HASP Student Payload Application for 2021

Payload Title:
Montana Space Grant Consortium Eclipse Payload Testing

Institution: Montana State University (MSU) / Montana Space Grant Consortium (MSGC)

Payload Class (Enter SMALL, or LARGE): SMALL	Submit Date: January 8, 2021

Project Abstract: There is growing interest within University and light payload balloon community to utilize zero pressure or solar heated balloons to provide extended or long duration flight capability. While the FAA regulations, which are only based on payload weight and not on balloon envelope construction, don't require flight termination capability for payloads conforming to FAR 101 it is highly desirable for balloon operators to possess the ability to terminate the flight of both the payload and balloon envelope for safety and logistical considerations. The Montana Space Grant Consortium (MSGC) balloon program has been developing, refining and utilizing flight termination systems for the past seven years and is proposing to use the HASP program as a testbed to demonstrate and validate the reliability of the termination system under actual long duration flight conditions.

The proposed termination system employs two redundant and independent circuits to activate a heated nichrome wire capable of severing the line connecting the balloon and payload. A programable microcontroller functioning as a countdown timer can execute the termination should communication with the balloon be lost. User-initiated control is accomplished via a command sent to an Iridium 9602 LP satellite modem and relayed to the termination unit via a paired set of low power, shortrange, XBEE radios.

Team Name: MSGC HASP 2021	Team or Project Website: Under Development

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Flight Hazard Certification Checklist

Hazardous Materials List		
Classification	**Included on Payload**	**Not Included on Payload**
RF transmitters	**Yes**	
High Voltage		**X**
Pyrotechnics		**X**
Lasers		**X**
Intentionally Dropped Components		**X**
Liquid Chemicals		**X**
Cryogenic Materials		**X**
Radioactive Material		**X**
Pressure Vessels		**X**
Magnets		**X**
UV Light		**X**
Biological Samples		**X**
Li-ion Batteries	**Yes-standard commercial AA Energizer Lithium L91 Batteries**	
High intensity light source		**X**

Student Team Leader Signature: Lance Nichols January 8, 2021

Faculty Advisor Signature: [signature] January 8, 2021

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1. Payload Description

1.1 Payload Scientific / Technical Background

Our payload exists to demonstrate the reliability of a flight termination system under long duration balloon flight conditions. There is growing interest within University and light payload balloon community to utilize zero pressure or solar heated balloons to provide extended or long duration flight capability. While the FAA regulations, which are only based on payload weight and not on balloon envelope construction, don't require flight termination capability for payloads conforming to FAR 101 (https://www.govinfo.gov/content/pkg/CFR-2018-title14-vol2/xml/CFR-2018-title14-vol2-part101.xml) it is highly desirable for balloon operators to possess the ability to terminate the flight of both the payload and balloon envelope for safety and logistical considerations. The Montana Space Grant Consortium (MSGC) balloon program has been developing, refining and utilizing flight termination systems for the past ten years[1] and is proposing to use the HASP program as a testbed to demonstrate and validate the reliability of the termination system under actual long duration flight conditions.

The termination system possesses redundant timer controlled (no contact) and user initiated activation of a heated nichrome wire capable of severing the line connecting the balloon and the flight payload. These systems are truly independent in that they do not share either circuitry or power. The connecting line between the balloon and associated payload passes under both the nichrome filaments such that activating either one will cause the line to be severed and the flight terminated. A programable microcontroller functioning as a countdown timer can execute the termination should communication with the balloon be lost. The user initiated system is controlled via a command sent to an Iridium 9602 LP satellite modem and relayed to the termination unit via a paired set of low power, shortrange, XBEE radios. MSGC developed the user initiated system as part of 2017 Nationwide Eclipse Ballooning Project (NEBP) where a motor driven razorblade was used to sever the line. In 2019 the system was modified to use a heated nichrome wire to reduce the size of the unit and to eliminate cutting hazards from the razorblade.

The termination systems rely on two independent AA lithium batteries for the system power and to provide the necessary current to heat the nichrome wire above the temperature required to sever the connection line. Because the AA batteries are only intended for a single termination, we are proposing to fly multiple units (8) to enhance the testing and demonstration of the unit's reliability. We are requesting for the termination units to be mounted on open areas of the framework providing the support structure for the small payloads and within the field of view of the camera systems. The termination systems will have an indicator flag captured by a line threaded through the unit that will flip up when the line is cut indicating a successful termination. The goal will be to execute the terminations via either the timer controlled or user-initiated command at predetermined times over the course of the flight.

