Hardware Integration Application Notes

Table of Contents

1 Revision History

Revision	Date	Description
1	03/18/2013	Initial Release
2	10/22/2013	Corrected pinout in migration app note

2 Application Note Summary

This collection of documents pulls together 6 documents related to integration of Linear's Dust WSN products into a design. These documents apply to both SmartMesh IP and SmartMesh WirelessHART products.

It includes the following Application Notes:

- Eterna Hardware Design Checklist - A series of questions used to guide design of a customer product that incorporates an Eterna (LTC5800) device.
- Antenna Selection - Understanding antennas and choosing a suitable antenna for a product.
- Battery Selection - How to choose an appropriate primary cell for a product.
- Designing for RF Certification - The RF certification requirements of different countries and commands for certification testing.
- Documents for New Mote Design - Links to a host of guides for each product family.
- Migrating WirelessHART Mote Designs from the DN2510 to an LTC5800 - Hardware considerations for migrating from legacy designs.

3 Application Note: Eterna Hardware Design Checklist

3.1 Summary

This application note outlines key elements that need to be considered in a complete and robust hardware design when interfacing to SmartMesh managers and motes. These include:

- LTC5800 chip (for IP or WirelessHART)
- LTP5901 (for IP or WirelessHART)
- LTP5902 modules (for IP or WirelessHART)
- LTP5903-WHR Manager

Details of the covered concepts are documented in the appropriate device datasheets and integration guides listed at the end of the document.

We recommend that the user first do a qualitative application review of requirements. Following this, there are several sets of quantitative or Yes/No questions to be answered. Once the user fills out the checklist, a review between the user and their FAE can address the details and implications/trade-offs of the responses. It is recommended that this review be done just before hardware integration is started (Initial Design Review) and again after the design is ready for layout/fabrication (Final Design Review).

3.2 Qualitative Application Review

It is important to consider any environmental conditions which may need to be addressed in the design. As a guide, the user should touch on the following list of topics:

- Analog and digital pin requirements - number of inputs, signal level, frequency content, etc.
- Environmental (temperature and humidity) requirements - e.g. a high humidity environment might require a conformal coating
- Temperature ramp conditions - SmartMesh parts are designed to stay connected to the network with a ramp of 8 °C/min.
- ESD requirements - are inputs (including the antenna input) going to be exposed to potential ESD?
- Vibration requirements
- EMI environment – Will the device be placed in proximity to strong electromagnetic fields, such as high-power motors, DC magnetic fields, permanent magnet motors, synchronous motors, fluorescent lights, high-current wires, etc.
- Storage/curing requirements
- Potting/conformal coating requirements
- Power supply requirements - battery, line-powered, or energy harvesting
- Form factor and size requirements
- Sensor processor type and operating system

- Certification requirements - to which countries will product be shipped
- Hazardous area requirements - ATEX/IS certifications
- Host and resources available to access manager API including available memory

3.3 Schematic Review

1. Has the recommend crystal being used for the 20 MHz crystal? _____ (Please ensure the use of qualified crystals only)
2. Has the recommend crystal being used for the 32 KHz crystal? _____ (Please ensure the use of qualified crystals only)
3. Does the application have less than 250 mVp-p noise on power supply? _____
4. Are batteries used to supply power? _____
5. What is the model/part number of the battery? _____
6. Is there protection built-in if the battery is inserted backwards? _____
7. Is the max supply voltage less than 3.76v? _____
8. Is the min supply voltage, including ripple and at peak currents, > 2.175V (or 2.75V for LTP5900)? _____
9. Is there power supply filtering provided via C23, C16, R14 and L1? _____ (n/a for LTP590x)
10. Is C16 a ceramic capacitor to support high frequency transients on the power supply? _____
11. Is the capacitor at the output of the DC-DC converter ceramic? _____
12. Is the power supply filter critically damped (i.e. no ringing in the LC circuitry)? _____
13. Is resistor R12 provided for, to de-Q L1? _____
14. Are capacitors C6-C13 and C16-C21 XR-7? _____
15. Are there supply-decoupling capacitors? _____ What size? _____
16. Does the power supply provide for the in-rush current with its source impedance and any additional decoupling caps without exceeding the 250mV transients? _____
17. Does the power supply provide for enough boot-up current (mean and peak) for the duration required (~800 µs) during start up? _____
18. Is this power supply shared with the host circuitry? _____
19. Are there any regulators on the power supply? _____ What kind? _____
20. What is the transient response of the regulator? _____
21. Are all inputs of the mote referenced to mote's own power supply? _____ (Absolute max on any digital IO pin < Vdd+0.3v)
22. If not, are proper isolators/level shifters used on such inputs(across supplies)? _____
23. Is the HW reset pin required for this application? _____
24. Is a Voltage Supervisor Circuit used in the design which can reset the mote at low voltage? _____
25. Can the RESETn pin be asynchronously asserted? _____ (If so we recommend that this be done after suspending the network and flash activity)
26. Can the SW reset be used for this application? _____ (SW reset is recommended whenever possible, since it is more orderly)
27. Is there a power-on-reset implemented in this design? _____
28. Does the reset signal meet the minimum pulse width (125us) requirement? _____
29. Does the reset signal have a low-impedance path to ground when asserted? _____
30. Which of the 5 UART modes is the chip used in (Mode 0, 2, 4 or Mode 1, 3)? _____

31. Is the mode B pin(pin 11 on LTP5900) tied low? _____
32. Is the mote serial interface operating at 9600 baud? ____
33. Is the mote serial interface operating at 115.2K baud? _____
34. Does the sensor processor generate accurate baud rate (within 2% of specified rate)? _____
35. Do the serial signals (Tx, Rx, MT_CTSn, MT_RTSn, etc) use LVTTL levels? _____
36. Are the mote CLI pins used? _____ (We recommend making them accessible)
37. Is this chip going to operate in EMI intensive environment? _____
38. Is this chip going to operate in a high vibration environment? _____
39. Are the mounting holes used to secure the LTP5900 PCB? _____
40. Are the mounting holes connected to the PCB GND on your board through conductive stand-offs? _____
41. Are there any piezoelectric ceramic caps in the design? _____
42. If in a high vibration environment, have the piezoelectric effects from capacitors been taken into account?_____
43. Is radio inhibit required for this application ? _____
44. Is deep sleep required for this application ? _____
45. Has this been implemented using the deep sleep SW command ? _____
46. What method of harmonic suppression being used? _____ (Quarter wave grounded stub, pi-matching circuit or other - applies only to LTC5800)
47. Are there any other radio transmitters in the vicinity of the chip on the same PCB? _____
48. Does the output of these radio transmitters violate the maximum input of the chip (10dBm)? _____
49. Have the interference issues related to these transmitters been reviewed? _____
50. What are the ESD requirements for this design? _____
51. Does the ESD requirement exceed +/- 2kV (1kV for LTC5800) for HBM? _____
52. Does the ESD requirement exceed +/- 200V (100V for LTC5800) for CDM? _____
53. Does the ESD requirement exceed +/- 8kV (1kV for LTC5800) HBM for antenna pad? _____
54. Has the design been evaluated against ESD requirements? _____
55. Are proper grounding paths provided for various ESD input points in the design? _____
56. Are there any split ground planes? _____ (We do not recommend split ground planes)
57. Are flash programming pins brought out on the pin header? _____ (This is a must for programming of LTC5800 and LTP590x in manufacturing)
58. Has a proper fuse table been created for programming (LTC5800 only)? _____
59. Does the fuse table contain proper "Manufacturer ID (0x00)" value? _____
60. Does the fuse table contain proper "20 MHz load trim (0x13)" values? _____

3.4 Layout Review

1. Have PADs or Gerbers been provided for review? _____
2. Has a complete stackup been provided? _____ (Include number of layers, layer thickness, prepreg and core thicknesses of the layers)
3. How many layers are there on the PCB? _____
4. Is the plane under the top layer a ground plane? _____
5. What is the stackup being used (including layer thickness)? _____
6. Is the ground plane extended under the RF connector to the via clear-out? _____

