any information regarding the actual signal bandwidth, you can use the chip rates provided in table 1.1 of the book and the actual range extension may end up slightly better than your estimate.

The external LNA Noise Figure and gain must be entered in cells D18 and D20 accordingly. Adding an external LNA may require an additional T/R switch. The loss due to the additional T/R switch must be entered in cell D22. The modified transceiver performances are in G18 to G26 cells.

Scroll down the sheet to get to the second section, where an external PA is added to improve the range. The configuration is shown in figure 5.10.a of the book. This is a simple calculation and you only need the external PA gain.

Scroll down further to the third section, where an external LNA and an external PA is added to each node. The configuration is shown in figure 5.10.c of the book. The extended range is calculated in cell G80.

As an example, assume node A and node B have the following performances:

Receiver sensitivity: -91dBm

Receiver NF: 17dB

Transmitter output power: 0dBm

Frequency of operation: 2450MHz

Signal actual bandwidth: 1.6MHz

For the effect of the environment, assume fade margin of 9dB and path loss exponent of 2.8. Then the range of nodes A and B (without any external LNA or PA) is 24 meters (cell G23). Now if an external LNA with 15dB of gain and 2dB of NF is added to the receiver, then the range will be improved to 59.4 meters (cell G25). If we remove the LNA and add a PA with 10dB gain to each node, the range will be improved from 24 meters to 54.7 meters (cell G50). Finally, if we add both the LNA and the PA, the range is improved to about 147 meters (cell G80).

IEEE 802.15.4 nodes are mostly used for two way communications. If receiver sensitivities (or transmitter output powers) of node A and node B are not the same, you need to calculate the extended range for the following two scenarios:

1. Node A is transmitting and node B is receiving
2. Node B is transmitting and node A is receiving

Then, the smaller of these two calculations will be the extended range.

3. Battery Life Analysis

Click on the “Battery life analysis” tab of the spreadsheet. This is a very simple battery life calculator based on the materials discussed in chapter 6 of the book. Most battery datasheets provide the battery performance for continuous current applications. In many short-range wireless sensor networks the batteries are pulsed. Although the average current consumption of a device is low; the instantaneous current can be much higher than the average current. The current consumption profile affects the deliverable energy from a battery and affects the battery efficiency. The nominal battery capacity is entered in cell E4. The battery efficiency, which depends on your application scenario, should be entered in cell E5. Each battery loses portion of its capacity each month. This is referred to as Discharge per Month (DpM). The value of DpM is entered in cell E7.

The next step is to define the application scenario. The steps 1-8 are examples of the steps in a possible use-case scenario. Feel free to modify the steps to customize the spreadsheet to your need. If the first communication attempt is not successful, steps 4-6 can be repeated multiple times. The number of additional attempts is specified in cell G21.

The battery life plotted in graph 1 is based on the battery characteristics and the application scenario. The x-axis is the duration of the sleep time between the events. An event is the act of waking up, performing some duties and going back to sleep. The y-axis is the expected battery life for the given scenario. The minimum and maximum sleep time are entered in cells J4 and J5 respectively.

The energy usage breakdown is shown in graph 2. The total energy consumed by the device is divided into four main categories. The active mode energy consumption is the energy dissipated by steps 2-7 of the event scenario at the top of the sheet. The sleep mode energy usage is mainly due to the device leakage and potentially the energy consumed by a timer. The battery self leakage is independent of the device performance and may vary considerably from one battery manufacturer to another. Graph 2 can be used to determine the dominant contributor to the battery life. For example, if the duty cycle is very low (i.e., the device is sleeping most of the time), the dominant factors may be the device leakage and the battery self leakage. On the other hand, if the

device is active most of the time, the device active current is the most important factor in the battery life.

Scroll down the sheet to get to section 4. This is the section where battery life calculations are performed. Recalling from section 6.1 of the book, the duration of sleep time between the events can affect the battery efficiency due to the relaxation phenomenon. If you have the battery efficiency for various sleep durations, you can enter them in cells K78 to K86. If you are going to use the same battery efficiency for all sleep time durations, you can enter it in cell E5. The default values entered in cells K78 to K86 is the same as E5, but feel free to change them to different values if necessary.

If all you need to calculate is the battery life for specific sleep duration, you can use the last table at the bottom of section 4 of this sheet.

4. Matching

Click on the “Matching” tab. This is simple calculator that can be used to determine the power transfer efficiency between the antenna and the transceiver based on materials discussed in section 5.9.5 of the book. The loss due to the non-ideal matching is also calculated in section 1 of this sheet. The reflection coefficient is calculated from the equation below:

$$\Gamma = \frac{Z_T - Z_A^*}{Z_T + Z_A}$$

where Γ is the reflection coefficient, Z_T is the transceiver impedance, and Z_A is the antenna impedance [1].

In section 5.9.4 of the book, it is discussed that the antenna-equivalent impedance changes with frequency, and because a transceiver is designed to perform optimally with certain antenna impedance, it is important to know whether or not the antenna impedance is close enough to the manufacturer-recommended value. To quantify close enough, the voltage standing wave ratio (VSWR) figure of merit is defined. Section 2 of this sheet calculates the VSWR, quantifying the deviation of the impedance from its nominal value.

5. FCC

If you click on “FCC” tab, you will see a small calculator in the upper left corner of the sheet. This calculator is based on section 5.10.1 of the book. Microvolts per meter ($\mu\text{V}/\text{m}$) is the unit FCC uses to specify the maximum allowed strength of an electric field (E) created by a transmitter in the restricted bands. The $\mu\text{V}/\text{m}$ unit can be converted to a more well-known unit such as dBm using this calculator. For example, the electric field limit of 500 $\mu\text{V}/\text{m}$ at 3m is equivalent to -41.3 dBm transmitted power.

Sections 2 and 3 of this sheet simply visualize the relative locations of the integer harmonics of the transmitted signal to the FCC restricted bands. For instance, all of the 2nd order harmonics of an IEEE 802.15.4 transmitter operating at 2.4GHz band will fall into 4500-5150MHz FCC restricted band. However, the 2nd order harmonics of a transmitter operating in 915MHz frequency band will not fall into any FCC restricted band.

More materials will be added to this sheet in future releases.

References:

[1] Nikitin P.V., et al, "Power Reflection Coefficient Analysis for Complex Impedances in RFID Tag Design", IEEE Trans. On Microwave Theory and Tech., VOL. 53, NO. 9, Sep 2005 2721-2725

Revision history:

Date	Action
Nov 3 rd 2008	Initial release