1.1.1 Mission Statement

A reliable and tested termination system is required to fly balloons that float for an extended mission duration. Long duration flight opportunities like HASP provide a unique testing opportunity for emerging technology development. This project hopes to capitalize on the opportunity by demonstrating a reliable cutdown system for termination of flights. By flying several termination systems on a single long duration flight, we will accelerate the in flight testing at altitude of the proposed termination system. This flight will demonstrate to NASA and stakeholders a viable cutdown system for use on small zero pressure or solar balloon termination.

1.1.2 Mission Background and Justification

Mission Background

Building on a successful NASA-sponsored project during the 2017 total solar eclipse, MSGC proposes to grow and augment our Nationwide Eclipse Ballooning Project (NEBP) by becoming integrated into NASA's Science Mission Directorate (SMD) Science Activation (SciAct) program. The overarching goal of NEBP 2021-2025 is to broaden participation of STEM learners by immersing teams in an innovative NASA-mission-like adventure that engages the participants with subject matter experts in the end-to-end, mission-oriented process of designing, building, testing, and flying instrumentation, and analyzing the data and publishing the results in peer-reviewed and popular literature. To achieve our goal, we will augment and engage a nationwide educational network to enable student teams to conduct scientific ballooning experiments during the 2023 annular and 2024 total solar eclipses. We hope that the broad NEBP 2021-2025 project will be jointly funded between the NASA SMD SciAct program, NASA Space Grant, NASA Minority University Research and Education Project (MUEP), and the National Science Foundation (NSF).

Since the early 2000s, scientific ballooning has been a common hands-on workforce development activity in the US. We generalize two types of scientific ballooning tools typically used in academia, radiosondes and balloons carrying payloads engineered by students, or "engineering platforms". Radiosondes are small, with payloads of less than 190 grams of balloon-borne instruments that are used to measure atmospheric parameters through the stratosphere. Engineering balloon platforms are capable of lifting up to 12 pounds of payload into the stratosphere to altitudes of approximately 100,000 feet. At these altitudes – above 99.5% of the atmosphere – payloads experience a space-like environment: the temperature profile can get cold (-10° to -85° F), the pressure is low (down to 0.1 lb/in2), and the curvature of the Earth with the blackness of outer space is visible. Due to this space-like environment, balloons are often said to fly "at the edge of space" or in "near space," though they do not reach the commonly agreed-upon 380,000 feet as representing the beginning of space. Typical experiments include atmospheric measurements, photography, GPS tracking systems, cosmic radiation measurements, and space technology proofs of concept.

In the first NEBP our vision was for student teams to fly engineering balloon platforms across the US and live stream the 2017 total solar eclipse from the edge of space.[2] Our objectives were to conduct meaningful science experiments based on common payloads, engage a wide audience beyond the student participants, involve students in impactful hands-on workforce development, build long-lasting partnerships, and raise the capabilities for academic scientific ballooning. To accomplish this vision we leveraged NASA SMD funding, the NASA Space Grant community, and several other partners to provide the common payload supplies, team support, ballooning expertise, training guidance, and other necessary resources. The main live streaming project had 54 student teams from 32 states. Each participating team was expected to fly the common payloads but retained about half of the balloon's lifting capacity for experiments of their choice. The common payloads consisted of the live-streaming video system; a live still-image system; a satellite tracking system; and a system that could cut the payloads away from the balloon should FAA air traffic control deem it necessary. Intensive event preparation included two in-person workshops, local practice, regular telecons and email communication, and constant assistance from project leaders.