7. Is the trace from the antenna pin to the connector 50Ω width? _____ (The drawn trace width is a function of dielectric constant, thickness of dielectric and thickness of the plating. E.g. on 8 mil thick FR4 substrate with 0.5oz copper plating, the width for 50Ω trace is 14.5 mils)
8. Is the antenna trace routed on the top PCB layer? _____
9. Is there clearance around RF traces from all metal? _____
10. Are there any signal traces routed between antenna, underneath this trace, and above its ground plane? _____
11. Are any other signal traces routed on the top PCB layer? _____
12. How far is the closest "Active" signal pin from this antenna trace? _____ (Active traces should be at least 5x dielectric height to the RF ground plane)
13. As it goes thru the shield gap, is the antenna trace >5x dielectric thickness, away from the shield edges? _____
14. Is the opening in the ground ring (for the shield) for the antenna trace >5x the height? _____
15. Is there ground fill on the top layer? _____ (It should be no closer than 5x the stackup height between the trace and the ground)
16. If using a chip antenna, does the chip antenna layout follow manufacturer's guideline? _____
17. If using a chip antenna, is the antenna placed over a ground plane cutout? _____
18. Is the antenna (or antenna connector) too close to the shield? _____
19. Are the ground vias on the pi-network (if used) as close to the pad as design rules allow? _____
20. For any customer DC-DC converters used, are any switching inductors placed as far away as possible from VCO and RF coils internal to the chip (pins 1–18 of LTC5800, Pin 20 of LTP5900, pins 1-14 of LTC5901/LTC5902) ? _____
21. Are all switching inductors ferrite core? _____
22. If a DC-DC converter is used, are a shield and ground planes included? _____
23. Are power supply decoupling caps C6-C13 and C16-C21, less than 250 mils from their respective pin leads (Pin 30, 31, 32, 4-5, 6-7, 8-9, Pin 65, 64-63, 62-61, 60-59, 58-57, 56-55)? _____
24. Are the ground sides of the decoupling caps for the LDO outputs connected to a ground plane? _____
25. Are the ground sides of the decoupling caps for the LDO outputs sharing grounds? _____
26. Are all power supply traces greater than 25 mils wide? _____
27. Do the pads of the caps match the trace width? _____
28. Is there a thick exposed metal trace encircling the chip on the top layer of the PCB for securing the RF shield? _____
29. Is this trace tapped into the ground plane every 100-250 mils? _____
30. Does this trace encircle C16, C6-C13, C16-C21? _____
31. Does it allow for a path for the antenna and crystal traces? _____
32. Is the 32kHz crystal trace routed on the top layer? _____
33. Is there any overlap from any signal trace? _____
34. Is the ground plane provided on the adjacent layer? _____
35. Do the crystal traces go over any unshielded signals? _____
36. Is proper shielding provided between 32kHz trace and 20MHz crystal footprint? _____
37. Are you using qualified 32kHz and 20MHz crystals? _____ (Please ensure the use of qualified crystals only)
38. Is the recommended NSMD (non solder mask defined) land pattern used for the QFN package for LTC5800 and for castellated motes LTP5901/5902? _____ (refer to respective integration guide)
39. Has the additional solder mask over pad been provided for the 20MHz crystal as recommended? _____
40. Does the ground paddle contain a pattern of 3x3 vias separated over 4.5mmx4.5mm square? _____
41. Has the solder stencil for the ground paddle been designed as recommended? _____
42. Will the recommended solder stencil be used for ground paddle? _____

43. Does the ¼ wave stub connect to ground at the end? _____
44. Is the ¼ wave stub AC coupled to the device? _____
45. Is the ¼ wave stub over a ground plane and separated laterally from other trace? _____
46. Is there exposed metal on the top surface of the pcb where LTP5901/5902 will be mounted? _____
47. For LTP5901, is an opening free of FR4 (any conductive material) provided? _____ (such an opening as far as possible will maximize the radio performance)
48. For LTP5902, is sufficient opening provided in the PCB for the MMCX connector?_____
49. Is part selection and layout suitable for conformal coating (if required for humidity)?_____
50. Does layout allow for potting of critical components (if required for Intrinsic Safety)?_____

3.5 Shield Review

1. Are there motors generating DC magnetic fields?_____
2. Are there any permanent magnet motors? _____
3. Are there any synchronous motors? _____
4. Are there any high-power motors? _____ How many Watts? _____
5. Does the shield design meet recommendations?_____
6. What metal is the can made of? _____
7. Does the environment (high AC, DC magnetic fields) require a mu-metal shield? _____
8. Is shielding required on "Top" <u>and</u> "Bottom" (ground plane under the chip) due to EMI considerations? _____
9. Does the RF shield have greater than 0.5 mm/20 mils clearance around the chip? _____
10. Does the RF shield include the area for capacitor C16 so that it can be near pin 65? _____
11. Does the shield have 1mm clearance from the top of the PCB to the inside of the shield? _____
12. Does the RF shield have at least 3 asymmetric throughhole pins? _____
13. Is the RF shield soldered to the PCB in 4 locations? _____
14. Is the majority of the RF Shield soldered to the PCB? _____
15. Is the RF shield opening greater than 5x the dielectric thickness between antenna trace and ground plane from the edge/top of the antenna trace to the nearest edge of the shield? _____
16. Is the RF shield opening small? _____ How small? _____
17. Can the PCB underneath the shield be cleaned? _____
18. What are the vibration requirements? (_____g Peak, freq Range _____)

3.6 Antenna Selection/Potting

1. Is the selected antenna certifiable considering Effective Isotropic Radiated Power? _____
2. Is this a dipole antenna (used in LTP5900-WHM and LTP590x modular certification)? _____
3. Is this a monopole antenna? _____
4. Is this a chip antenna? _____
5. Is the antenna shielded with plastic? _____
6. Does the antenna include any exposed pieces of metal ? _____ (Any exposed antenna conductor can be an input for ESD. The antenna input has lower damage thresholds than other inputs)

7. Is the antenna fully enclosed in a case (such as a potted chip antenna)? _____
8. Is there a radome exposed to the environment? _____
9. Has a DC-grounded antenna been considered? _____ (DC grounded antennas have a short between the antenna terminal and antenna ground at frequencies other than at the band of interest)
10. Is there a DC path to earth ground from the LTC5800/LTP590x ground? _____
11. Is the ESD limit of +/- 8kV (1kV for LTC5800) HBM for antenna pad sufficient? _____
12. Is the proper antenna connector used for application fit (i.e. vibrations etc)? _____
13. What antenna connector is used? _____
14. Is it silver or gold plated? _____
15. Is adequate ground plane being provided to the antenna? _____
16. Has the antenna manufacturer reviewed and verified the design? _____
17. Have the PCB layout effects been taken into account? _____
18. Have the packaging-related effects been taken into account? _____
19. Is the pattern omni-directional? _____
20. Has the antenna manufacturer characterized the design? _____
21. Has the design assembly been verified for vibration requirements? _____
22. Has the design assembly been verified for shock requirements? _____
23. Is the design going to be potted ? _____
24. Is the radiating portion of the antenna going to be potted? _____
25. If so, has the antenna connector impedance and radiation pattern been characterized after potting? _____ (The impedance can change significantly after potting so the unit must be characterized after potting)
26. If the antenna is potted, are the new are matching circuits in place to match to the newly the characterized antenna impedance to 50Ω? _____
27. What temperature is the potting material going to be cured at? _____
28. How long does the curing process take? _____
29. Have the temperature and time of curing been verified against the storage temperture requirements described in the chip datasheet? _____
30. Is this pressurized potting? _____

3.7 Certification

1. What kind of certification is desired? _____
2. For modular certification, is the antenna type and gain appropriate? _____
3. Is it certified for all the countries this product is intended to be shipped? _____
4. Does this product need FCC certification? _____
5. Does this product need CE certification? _____
6. Does this product need to operate in Japan? _____
7. Does this product need to operate in China? _____
8. Has the app note on certification been reviewed for information needed? _____
9. Are all certification RF test commands available via the Host User Interface? _____
10. Is this part going to be used in Hazardous Areas? _____
11. Does this part need certification for ATEX-n (or Zone 2)? _____

12. Does this part need certification for ATEX-1 (or Zone 1)? _____
13. Does the design need to adhere to Intrinsic Safety guidelines? _____
14. Are there adequate changes made to schematics and layout of the design to adhere to IS requirements? _____
15. Are there DC-blocking capacitors (capacitors with large dielectric breakdown voltage and reactance < 1 Ohm at the frequency of operation) between the radio and the antenna in the design? _____

3.8 Case/cover design

1. Is there proper grounding provided for various ESD input points in the design? _____
2. Is the chassis ground connected to the PCB ground? _______

3.9 References

3.9.1 SmartMesh IP

The following documents are available for the SmartMesh IP network:

Getting Started with a Starter Kit

- SmartMesh IP Easy Start Guide - walks you through basic installation and a few tests to make sure your network is working
- SmartMesh IP Tools Guide - the Installation section contains instructions for the installing the serial drivers and example programs used in the Easy Start Guide and other tutorials.

User Guide

- SmartMesh IP User's Guide - describes network concepts, and discusses how to drive mote and manager APIs to perform specific tasks, e.g. to send data or collect statistics. This document provides context for the API guides.

Interfaces for Interaction with a Device

- SmartMesh IP Manager CLI Guide- used for human interaction with a Manager (e.g. during development of a client, or for troubleshooting). This document covers connecting to the CLI and its command set.
- SmartMesh IP Manager API Guide - used for programmatic interaction with a manager. This document covers connecting to the API and its command set.
- SmartMesh IP Mote CLI Guide- used for human interaction with a mote (e.g. during development of a sensor applicaition, or for troubleshooting). This document covers connecting to the CLI and its command set.
- SmartMesh IP Mote API Guide - used for programmatic interaction with a mote. This document covers connecting to the API and its command set.

Software Development Tools

- SmartMesh IP Tools Guide - describes the various evaluation and development support tools included in the SmartMesh SDK , including tools for exercising mote and manager APIs and visualizing the network.

Application Notes

- SmartMesh IP Application Notes - Cover a wide range of topics specific to SmartMesh IP networks and topics that apply to SmartMesh networks in general.