The NEBP 2021-2025 includes development, training, and follow-through for two primary tracks – engineering/large balloon and atmospheric science. At sites along the eclipse path, student teams participating in the atmospheric science track will make frequent observations by launching hourly radiosondes on helium-filled weather balloons to 110,000 feet. In addition, we will collect high temporal-resolution, surface-site data. This design will provide surface, lower, and middle atmospheric observations with enough spatial and temporal sampling to contrast the meteorological differences before, during, and after each eclipse. Student teams participating in the engineering track will use innovative larger balloon systems to live stream high-quality video to the planned NASA eclipse website, measure eclipse-induced atmospheric phenomena, and conduct other applicable, individually designed experiments. Project participants will work with atmospheric science experts to analyze the recorded data and publish the results. Together, the unique combination of the data from two activity tracks will provide answers to important scientific and engineering questions. NEBP 2021-2025 will involve 70 teams, 30 for atmospheric science and 40 for engineering. Each team is comprised of 7-30 students and 1-6 mentors. The 70 teams will be divided into eight pods, four for each atmospheric science and engineering. The pod structure will facilitate effective communication and training. Every official team will receive ballooning supplies and engineering system materials or radiosondes. The NEBP leadership team is headed by the Montana Space Grant Consortium (MSGC) and includes atmospheric scientists as well as academic ballooning experts who will serve as leads for each of the eight pods of teams. NEBP will positively impact participating students and partners via attainment of our four goals: 1) Enhance STEM learning of participating students, 2) Contribute to NASA's solar eclipse efforts, 3) Raise the capabilities of academic scientific ballooning in the US, and 4) Enhance the NEBP interconnected network of partnerships.

Justification

A reliable and tested termination system is required for NEBP 2021-2025 as the goal is to fly balloons that float for an extended mission duration for the solar eclipses in 2023 and 2024. Long duration flight opportunities like HASP provide a unique testing opportunity for emerging technology development. This project hopes to capitalize on the opportunity by demonstrating to stakeholders a reliable cutdown system for termination of student flights. By flying several termination systems on a single long duration flight, we will accelerate the in flight testing at altitude of the proposed termination system for the NEBP 2021-2025 project.

1.1.3 Mission Objectives

This project seeks to develop and test a highly reliable and effective cutdown system under actual high altitude balloon flight conditions. In accomplishing our mission, we will complete four objectives.

- Finish development of a robust cutdown system with entirely redundant backup cutdown system.
- Successfully pass environmental chamber tests at Palestine, Texas.
- Demonstrate the effectiveness of our primary radio controlled cutdown while in flight on the HASP flight in September using four cutdown units.
- Demonstrate the effectiveness of our backup timer-based cutdown system utilizing four more cutdown units.

Objective 1: Development

This objective will include development and testing of the updated cutdown electronics and hardware. This objective will be considered a success if the following can be demonstrated.

- The following capabilities at: 1 Atm and at both a temperature of –30 C and a temperature of +40 C
  - 14 hours of operation of the cutdown unit followed by the cutting of a string under an arrangement meant to mimic in flight conditions using radio capabilities
  - 14 hours of operation of the cutdown unit followed by the cutting of a string under an arrangement meant to mimic in flight conditions using timer capabilities

Objective 2: Environmental Test

This objective is part of the HASP payload integration process. This rigorous test will demonstrate the capabilities of the cutdown system in extreme conditions

- The units operate at 5 mbar and -40 C to +50 C

Objective 3: Primary Cutdown Effectivity

This objective seeks to begin to prove the effectiveness of the remotely controlled cutdown. This objective will be considered a success if the following can be demonstrated.

- The cutdown systems are set up such that an actual cutdown scenario is mimicked.
- A physical flag is observed to have been raised, indicating the string was cut, within 10 minutes of command sent.
- While at float the four cutdowns are demonstrated at the most extreme temperature conditions possible (i.e., If the flight occurs partially in the day and partially at night the cutdowns would be demonstrated at both night and day).
- While at float the cutdowns will also be tested over a long time interval with a maximum time of 14 Hours since device turn on to demonstrate battery longevity given power draw. This will prove the capability of the system in an interval that exceeds proposed future flight durations.

Objective 4: Secondary Cutdown Effectivity

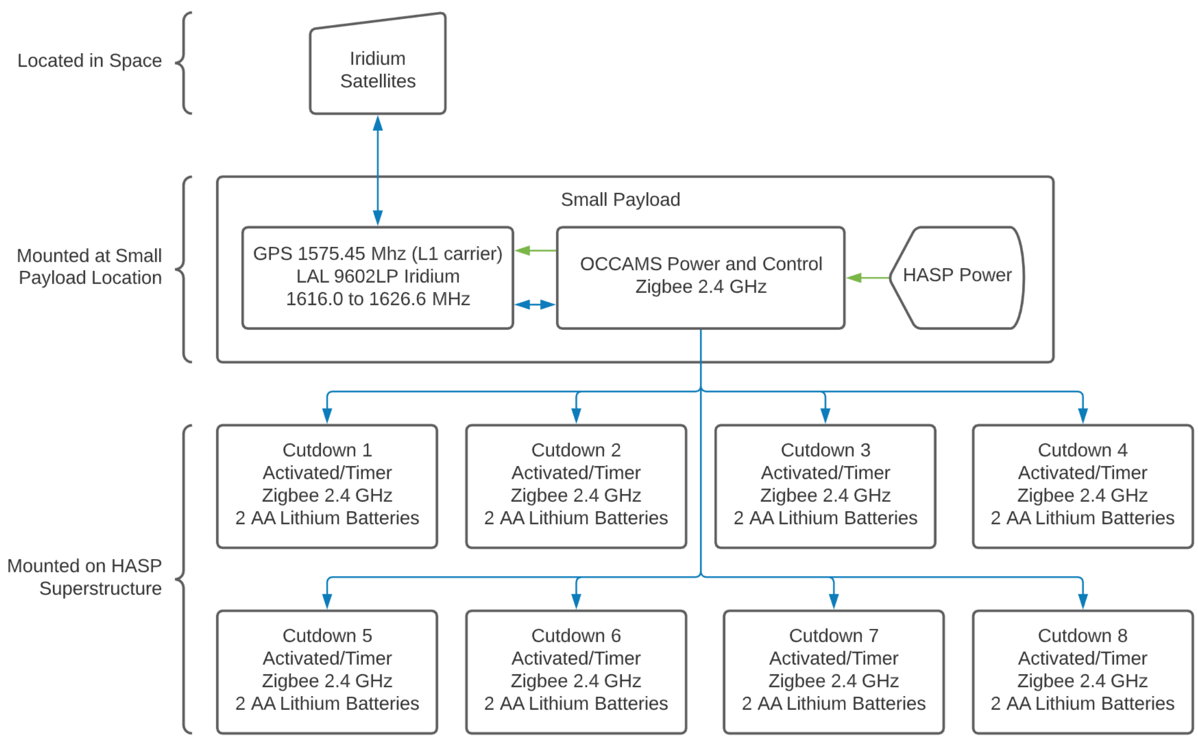
This objective seeks to begin to prove the effectiveness of the time controlled cutdown. This objective will be considered a success if the following can be demonstrated.

- The cutdown systems are set up such that an actual cutdown scenario is mimicked.
- A physical flag is observed to have been raised, indicating the string was cut, within 5 minutes of timer expiration.
- Have the systems trigger at the following time intervals to be counted from launch. This will prove the capability of the system in an interval that exceeds proposed future flight durations.
    - Timer at 5 hours
    - Timer at 6 hours
    - Timer at 7 hours
    - Timer at 8 hours

1.2 Payload Systems and Principle of Operation

This is a high-level description of your experiment including a statement of the principle of operation of your experiment plus showing and explaining the major components, processes and interfaces that make up your payload. A preliminary system level diagram should be included here. This diagram is then explained in detail in sections 1.3, 1.4, 1.5 and 1.6.

The following figure shows the complete MSGC HASP 2021 system consisting of the small payload and 8 cutdown/termination units.