Documents Useful When Starting a New Design

- The Datasheet for the LTC5800-IPM SoC, or one of the modules based on it.
- The Datasheet for the LTC5800-IPR SoC, or one of the embedded managers based on it.

- A Hardware Integration Guide for the mote/manager SoC or module - this discusses best practices for integrating the SoC or module into your design.
- A Hardware Integration Guide for the embedded manager - this discusses best practices for integrating the embedded manager into your design.
- A Board Specific Integration Guide - For SoC motes and Managers. Discusses how to set default IO configuration and crystal calibration information via a "fuse table".
- Hardware Integration Application Notes - contains an SoC design checklist, antenna selection guide, etc.
- The ESP Programmer Guide - a guide to the DC9010 Programmer Board and ESP software used to program firmware on a device.
- ESP software - used to program firmware images onto a mote or module.
- Fuse Table software - used to construct the fuse table as discussed in the Board Specific Integration Guide.

Other Useful Documents

- A glossary of wireless networking terms used in SmartMesh documentation can be found in the SmartMesh IP User's Guide.
- A list of Frequently Asked Questions

3.9.2 SmartMesh WirelessHART

The following documents are available for the SmartMesh WirelessHART network:

Getting Started with a Starter Kit

- SmartMesh WirelessHART Easy Start Guide - walks you through basic installation and a few tests to make sure your network is working
- SmartMesh WirelessHART Tools Guide - the Installation section contains instructions for the installing the serial drivers and example programs used in the Easy Start Guide and other tutorials.

User Guide

- SmartMesh WirelessHART User's Guide - describes network concepts, and discusses how to drive mote and manager APIs to perform specific tasks, e.g. to send data or collect statistics. This document provides context for the API guides.

Interfaces for Interaction with a Device

- SmartMesh WirelessHART Manager CLI Guide - used for human interaction with a Manager (e.g. during development of a client, or for troubleshooting). This document covers connecting to the CLI and its command set.
- SmartMesh WirelessHART Manager API Guide - used for programmatic interaction with a manager. This document covers connecting to the API and its command set.
- SmartMesh WirelessHART Mote CLI Guide - used for human interaction with a mote (e.g. during development of a sensor applicaition, or for troubleshooting). This document covers connecting to the CLI and its command set.
- SmartMesh WirelessHART Mote API Guide - used for programmatic interaction with a mote. This document covers connecting to the API and its command set.

Software Development Tools

- SmartMesh WirelessHART Tools Guide - describes the various evaluation and development support tools included in the SmartMesh SDK including tools for exercising mote and manager APIs and visualizing the network.

Application Notes

- SmartMesh WirelessHART Application Notes - app notes covering a wide range of topics specific to SmartMesh WirelessHART networks and topics that apply to SmartMesh networks in general.

Documents Useful When Starting a New Design

- The Datasheet for the LTC5800-WHM SoC, or one of the castellated modules based on it, or the backwards compatible LTP5900 22-pin module.
- The Datasheet for the LTP5903-WHR embedded manager.

- A Hardware Integration Guide for the mote SoC or castellated module, or the 22-pin module - this discusses best practices for integrating the SoC or module into your design.
- A Hardware Integration Guide for the embedded manager - this discusses best practices for integrating the embedded manager into your design.
- A Board Specific Integration Guide - For SoC motes and Managers. Discusses how to set default IO configuration and crystal calibration information via a "fuse table".
- Hardware Integration Application Notes - contains an SoC design checklist, antenna selection guide, etc.
- The ESP Programmer Guide - a guide to the DC9010 Programmer Board and ESP software used to program firmware on a device.
- ESP software - used to program firmware images onto a mote or module.
- Fuse Table software - used to construct the fuse table as discussed in the Board Specific Integration Guide.

Other Useful Documents

- A glossary of wireless networking terms used in SmartMesh documentation can be found in the SmartMesh WirelessHART User's Guide.
- A list of Frequently Asked Questions

4 Application Note: Antenna Selection

This document is intended to give an overview of factors important in antenna selection and make recommendations where possible. Key antenna concepts are explained, and then design considerations will be explored. Finally, an example will be drawn to illustrate a selection process.

For detailed information on any of the antennas mentioned in this document, contact the antenna manufacturer.

4.1 Selection Considerations

4.1.1 Input Impedance Match (VSWR)

Voltage Standing Wave Ratio represents the efficiency at which the antenna transfers the energy from the electronics to the transport medium (air). The lower the ratio the more efficient the antenna is at transferring the signal to the air.

VSWR	Reflected Power %	Mismatch Loss (dB)
1:1	0	0.0
1.5:1	4	0.18
2:1	11	0.51
2.5:1	18	0.88
3:1	25	1.25

At a VSWR of 1.5:1, approximately 0.2 dB (4%) is lost due to mismatch. Targeting a lower VSWR is likely to significantly increase the cost of the antenna, while only marginally improving performance, so 1.5:1 should be considered the lower practical bound. While the radio can tolerate a VSWR of up to 3:1, most antennas available today will be ~2:1 VSWR.

4.1.2 Gain

Antenna gain is measurement of the intensity of an antenna's radiation pattern in the direction of strongest radiation. It is typically expressed in dBi (decibels over isotropic). The gain will be a primary factor in antenna selection.
The stronger the gain, the greater the distance at which the radio is typically capable of communicating. However, certification bodies in different countries have varying requirements for maximum radiated power output for radios, so the antenna gain must be included in the total output power. Typical dipole antennas have a gain of ~2 dBi - this is the nominal gain assumed by WirelessHART. Gains < 1 will result in lower range for your device, and should be avoided if possible.

Antennas with gains >2 will have directional dependence in their radiation pattern, which increases with gain. See "Radiation Pattern" for more details.

4.1.3 Radiation Pattern

An ideal antenna radiates equally in all directions - this is called an *omnidirectional* antenna. Real antennas do not emit their energy uniformly. For example, a typical dipole antenna will have much less energy radiating along its axis - a *null*. The null region will increase as gain is increased. Think of a donut with the antenna in the center - for low gain antennas it's a very plump donut. As gain increases, our donut gets flatter. For mesh network products, having as close to an omnidirectional is desirable, as this allows us to place motes at various heights without having to worry that a mote will be in null of all its neighbors and unable to communicate.

4.1.4 Polarization

Vertical and Horizontal

Most antennas under consideration will be vertically polarized - this means that the electromagnetic wave goes up and down relative to the earth's surface. If you mount a vertically polarized antenna horizontally, then it is now horizontally polarized, since the waves will move up and down parallel to the earth's surface. For outdoor applications where there are few reflections, polarization can be important, since a vertically polarized antenna will see more loss with an incoming horizontally polarized signal. In indoor applications or where there are many reflecting surfaces in an outdoor application, polarization is less significant, since it changes with each reflection and multiple reflections typically reach the receiver.

Circular

Circularly polarized antennas radiate in a corkscrew (left or rright handed) fashion. They are typically more costly without providing additional benefit, and are not typically with our products.

4.1.5 Ground Plane

The ground plane of the antenna is important because it can be affected by the electronics around it. If the antenna is near metal objects like batteries, enclosure, or a radio shield, the ground plane of the antenna may be affected. This often results in a change in the radiation pattern. In the extreme it could cause a "blind" spot that makes it hard for the radio to send or receive signals from a specific direction or directions.
If you must put your antenna near a large ground plane, then it may be necessary to have a design company create the antenna for your device. For example, Dust Networks contracted with Nearson, Inc. for the creation of the antenna that is part of some ofour evaluation modules. The antenna depends upon being inside that box in a specific position. If it is removed from that box the performance decreases because the ground plane has been changed.

4.1.6 Radiating Element

Monopole or Dipole
These are typical antennas that you have on your car or portable radio.

PCB
On a PCB antenna the radiating element and ground plane are laid out as traces on a PCB. This can allow them to be small and easy to integrate into existing PCB real estate on a device's board.

Chip
Most antennas on a chip antennas have traditionally beenare designed for short range, but lately there have been changes in this type of antenna technology that improve radiating characteristics to the point where they should may be considered. These types of antennas are often the size of a resistor and can be soldered to a PCB on an assembly line. This is further detailed in the "Small Form Factor Antenna Considerations" section. Some of the things that should be considered include-

1. These tend to be more directional that traditional dipoles. The gain may vary significantly relative to direction. Make sure to get antenna radiation plots from the manufacturer to ensure that radiation patterns are acceptable for the desired application / installation use cases.
2. These antennas' radiation pattern and impedance will generally be sensitive to what is near them. The manufacturer should be consulted regarding the guidelines for design and install for these antennas.
3. These may require a design/use of a matching network. If the antenna needs to be potted- care should be taken to compensate for the effects of the potting material of that as it potting often could likely causes shifts in radiation pattern and input impedance.

4.1.7 Frequency Band

The frequency band of an antenna is the frequency range to which the antenna is tuned. Antennas will emit a signal in all frequencies, but are designed for a specific range or set of ranges. Make sure that the antenna selected is designed for the correct frequency range.
Some antennas are designed for multiple frequency ranges. They are typically more expensive and are not necessary for Dust Networks radios. Check the datasheet of the mote in your design, it will provide the frequency range of the radio.