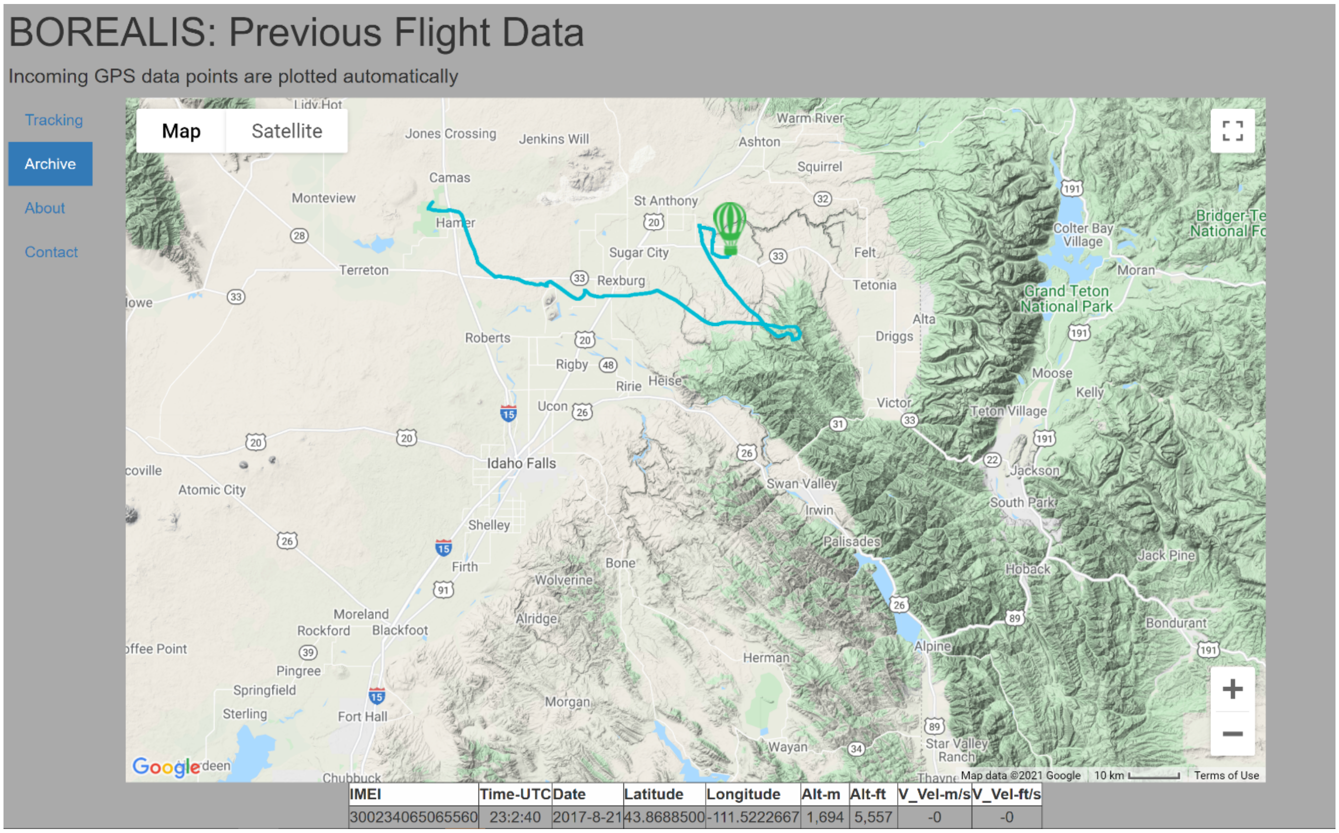


Proposed MSGC HASP 2021 System Sketch

Our small payload will have a proven NAL 9602-LP ultra-low power Iridium based asset tracker that will be used to track the balloon during their flight.[3] The modem will report via short burst data (SBD) packets the GPS coordinates to a central server that will then populate a central database for the balloon. The database will then be used to display the near real-time location of the balloon onto our flight tracker website for use by the FAA and other stakeholders. The HASP power supply will be used to power a custom design power supply and embedded microcontroller printed circuit board. The microcontroller will interface to the NAL modem input and output pins to provide status and payload control (one being cutdown) via custom email packets sent thru the Iridium network to the balloon. The microcontroller has a XBEE 2.4 GHz radio for wireless transmission of the unique control signals throughout the HASP balloon payload string.

Under actual flight conditions the cutdown system would be deployed on the lead line between the parachute and the balloon. To emulate this condition on HASP, the lead line will tensioned by a spring assembly (shown in the mechanical structure section) that will release and raise an indicator flag signaling that the line has been cut. The cutdown system utilizes a proven design that has a microcontroller interfaced to an XBEE 2.4 Gz radio for wireless receiving of the unique cutdown control signal from the NAL modem wireless link mentioned above. When commanded by an email cutdown message, a hot wire line cutter will sever the lead line. The cutdown system is powered by a standard commercial AA Energizer lithium L91 battery. Since two methods of flight termination substantially enhance flight safety requirements, a redundant and independent microcontroller timer-based system will time out and a secondary hot wire line cutter will severe the lead line. This secondary cutdown system will be powered by a second standard commercial AA Energizer lithium L91 battery. The two separate hot wire cutdown systems are placed in series along the lead line between the parachute and the balloon. Either one of the cutdown methods will allow the flight to be terminated.