4.1.8 Splitters and Switches

For specialty applications a splitter or switch may be used between the antenna and radio. Typical applications are for multiple transmitters using a single antenna or manually switching between two different antennas addressing different environmental needs. This topic is very specialized and an antenna or RF engineer should be consulted when considering this type of device.

4.1.9 Coating and Potting

For specialty applications an antenna may need to be potted. Applications with high vibration are one example where the antenna and connector could be potted. It is important to note that any conductor, including potting material that comes in contact with the antenna, lead or connector, can change the resistance of the circuit. Dust Networks motes require 50 Ohm antennas. Any material that changes that requirement could require custom antenna design work.

4.1.10 Regulatory Testing and Certification

There are several issues to consider in relation to regulatory certification when selecting an antenna.

- Does the antenna conform to any modular certification that the end device will be relying upon?

Modular certification is only available on the motes that are pcbs and have an antenna or antenna connector on them (LTP59xx parts). Check the mote or embedded manager datasheet for specific antenna requirements to reuse modular certification (FCC and IC). The antenna type (monopole, dipole etc) must conform to the same type of antenna used to modularly certify the mote and or the embedded manager. Unintentional radiator testing is also typically required for devices, or products that include a radio that has modular approval. (for FCC- the requirements are covered in FCC part 15.33(b), and depending on the product may be governed by other sections). Consult with appropriate testing lab for all the specific requirements.

- Will the antenna gain take the EIRP output power beyond the acceptable level of power that the regulatory requirements state?

If the regulation is for a maximum of 15dBm EIRP output power and the antenna chosen takes the output power to 17dBm, then the device will fail.

> The Customer <u>must</u> consult with appropriate testing lab to ensure that the antenna and additional testing will meet the specific certification requirements per your product geographical shipment needs (FCC, IC, CE etc).

4.2 Small Form Factor Antenna Considerations

In general small form factor antennas come in three varieties:

1) PCB antennas
2) Ceramic (LTTC) antennas
3) Fractal antennas

The performance improves from 1) to 3) and the cost increases as well from a few cents for the PCB antenna, ~$0.50 for the LTTC antennas to ~$2 for a fractal antenna. The performance varies almost as much. Unfortunately there is a fair bit of specmanship in the data sheets for chip antennas. PCB antennas are difficult to design well and even the better designed PCB antennas (at least those designed on a typical PCB substrate) tend to perform poorly relative to the other two options.

The performance of the average device over a large number of networks will be maximized by the efficiency of Antennas. The generic applicability of an efficient antenna will be influenced by the uniformity of the gain pattern of the antenna. Unfortunately the efficiency is often not well documented in the antenna data sheets with some data sheets backing out the efficiency loss when showing the gain of the antennas. In general a good LTTC antenna has an efficiency of around 50%, while the better Fractal antennas have an efficiency of closer to 70%. The gain variation of the Fractus 2FR05-S1-N-0-102 is roughly +2/-12 dB over the center 120 degrees of elevation, while the gain of the Johanson 2450AT43B100 LTTC antenna has a gain variation of -5/-35 dB over the center 120 degrees of elevation. So on paper the Fractus antenna should have roughly a 6 dB better link budget and some difficult to quantify greater consistency when deployed. Some of the other significant design considerations include-

1. These antennas tend to be more directional that traditional dipoles. The gain may vary significantly relative to direction. Make sure to get antenna radiation plots from the manufacturer to ensure that radiation patterns are acceptable for the desired application / installation use cases.
2. These antennas' radiation pattern and impedance will generally be quite sensitive to what is near them. The manufacturer should be consulted regarding the guidelines for design and install for these antennas.
3. These may require design/use of a matching network. If the antenna needs to be potted- care should be taken to compensate for the effects of the potting material as potting often causes shifts in radiation pattern and input impedance.

> ⚠ Any of the three small form factor antennas described above will be worse than using a 1/4 wave monopole.

4.3 Dust TSCH and Antenna Considerations

Time Slotted Channel Hopping (TSCH) is at the heart Dust Network's products. Unlike point to point systems, the strength in a TSCH mesh network is it's ability to use a multitude of paths, not relying on any one antenna link to be good. Since individual RF links are inherently unreliable, any system that depends on an individual link to work all the time is bound to fail. Another characteristic of RF is that for any distance in the range of 10m – 100m that does not work, there is usually a distance farther away that does. Finally, individual RF paths are prone of multi-path fading which is channel dependant. TSCH is designed to overcome these by constantly performing channel hopping and building a reliable network by determining if knowing when a path is good (regardless of the distance) and using it when it is good.
Hence, it is recommended that testing and comparing the performances of different antennas in a TSCH network may be done as follows-
Start by building a network inchoosing a few sets of representative physical locations designed(i.e. indoors, and outdoors, industrial, etc.).. Deploy enough devices to insure that there are some single hop devices as well as many multi-hop devices. As the devices are deployed to spread of path stabilities(ratio of number of successful packet transmissions w.r.t. total packet transmissions). , Deploy a network and record the x-, y- and if necessary z- coordinates of eachvery device. From those coordinates, you can calculate all of the pair-wise distances between all devices can be calculated. After you install the network has been running for several hours, obtainyou can then obtain path statistics for all the paths that have been discovered in the mesh. Plot the signal strength (RSSI) vs. distance of all these paths. Determine from that data the **distance** below which **most** of the paths have **better than** -75dBm RSSI. Some judgment will be required on how exactly you will analyze this data. The more data points you have, the better. The number of data points you obtain in a deployment will grow like the square of the number of devices in your network. 10 different 10-device deployments can yield data for as many as 450 different paths (10 * (10 * 9)/2). One 100-device deployment can tell you about as many as 4450 different paths ((100 * 99)/2).

This approach can be used to qualify and validate a particular antenna choice. The distance obtained from the data above will be an empirically obtained 'range' distance that can be used for designing future deployments. If the results of this testing do not meet design objectives for range, or if the desire is to compare multiple antenna types, then this testing will need to be repeated with each antenna type. Since the antenna participates on both the transmit and the receive side of an RF path, it will be difficult to reach concrete conclusions with a mix of different types of antennas, unless that mix is one that needs to be evaluated for product planning. Then at each location across the network replace one type of antenna with another and see how the path statistics vary. The key here is to try to hold the comparisons relatively constant (they will never be truly constant) and see how the performance varies. Expect that deltas to vary between types of environment- open field versus indoor. That should then give the appropriate degree of effectiveness of each antenna.

4.4 Example Selection Scenarios

4.4.1 Example A

If my design constraints are +10dBm EIRP and a very small package, then some of my decisions might go like this:
Must have:

- VSWR 1.5 or better
- Radio power is +8dBm, so my antenna can only have a gain of +2dBm
- Frequency: 2.4GHz
- Omni directional

So far most antennas will meet these specifications.

- Must fit into my 2" by 2" package
- Must be easily potted to reduce the effect of vibration
- Easy to manufacture/assemble into device

With the size and manufacturing constraints I should look at small form factor PCB or chip antennas. These types of antennas are small and can typically be placed by automated assembly equipment.

4.4.2 Example B

If I take this same device from example A and change a few requirements, then I need a very different type of antenna. Now my device is outdoors and needs as much power as I can get for range.
Must have:

- VSWR 1.5 or better
- Radio power is +8dBm, so my antenna can have a gain of +6 to +10dBm (If the gain is higher, then the directionality of the antenna may become more of an issue. Must stay under the power limits of the governing body in the country I wish to sell into.)
- Frequency: 2.4GHz
- Omni directional
- NOT required to fit into my 2" by 2" package
- Can be more expensive to manufacture/assemble into device because this SKU is going to cost more

This antenna will probably be a dipole of large size with outdoor ratings for weather. The loss of the cable should be considered because it could be long enough to allow the antenna to be placed in an optimal location.

4.5 Appendix 1

4.5.1 Sample Antenna List

Antek Wireless	http://www.antekwireless.com/	TPF-3000-01	0 dBi	PCB
Nearson	http://www.nearson.com/	S152XX-2450S	+4 dBi	Dipole

Nearson	http://www.nearson.com/	AA02_01535-1	+2 dBi	Dipole
MaxRad	http://www.maxrad.com/	MMSO2300	0 dBi	Dipole
Hyperlink Technologies	http://www.hyperlinktech.com/	HGV-906U	+6 dBi	Dipole
Inpaq Technology Co.	http://www.inpaq.com.tw/	ACA7636A1SXX	+2.5 dBi	Chip
Fractus	http://www.fractus.com/	FR05-S1-N-0-001 2FR05-S1-N-0-102	+2 dBi +2 dBi	Chip Chip

4.5.2 Additional Antenna Resources

Antenna Systems and Technology Magazine	Helpful how-to articles on antenna selection and design	http://www.antennasonline.com/
RF Design Line	Articles on all aspects of radio and antenna design and selection	http://www.rfdesignline.com/
RF Globalnet	Radio and antenna design articles	http://www.rfglobalnet.com/

4.6 Appendix 2 – Key Concepts

4.6.1 Decibel (dB, dBm, dBi)

The **decibel** (**dB**) is a measure of the ratio between two quantities, and is used in a wide variety of measurements in acoustics, physics and electronics. The decibel is widely used in measurements of the loudness of sound. Likewise, they are used to express the power of a radio signal. This is the frame of reference for decibels in this document.
The decibel level in reference to one milliwatt of power is called dBm or dBmW.
The gain of an ideal isotropic antenna (theoretically perfect) compared to a measured, real-world antenna is referred to as dBi.