The flight tracker website *https://borealis.rci.montana.edu/tracking* displays all balloons in flight on a Google map that is color coded to show balloons below, above and currently in airline airspace. Individual statistics and flight tracks are available for each balloon. The maps are interactive, and one can zoom in or out for a custom view. The tracking website is designed to work across multiple platforms including cell phones.



Flight Tracker Website showing a typical flight and Iridium tracking modem data.

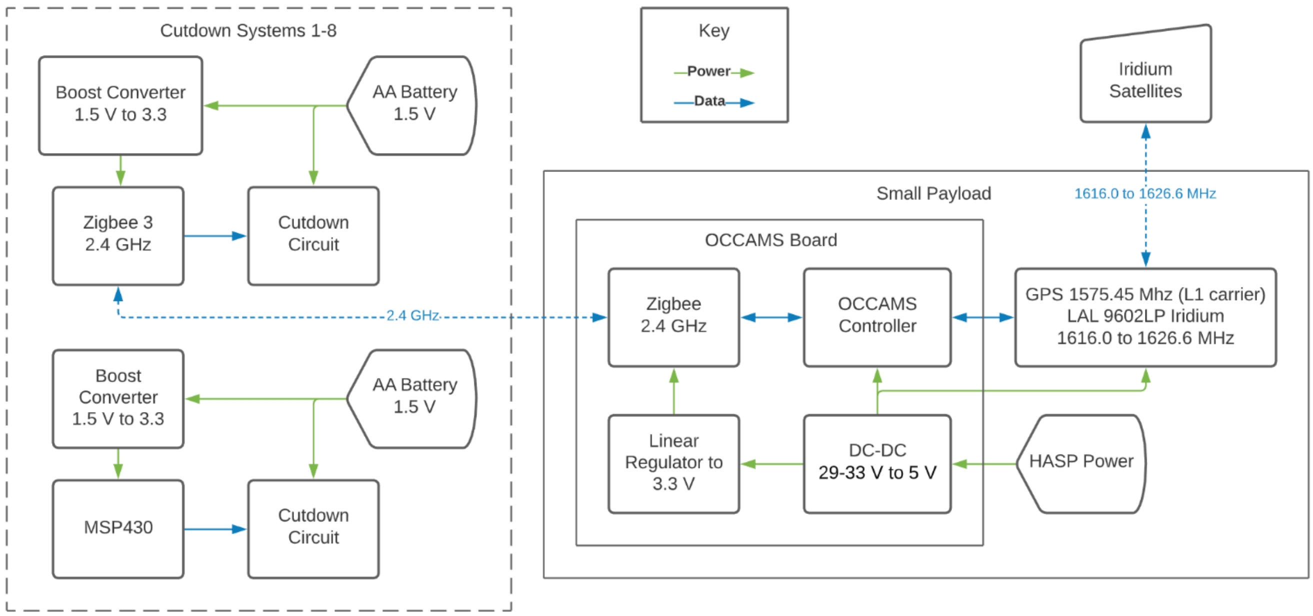
1.3 Major System Components

The major component groups of the payload are split into two categories; the Small Payload and the Cutdown/Termination Systems.

Small Payload
The small payload is powered by the HASP power supply and includes a DC-DC converter to generate the required 5 volts for the payload power. This 5 volts powers the NAL 9602-LP ultra-low power Iridium asset tracker modem and the OCCAMS controller. The OCCAMS controller is a microcontroller that is interfaced to the NAL 9602-LP and converts the control signals received from the Iridium Satellite network to control packets that are then sent to the Xbee/Zigbee radio module. The Xbee/Zigbee radio module will then send these commands wirelessly to the 8 different Cutdown/Termination Systems for processing. A liner low drop out regulator is used to convert the 5 volts to the required 3.3 volts of the Xbee/Zigbee radio modules.