4.6.2 Attenuation

Attenuation is the reduction in amplitude and intensity (power) of a signal. Different mediums attenuate radio waves at different levels. A typical chart for 2.4GHz signals is shown below. However, subtle differences in materials can attenuate RF significantly. For example, if you have foil-backed insulation in a wall, then it will attenuate much more than paper-backed insulation.

Material	Signal reduction
Clear glass window	2 dB
Brick wall	2 to 8 dB
Metal frame glass with reflective coating (wall or window)	6 dB
Interior office wall	6 dB
Cinder block wall	4 dB
Solid wood door	3 dB
Cubicles	3 to 5 dB
Drywall/sheetrock wood framed	4 to 6 dB
Marble	5 dB
Concrete wall	10 to 15 db
Glass window with security wire	8 dB

To put the numbers in perspective, 6dB is equal to cutting the free space range in half. 12dB is 1/4th the range.

4.6.3 Path Loss

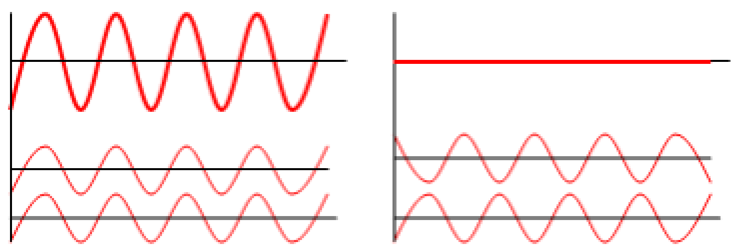
Path loss is the attenuation undergone by an electromagnetic wave in transit from a transmitter to a receiver.
This term is commonly used in wireless communications. Path loss may be due to many effects such as free-space loss, refraction, diffraction, reflection, and absorption. Path loss is affected by factors such as terrain contours, different environments (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, the height and location of their antennas, etc.
In the study of wireless communications, path loss can be represented by the path loss exponent, whose value is normally in the range of 2 to 4 (where 2 is for propagation in free space, 4 is for relatively lossy environments). In some environments, such as buildings, stadiums and other indoor environments, the path loss exponent can reach values in the range of 4 to 6. On the other hand in tunnels a waveguide type of propagation may occur with the path loss exponent dropping below 2 because the radio signal follows the tunnel and is reflected much the same way light travels in a glass strand.
Path loss is usually expressed in dB. In its simplest form the path loss can be calculated using the formula $P = 10\, n \log(d) + C$, where P is the path loss in decibels, n is the path loss exponent, d is the distance between the transmitter and the receiver, usually measured in meters, and C is a constant which accounts for losses occurring due to penetration through the walls of the building, due to absorption in the human body, etc.
Path loss is a major component in the analysis and design of the link budget of a wireless system.

4.6.4 Multipath

Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. This can be cause by any RF reflective or RF absorptive surface, including buildings, earth, metal objects, etc. Multipath signals are not necessarily bad. Most wireless systems depend on them because line of site is not available between all nodes. Fading (multipath fading) results from transmitted signals that have experienced differences in attenuation, delay and phase shift while traveling from the transmitter to the receiver. It may also be caused by attenuation of a single signal.

4.6.5 Interference and Noise

At its most basic, **interference** is the sum of two or more waves resulting in a new pattern. For radios, interference results in damaged packets or unrecognized signals. Large quantities of radio signals or strong signals, either close in proximity or high in transmit power, are more likely to result in problems.

combinedwaveform		
wave 1		
wave 2		
	Two waves in phase	Two waves 180° outof phase

4.6.6 Fresnel effect

The **Fresnel Effect**, in this context, refers to the degradation of radio signals due to the proximity of the antenna to a very large object, such as the earth. Early 19th century French physicist, Augustin Fresnel (pronounced "Freh-Nel"), observed this phenomenon with light waves. It also applies to other RF waves.
For this discussion, the closer an antenna is placed to the ground (earth) the shorter the distance it can transmit, and the greater problem it has receiving signals.
There are many Fresnel calculators on the internet. However, Dust Networks general recommendation is to keep antennas at approximately 2 meters to minimize the Fresnel effect.

4.6.7 Link Budget

The accounting for all of the transmitted power and power gains (ex. antenna gain) and all of the power loss in a system of transmitter and receiver is the link budget. A simple equation might look like this:
Received Power = Transmitted Power + Gains – Losses
The gains include:

- Transmitter antenna gain
- Receiver antenna gain

Losses include:

- Antenna cable
- Connectors
- Path Loss
- Fading
- Body Loss
- Polarization Mismatch

The link budget must be greater than the receiver sensitivity for the receiver to "hear" the transmitter. For the link budget of the mote see the corresponding mote datasheet.

4.6.8 Installation Orientation

There are some environmental elements that the installer of a wireless system has control over. The orientation of the radio antennas in relation to each other is one of them.

4.6.9 Polarization Issues

Orientation Angle	Polarization Mismatch (dB)
0	0
15	0.3
30	1.2
45	3
60	6
75	11.7
90 (orthogonal)	infinite

Linearly polarized antennas, most common type of antenna, should be mounted in the same orientation to each other to maximize the link budget. The table above describes the amount of loss that can be expected when antennas are at different angles to each other. This is not to say that two antennas that are 90 degrees different in their orientation will not communicate. As the radio signals bounce off of objects they will change orientation, and that will allow the two devices to communicate. However, a direct (line of sight) signal is typically better than an indirect signal.

4.6.10 Radiation Pattern Issues

Antenna radiation patterns are typically not perfect spheres. Even omni directional antennas have directions that are weaker than others. A typical monopole or dipole antenna has null spots located directly above and below the antenna, along the axis of the antenna. The datasheet from the antenna manufacturer should provide radiation pattern graphs in three dimensions.

4.7 Assumptions

4.7.1 Hardware

This application note applies to all motes and embedded manager hardware. See datasheets for detailed antenna and regulatory approvals of motes and managers.

5 Application Note: Battery Selection

This document discusses the factors to consider when making a battery selection, the trade-offs made with each, and minimum requirements. There is a table that compares several of the most popular sizes batteries and manufacturers. Only lithium batteries will be considered here. There are many other battery chemistries; however, some of them are not up to the task of supplying reliable current for long periods of time over temperature.

Minimum requirements of the mote must be met in order to maintain communication with the network. Some batteries do not supply the minimum voltage over their entire temperature range or over their entire lifetime. For battery lifetime calculation, see the SmartMesh Power and Performance Estimator and the "Using the SmartMesh Power and Performance Estimator" Application Note included with the spreadsheet.

5.1 Selection Issues

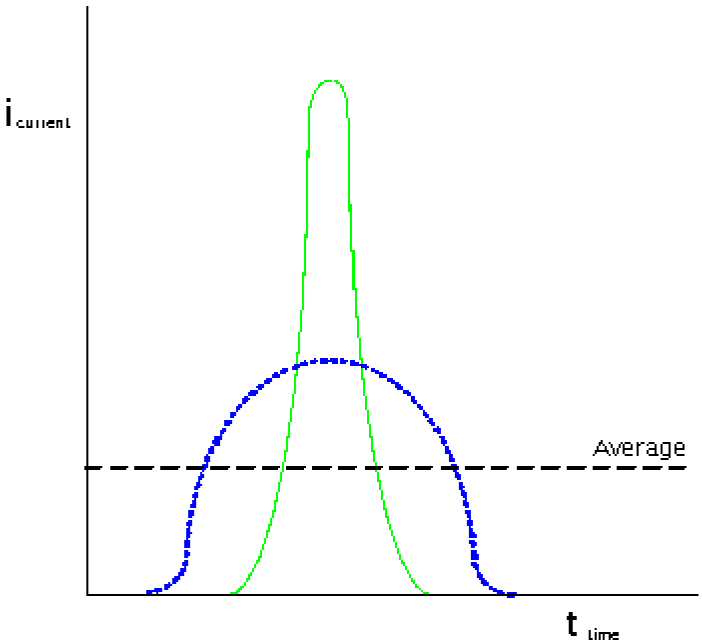
These points are important to battery selection in different ways. Some may be considered because they are minimum requirements; others because your particular application may require it. A few may not be of significance to your application, but need to be noted.

5.1.1 Storage Capacity

The storage capacity of the battery will be of primary concern in many applications. Industrial batteries can have up to 21,000 mAh of capacity. Battery life will depend on the storage capacity of the battery, the traffic the device handles in the network, and any sensor circuit power consumption. See appropriate application notes for battery lifetime calculations. There may be installation or replacement issues that battery storage capacity can solve. For example, if the sensor is in a very difficult or dangerous place to reach, then large D cells may be a better choice that gives the device a significantly larger lifetime.

Drawing large amounts of current for short periods of time can accelerate the end of battery life. Battery manufacturers of lithium cells recommend keeping the power draw close to the average rather than having dramatic fluctuations. For example,

1. Start with capacity "x".
2. Capacity consumed "i" over time "t".
3. One would guess that x – i = r (remaining capacity).
4. However, the actual remaining capacity is (x – i) – ƒ(it), where ƒ(it) is some function based on the time over which the consumption occurs. As "t" decreases ƒ(it) increases.



Even though the total current consumed for both applications is the same, the blue-dotted consumption profile will have a longer battery life because the peak current is closer to the average current. The green-solid current consumption profile will have a larger value for ƒ(it) because it deviates from the average more than the blue. The function ƒ(it) is not typically found in a battery datasheet and you should contact the battery manufacturer for that information. Tadiran recommends capacitor support for high rate current pulses of short duration to extend battery life. Their application note number is LTN6001B dated September 1997. Tadiran estimates that a TL-4903 with a 47 µF capacitor supporting the mote will last approximately 10 percent longer than one without a capacitor. Dust Networks motes' power consumption can be considered a high rate current pulse of short duration and, depending on the battery selected, it could benefit from normalization of the current draw.

5.1.2 Peak Source Current

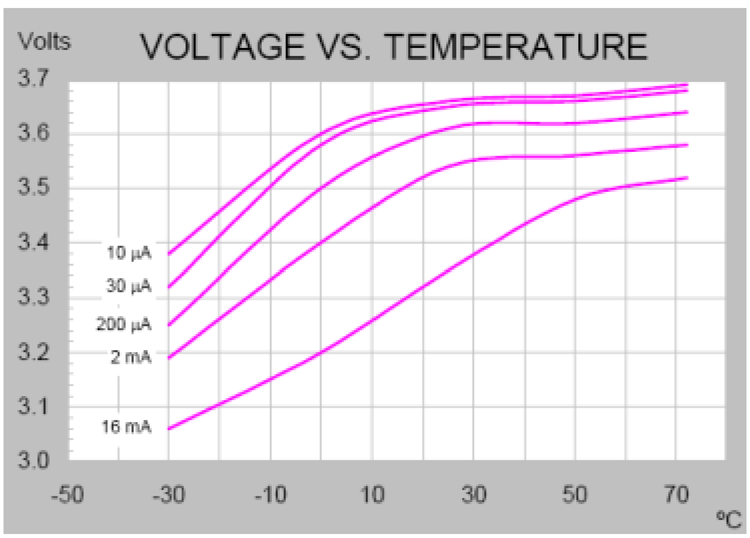
Often called 'maximum pulse current', *peak source current* is the load the battery can support for short periods of time. The load and voltage and time are typically different for each manufacturer, making it harder to compare this metric. However, if your sensor needs large amounts of current for short periods of time, this will be important. The most that the mote will draw is during the transmit process (see mote datasheet for specific Tx current number). Dust Networks motes draw higher amount of current (see mote datasheet for specific current) during the search cycle when a mote is looking for a network to join. The mote will stay in this receive mode until another mote is "heard." Even though most motes typically spend several seconds in this mode it is possible for a mote to consume its receive current for several times longer depending on availability of the network near where the mote is installed. It is important to note that a mote will consume orders of magnitude less current when it is in-network compared to when it is out searching for one. Also, the search at full receive current need not be at 100%. The mote can be programmed to search at duty cycles lot less than 100% (say 5%), in cases where the availability of network is doubtful at the time of installation of a mote. The batteries of motes that consume above their rated maximum current will lose battery life. Most batteries will supply the necessary current for that period of time, but the trade-off is accelerated mortality.

5.1.3 Operating Temperature

Temperature range will depend on the application. A manufacturer may rate their battery for "cool" temperatures or "hot" temperatures. This usually means the battery technology/chemistry performs better at those temperatures. It is important to note any conditions the manufacturer puts on temperature range.

5.1.4 Voltage/Source Current Over Temperature

This can be a big problem for an application if it is not considered up front. Not only does the battery need to be able to perform over temperature, it must be able to source enough current and voltage over the temperature range of the application. For example, if the range of the application is 0 to 70 °C, but the battery current or voltage drops below the minimum required (refer to specific datasheet) at 50 °C, then the mote will reset when the device reaches 50 °C. For example, the Tadiran TL-2100 is able to source enough power to allow a mote to join at -30 °C. That is, it can supply the required 4.4 mA at 2.75 V for the LTP59xx to function normally.



5.1.5 Voltage

Manufacturers express this as a value at a specific temperature. It is important to review the voltage over your application's temperature range. If the voltage dips below the minimum voltage (refer to specific datasheet), then the mote will reset. Industrial batteries can have voltage output as high as 3.6 volts. This is within the range for the mote; however, if the mote should be supplied above its maximum rated voltage (refer to specific datasheet), an appropriate circuit should be provided. Note that the Eterna based motes come rated at 3.76 volts, which is in line with the max open circuit voltage of commercially available lithium batteries and an external circuit is not required.

5.1.6 Form Factor

The size and shape of the battery may be a concern for the application. Batteries are available in all shapes and sizes. Typically the smaller the battery the less storage capacity it has. However, 3 AA batteries can have more capacity than one C cell battery. So size and shape can be used in different ways depending on the needs of the application and packaging.

5.1.7 Intrinsically Safe (Ex or ATEX certification)

If you design, manufacture or sell any equipment or protective system intended for use in potentially explosive atmospheres you will need to comply with the ATEX Directive 94/9/EC and the CE Marking Directive and the corresponding UL intrinsically safe certification in the US. Some batteries do have Ex certification, but often the issues with batteries exist when they are replaced/removed, causing sparks. Check with your UL or CE certification lab for more information.

5.1.8 Transportation

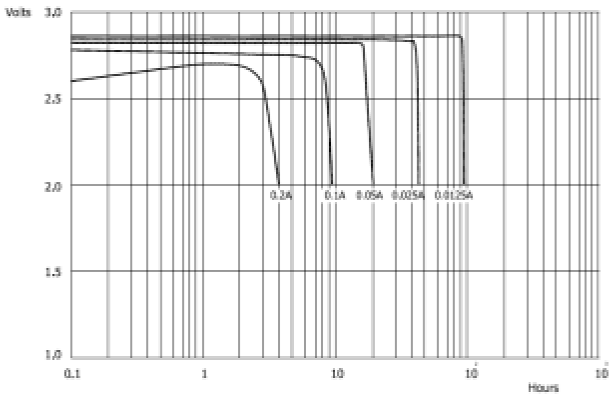
Transportation of lithium is regulated by the National Transportation Safety Administration. It may also be regulated differently by different states or countries. The amount of lithium in a battery can determine if a device can be shipped via US Postal Service or via airline. Most datasheets describe the class of material the battery falls into for transportation purposes. US Government regulations can be found at http://hazmat.DOT.gov.

5.1.9 Cost

Cost is always a concern in any application. However, cost of replacing batteries should be taken into account as well. For example, a network using 100 AA batteries that will last 4 years may be more expensive than a network using 50 C cell batteries that will last 6 years, simply because of the labor cost incurred to change batteries. One other consideration is to match the battery change with a maintenance period. That way the cost of changing batteries is minimized.

5.1.10 Discharge Behavior

As mentioned in the summary above, alkaline batteries do not have the discharge curve to supply enough voltage for a device to run for years. Alkaline batteries have a long life, but a very gradual discharge slope for voltage. Any battery selected must be able to supply the minimum voltage and peak current for the mote (see mote datasheet for specific voltage and current values) over the majority of the battery's lifetime. Lithium batteries are well suited for wireless sensor networks because they provide a relatively constant voltage, and drop off sharply at the end of their life.



Typical battery voltage over lifetime graph for a lithium battery.

5.1.11 Shelf Life

The amount of charge lost by a battery while in storage will be of concern in some applications, particularly if the product will be inventoried with the batteries in it until installed. Check the self-discharge rate of the battery. It is sometimes called the storage loss per year. The manufacturer will often have recommended storage temperatures. At higher temperatures batteries will typically discharge more quickly.

5.1.12 Disposal Requirements

See the manufacturers Material Handling Datasheet for the battery you select to determine the proper disposal method. It is unlikely, but the disposal process may be onerous for some applications.

5.1.13 Primary vs. Secondary

Primary batteries are discarded when they are discharged. Secondary batteries are rechargeable. Check the charging and storage characteristics of any secondary battery before using it in an application. Some lithium secondary batteries can have a very short recharge life if they are allowed to cycle deeply and recharge. This application note does not cover secondary battery selection.

5.2 Conclusions

There are combinations of the above elements to consider. For example, the Tadiran C2032 is a very small button battery that has 220 mAh of storage and costs about twenty cents. Most applications would not work well with this battery alone. However, if space or cost is a consideration, then five C2032 batteries might be about a dollar and have more capacity than one C2477 large button battery that has 1,000 mAh of storage and costs about double that amount. The five C2032's could be configured to take up less volume in the sensor package than the larger C2477.
Once you have narrowed your battery selection down based on minimum requirements, then you can begin to make trade-offs in areas where your application has flexibility.