Cutdown/Termination Systems
There are 8 cutdown/termination systems that are mounted on the super-structure of the HASP gondola. Each cutdown/termination system consists of a Xbee/Zigbee radio module for receiving command packets from the small payload module, a standard off the shelf AA lithium battery, a boost converter to give us the required 3.3 volts for the radio module and a cutdown/termination circuit. In addition there is an independent timer based system consisting of an ultra low power MSP430 microcontroller, another standard off the shelf AA

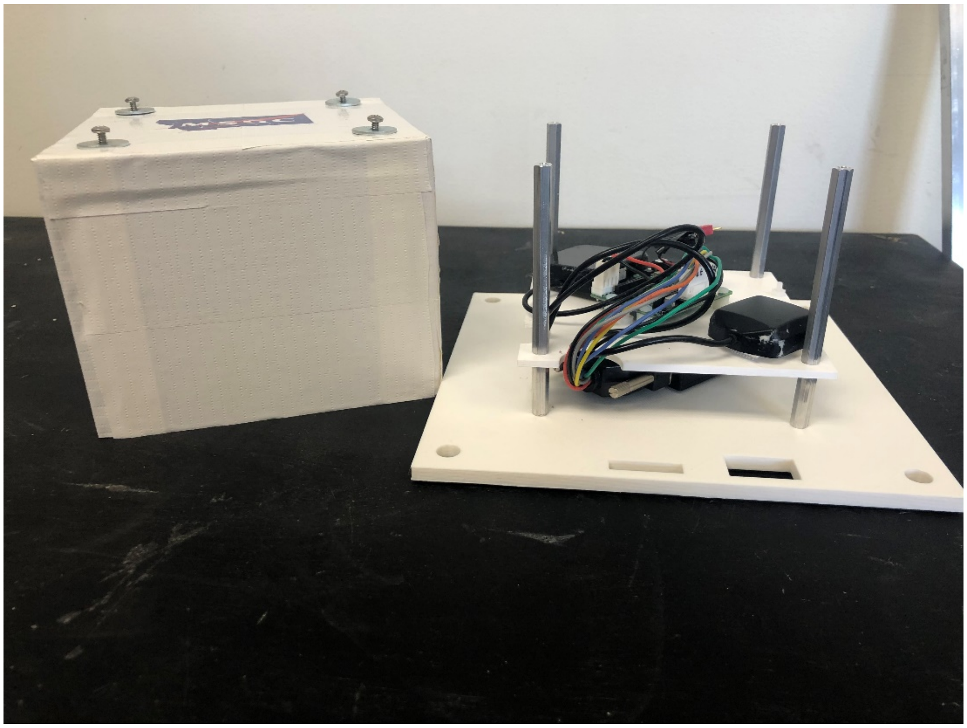
lithium battery, a boost converter to give us the required 3.3 volts for the radio module and an independent cutdown/termination circuit.