5.3 Battery Characteristics

Battery Model	Size	Storage Capacity	Rated Voltage	Peak Source Current	Operating Temperature	Voltage / Current over Temperature	Cost	Shelf Life
Energizer L91 (2 in serial)	AA	3,000 mAh	1.5 V @ +20 °C	1.5 V 3.0A @ +20°C	-40 °C to +60 °C	Drops below 22 mA @ 2.7 V at 10 °C	$2	15 years at room temperature
SAFT LS14250C	½ AA	1,200 mAh	3.6 V @ +20 °C	3.0+ V 50 mA @ +20 °C	-60 °C to +55 °C	Drops below 22 mA @ 2.7 V at 0 °C	$6	1% self-discharge per year at +20 °C
Tadiran TL-5902S	½ AA	1,200 mAh	3.6 V @ +25 °C	3.0+ V 50 mA @ +25 °C	-55 °C to +85 °C	Drops below 22 mA @ 2.7 V at 0 °C	$7	Not Available
Tadiran TL-5955	2/3 AA	1,650 mAh	3.5 V @ +25 °C	3.0+ V 150 mA @ +25 °C	-55 °C to +85 °C	Drops below 22 mA @ 2.7 V at 0 °C	$8	Not Available
SAFT LS14500	AA	2,700 mAh	3.6 V @ +20 °C	3.0+ V 150 mA @ +20 °C	-60 °C to +55 °C	Drops below 22 mA @ 2.7 V at -30 °C	$7	1% self-discharge per year at +20 °C
Tadiran TL-5903S	AA	2,400 mAh	3.6 V @ +25 °C	3.0+ V 240 mA @ +25 °C	-55 °C to +85 °C	Drops below 22 mA @ 2.7 V at -50 °C	$8	Not Available

SAFT LS26500	C	7,700 mAh	3.6 V @ +20 °C	3.0+V300mA @ +20°C	-60 °C to +85 °C	Drops below 22 mA @ 2.7 V at -50 °C	$16	1% self-discharge per year at +20 °C
Tadiran TL-5920S	C	8,500 mAh	3.6 V @ +25 °C	3.0+ V 400 mA @ +25 °C	-55 °C to +85 °C	22 mA @ 2.7 V or above across full temp range	$17	Not Available
SAFT LS33600C	D	18,500 mAh	3.6 V @ +20 °C	3.0+ V 250 mA @ +20 °C	-60 °C to +55 °C	Drops below 22 mA @ 2.7 V at -20 °C	$23	1% self-discharge per year at +20 °C
Tadiran TL-5930S	D	19,000 mAh	3.6 V @ +25 °C	3.0+ V 500 mA @ +25 °C	-55 °C to +85 °C	22 mA @ 2.7 V or above across full temp range	$25	Not Available
Tadiran TL-2300S	D	16,000 mAh	3.6 V @ +25 °C	3.0+ V 500 mA @ +25 °C	-55 °C to +85 °C	22mA @ 2.7V or above across full temp range	$23	Not Available
Panasonic CR2477N	Large Button 24x7.7 mm	1,000 mAh	3.0 V @ room temperature	Not Available	-30 °C to +60 °C	Not Available	$4	1% self-discharge per year.
Tadiran TL-5186SP	Large Button 23x7.5 mm	400 mAh	3.6 V @ +25 °C	Not Available	-55°C to +85°C	Not Available	$8	Not Available

*Costs are approximate and for comparison only. See vendor for availability and current pricing.

5.4 Example – Extreme Temperature Application

A sensor network in a Norwegian oil field may be exposed to an average temperature of 0°C. However, the temperature can drop as low as -40 °C. All other aspects of the network considered, the temperature will be the driving selection criteria for a battery. Reviewing the battery characteristics the "Voltage / Current over Temperature" column will be the most important for this application. The top four and the two button batteries are out of the running because they cannot supply the peak current at -40 °C. This leaves us with the Tadiran TL-5920, TL-5930, and TL-2300. There is still a choice of lifetimes for the batteries because there is a C cell (TL-5920) and two D cell (TL-5930, 2300) batteries that meet the minimum criteria.

5.5 Example – Commercial HVAC Application

In an HVAC application sensing room temperature where the environment is always between 15°C and 30°C, almost any battery can be selected based on environmental characteristics. The driving issue now becomes battery life based on cost. Two Eveready L91 AA batteries have 3,000mAh of charge. Adding up the sensor and radio current L91 batteries could be a viable option. There are other batteries that might last as long, but the L91 is the least expensive on the list. For an office environment where temperatures do not vary beyond a 60 to 80 °F range the L91 battery may be a reasonable option for several years of life. The next step up in lifetime is the Tadiran TL-5920S at 8,500 mAh (almost thrice the lifetime of the L91). At eight times the cost per cell it is an expensive choice. However, if some of the temperature sensors are accessible only with special equipment, the cost of changing batteries may make the Tadiran TL-5920S battery a good choice.

6 Application Note: Designing for RF Certification

This application note outlines the software commands required to perform the tests for RF certification by various governing bodies. Certification processes require the devices to be put into special modes since the test protocols do not reflect typical in-network behavior. For example, while Dust devices typically operate in a deep duty cycle, both the FCC and ETSI tests require a device to transmit at full power on a specific channel continuously. The details of these commands are documented in the device datasheets. This discussion will only include which commands are best suited for specific types of tests. The exact implementation of those commands is left to the reader.

Dust Networks' Modular certified devices (LTP59xx) also require some level of RF testing but may not require any special implementation. This document briefly outlines this process.

> The customer must consult with the appropriate testing lab to ensure that the design (including antenna and testing) will meet the specific certification requirements per the product geographical shipment needs (FCC, IC, CE etc).

Governing Body	**Radio Requirements**	**Where to find more information**
Federal Communications Commission (FCC)	Part 15.247	http://www.fcc.gov
European Radio Communications Office (R&TTE)	EN 300 328 V1.6.1 (2004-11)	http://www.ero.dk/rtte
Industry Canada (IC)	RSS 210	http://www.ic.gc.ca/

6.1 Certification Overview

Much of the testing for RF certification by various governing bodies is designed to check the likelihood of the Device Under Test (DUT) of interfering with other RF devices already on the market. Some additional tests are required by Industry Canada (IC) and European Union (CE) that check the DUT's ability to resist interference by external RF sources. All certification testing in the document refers to FCC Part 15 subpart C or the equivalent. Necessary data for most testing requirements is contained in the Technical Construction file for that product. See document references section.

6.1.1 Modular Device Testing

Modular certification is the ability to test a "radio module" that will later be inserted in a finished product, allowing that product to inherit the modular certification and only require a subset of electromagnetic testing to be performed on the finished product. The first certification body to recognize this type of certification was the FCC. The FCC has specific requirements for modular certification that finished products do not have. Some of those requirements are that a "shield" be placed over the radio components of the module and that antenna specifications be provided to the user of the module. Chip radios cannot be modularly certified because of the requirements of the FCC.

Modular certification is available on the motes that are PCBs and have an antenna or antenna connector on them (mote part numbers starting with LTP59xx). Check the mote or embedded manager datasheet for specific antenna requirements to reuse modular certification (FCC and IC). The antenna type (monopole, dipole etc) must conform to the same type of antenna used to modularly certify the mote and or the embedded manager. Unintentional radiator testing is also typically required for devices, or products that include a radio that has modular approval. (covered in FCC part 15.33(b), and depending on the product may be governed by other sections).

An OEM may design a radio module using the chip LTC5800 or DN2510 that can then be included in the OEM's other products. This can be an efficient means of leveraging design and testing costs.

6.1.2 Intentional Radiator Testing

Full device testing, often called intentional radiator testing, requires the DUT to adhere to many different requirements, including but not limited to: in-band signal strength, out-of-band emissions, frequency hopping order, frequency dwell time, etc. Intentional radiator testing is generally covered in FCC section 15.247. Dust Networks devices are both direct sequence spread spectrum (DSSS) and frequency hopping (FH), which in FCC terminology is called a hybrid device. This differs from modular testing in that the certification is not portable to other devices that include the DUT inside them. The modular requirements on how the DUT must be designed do not apply. For example, no power regulator on the radio is required and no RF shield is required. Most CE Mark testing is intentional radiator.

6.1.3 Unintentional Radiator Testing

This category of testing is applied to devices, or products that include a radio that has modular approval (or has no radio at all). The requirements are covered in FCC part 15.33(b), and depending on the product may be governed by other sections.

6.2 LTC58xx and DN2510-Based Device Requirements

All products created based on the LTC58xx or DN2510 radio chip require full testing. Dust Networks has verified that the products are certifiable by obtaining certifications for our development and evaluation products.

> Customers must have their product certified once the LTC58xx or DN2510 is designed into their device.

As with our other Dust Motes, there are specific commands that must be implemented to place the LTC58xx or DN2510 into specific test modes for various types of tests. These commands (*testRadioTxExt*, *testRadioRx*, *getParameter<testRadioRxStats>*) are described in the appropriate Mote Serial API Guide. The Dust Networks utilities, available with the SDK (software development kit), further implement these commands which the user can use as reference to develop its own product specific commands.
The *testRadioTxExt* command allows transmission of a known number of packets on a selected channel. *testRadioRx* command allows for packet reception on specified channel and the command *getParameter<testRadioRxStats>* provides statistics on packets received (with or without error).

6.3 Test Types

6.3.1 Single frequency transmission

Command: *testRadioTxExt*
The majority of the tests performed during FCC, CE Mark, or IC testing require a DUT to be transmitting on a single channel at full power. A means to place a device into this mode must be provided to facilitate these tests. The test mode transmits N packets of 128 bytes in length with a 100 ms interval between packets with the number of packets sent and the channel number as parameters. Power measurements can be made based on modulation bandwidth and Tx duty cycle.
The FCC only requires the lowest, middle, and highest frequency to be tested. However, we recommend implementing this for all channels. Other countries may require tests performed at all or different frequencies.

6.3.2 Receive mode

Command: *testRadioRx*
Few governing bodies require a device to be tested for emissions when the radio is in receive mode. However, there are HDLC commands to place a device into receive mode on a specific frequency. See the product datasheet for specific implementation of the commands. Check with your test laboratory to determine if you need to implement these commands for your certification tests.

Command: *getParameter<testRadioRxStats>*
This command provides the statistics generated by the *testRadioRx* command. Hence this command should be implemented for tests performed in the receive mode.

6.3.3 Radio off

Command: N/A (default state when in test mode)
Unintentional radiator types of tests are performed with the radio neither transmitting nor receiving. The command to turn the radio off on the device should be implemented.

6.3.4 Frequency hopping

All frequency hopping tests should be performed with normal networking software in operation. There are no radio test HDLC commands for tests such as dwell time or hopping order. Dust Network devices only begin hopping when they have established communication with another device that is connected to the network (manager or mote). Thus another network device, typically a manager, is used at a distance to facilitate this type of test.
Please note that it is best to describe to the test laboratory that the radio in your device is deeply duty cycled. They may not be able to detect the transmissions at first as most test labs look for relatively frequent transmissions.

6.3.5 Interference immunity

This is a set of tests that must be performed with the radio operating in normal network mode. Often these tests take the form of sending data from a mote to a manager and monitoring the connection. If the mote loses connection to the manager during the test, then it has failed. If the mote maintains its connection with the manager during the test, then it has passed. However, check with your specific test lab to determine how they typically perform interference immunity tests.

7 Application Note: Documents for New Mote Design

7.1 SmartMesh WirelessHART

- The Datasheet for the LTC5800-WHM SoC, or one of the 22-pin module or 66-pin modules based on it.
- A Hardware integration guide for the SoC or module - this discusses best practices for integrating the SoC or module into your design.
- A Board Specific Configuration Guide - this discusses how to set default IO configuration and crystal calibration information via a "fuse table".
- SmartMesh WirelessHART User's Guide - contains description of device behavior including joining a network, services, and how to communicate with a host application. This provides context for the APIs.
- SmartMesh WirelessHART Mote API Guide - contains a description of the API for programmatic access to the mote. This is the interface your mote application will use.
- SmartMesh WirelessHART Mote CLI Guide - contains a description of the commands available on the CLI human interface. Useful during development for debug.
- The ESP Programming Guide - a guide to the ESP software used to program firmware on a device.
- ESP software - used to program firmware images onto a mote or module.
- Fuse Table software - used to construct the fuse table as discussed in the Board Specific Integration Guide.

7.2 SmartMesh IP

- The Datasheet for the LTC5800-IPM SoC, or one of the modules based on it.
- A Hardware integration guide for the SoC or module - this discusses best practices for integrating the SoC or module into your design.
- A Board Specific Integration Guide - this discusses how to set default IO configuration and crystal calibration information via a "fuse table".
- SmartMesh IP User's Guide - contains description of device behavior including joining a network, services, and how to communicate with a host application. This provides context for the APIs.
- SmartMesh IP Mote API Guide - contains a description of the API for programmatic access to the mote. This is the interface your mote application will use.
- SmartMesh IP Mote CLI Guide - contains a description of the commands available on the CLI human interface. Useful during development for debug.
- The ESP Programming Guide - a guide to the ESP software used to program firmware on a device.
- ESP software - used to program firmware images onto a mote or module.
- Fuse Table software - used to construct the fuse table as discussed in the Board Specific Integration Guide.

8 Application Note: Migrating WirelessHART Mote Designs from the DN2510 to an LTC5800

8.1 Overview

This application note is intended to be used in conjunction with the Eterna Integration Guide. The LTC5800-WHM can be configured to provide a nearly identical implementation to previous DN2510-based products, with significant performance increases in most areas. Differences will be highlighted in this document. Note that for previous users of the M2510 22-pin module, the LTP5900-WHM is a drop-in replacement with similar caveats. Table 1 shows the list of signals previously exposed on DN2510 and M2510 designs and their equivalent signals on the LTC5800-WHM and LTP5900-WHM.

Table 1 - Signal Mapping

DN2510			**LTC5800**		
Signal Name	**M2510 Pin**	**DN2510 LGA Pin**	**Signal Name**	LTP5900 Pin	**LTC5800 QFN Pin**
Antenna	-	4	ANTENNA	-	14
RX	4	26	UART_RX	4	68
TX	5	24	UART_TX	5	71
MT_RTS	7	20	UART_TX_RTSn	7	69
MT_CTS	8	29	UART_RX_CTSn	8	67
SP_CTS	9	22	UART_TX_CTSn	9	70
TIME	10	23	TIMEn	10	72
FLASH_P_EN	12	17	FLASH_P_ENn	12	55
SCK	17	31	IPCS_SCK	17	44
MOSI	18	32	IPCS_MOSI	18	42
MISO	19	33	IPCS_MISO	19	40
SPI_CS	21	18	IPCS_SSn	21	45
RST	22	11	RESETn	22	22
			TDI	16	23

			TDO	17	24
			TMS	18	25
			TCK	19	26
			RADIO_INHIBIT	64	1
			SLEEPn	27	35
			UARTC0_TX	62	37
			UARTC0_RX	59	38

8.2 Boot Time

DN2510-based designs had two options for boot - normal (~6 s from reset to boot event and API available) and slow (many minutes). The LTC5800-WHM boots in ~800 ms. The boot event is repeated if not acknowledged (e.g. in cases where the customer processor is not ready in time).

8.3 Supply

The LTC5800-WHM can operate over a wider input supply range, 2.1 to 3.76 V versus 2.75 to 3.6 V; however, support for operation of the API serial port in Mode 3 is limited to 2.7 V and above. The LTC5800-WHM requires significantly less energy to boot reducing the maximum quantum of charge to be consumed down from 2.3 mC to 200 µC, which should in current limited designs reduce the required supply capacitance. The LTC5800-WHM requires significantly different bypassing than the DN2510 - see the Eterna Integration Guide for details on correct use of bypass capacitors.

8.4 Serial Port

Users of the LTP5900-WHM can select the same UART modes available in the M2510. For new designs incorporating the LTC5800-WHM, we recommend using the one of the modes described in the LTC5800-WHM Datasheet.

Monitoring buffer fullness as was done on the DN2510 is not required. Should the LTC5800-WHM encounter a buffer shortage, packets destined for the network will indicate an error in the acknowledgement (a *NACK*). Note that Eterna's UART_RX_RTSn signal is an unused input and should be tied to VSUPPLY.

8.5 Crystals

Unlike the DN2510, which contained all needed crystals onboard, the LTC5800-WHM requires external 20 MHz and 32 kHz crystals. It is important that you only use crystals from the recommended list found in the Eterna Integration Guide. Sample routing for crystal traces is included in the integration guide.

8.6 Additional Pins

There are additional pins available that may be incorporated when a design is migrated to the LTC5800. These signals are not available in DN2510-based designs. See the LTC5800-WHM Datasheet for information.

- TDI, TDO, TMS and TCK Pins are available for JTAG programming, debugging, and Boundary Scan.
- SLEEPn is reserved for future use. It should be tied to VSUPPLY.
- RADIO_INHIBIT (active high) can be used to prevent usage of the radio for short periods of time, for example during a sensor measurement.
- CLI_Tx and CLI_Rx - The LTC5800 supports a second UART that can be used for human interaction with the chip, e.g. for configuration or diagnostic traces. This interface is particularly useful during development.

8.7 Time Pin

In DN2510-based designs, the TIME pin latched the time when it was asserted (active low). For LTP5900-WHM based products, driving the TIMEn pin low (assert) wakes the processor. The pin must asserted for a minimum of t_{strobe} µs. De-asserting the pin latches the time, and a *timeIndication* will be generated within $t_{response}$ ms. Refer to the LTC5800-WHM Datasheet for timing details.

> The processor will remain awake and drawing current while the TIMEn pin is asserted. To avoid drawing excess current, take care to minimize the duration of the TIMEn pin being asserted past tstrobe minimum.

8.8 Programming

Programming of application code onto LTC5800 is done using the DC9010 Eterna Serial Programmer. Connector J3 from the example schematic found in the Eterna Integration Guide is required for mating to the DC9010

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