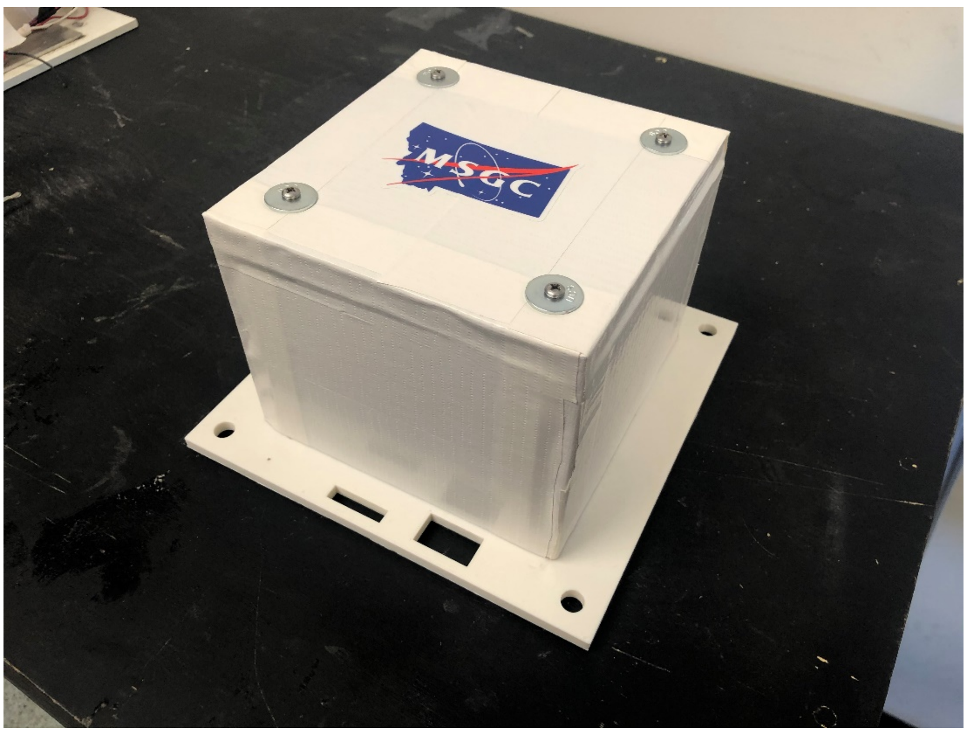


MSGC HASP 2021 Payload; 1 Small Payload and 8 Cutdown/Termination Systems

1.4 Mechanical and Structural Design

A mockup of the payload housing and support structure is provided below using 3D printed parts. The payload hardware will be mounted to a 1/8th inch thick aluminum plate that serves as both the mounting structure and an electrical ground plane for the system. The plate is elevated an inch above the HASP mechanical interface plate using ¼ hex aluminum standoffs that are bolted to the mechanical interface plate. The Iridium modem will be bolted onto the bottom of the aluminum plate. The Iridium modems antennas will be fixed to the top of the aluminum plate as well as the OCCAMS board and XBEE. This entire structure will then be encased in a foam solar shield that is bolted on.

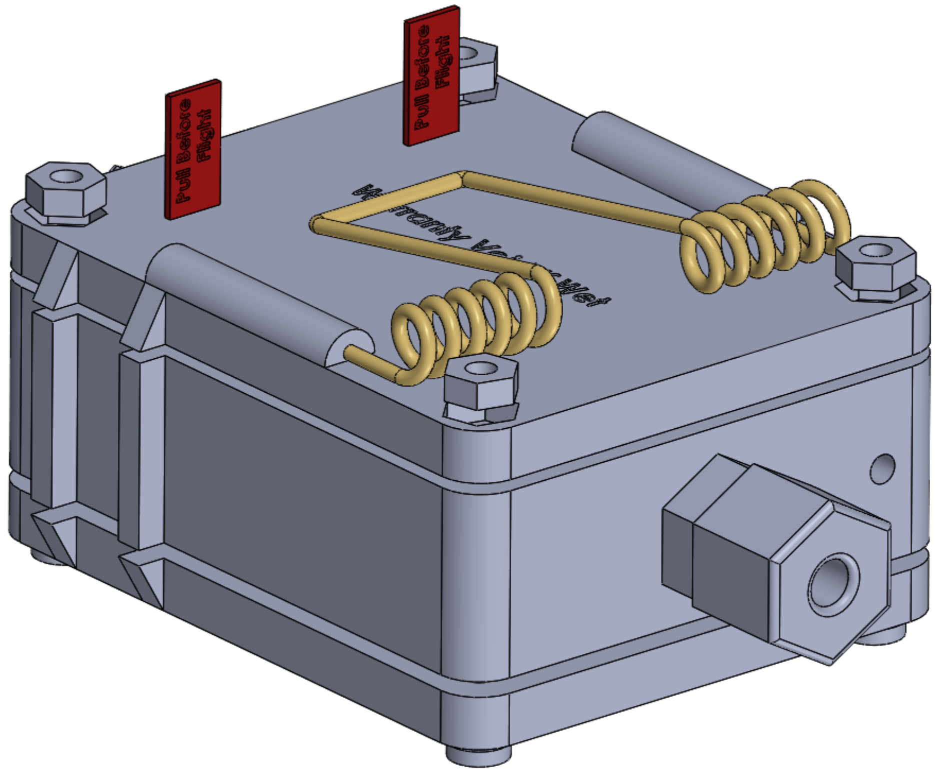




Mockup of payload using current hardware and 3D printed parts

The individual cutdown boards will be housed in a 3D printed ASA box. ASA was chosen as the material due to its resistance to UV and water, high impact strength, even at cold temperatures, and glass transition temperature of about 100 °C. This box will be attached to the outside of the HASP gondola using steel hose clamps. The box will feature a mechanical flag such that when the cutdown board is activated and string running through the cutdown will cut allowing the flag to raise itself for a visual confirmation of success via the HASP cameras. There will also be slots for pull tabs that block the batteries from connecting so that right before flight the tabs can be pulled allowing the board to turn on without having to unscrew anything. The total length of the cutdown unit is about 6”.

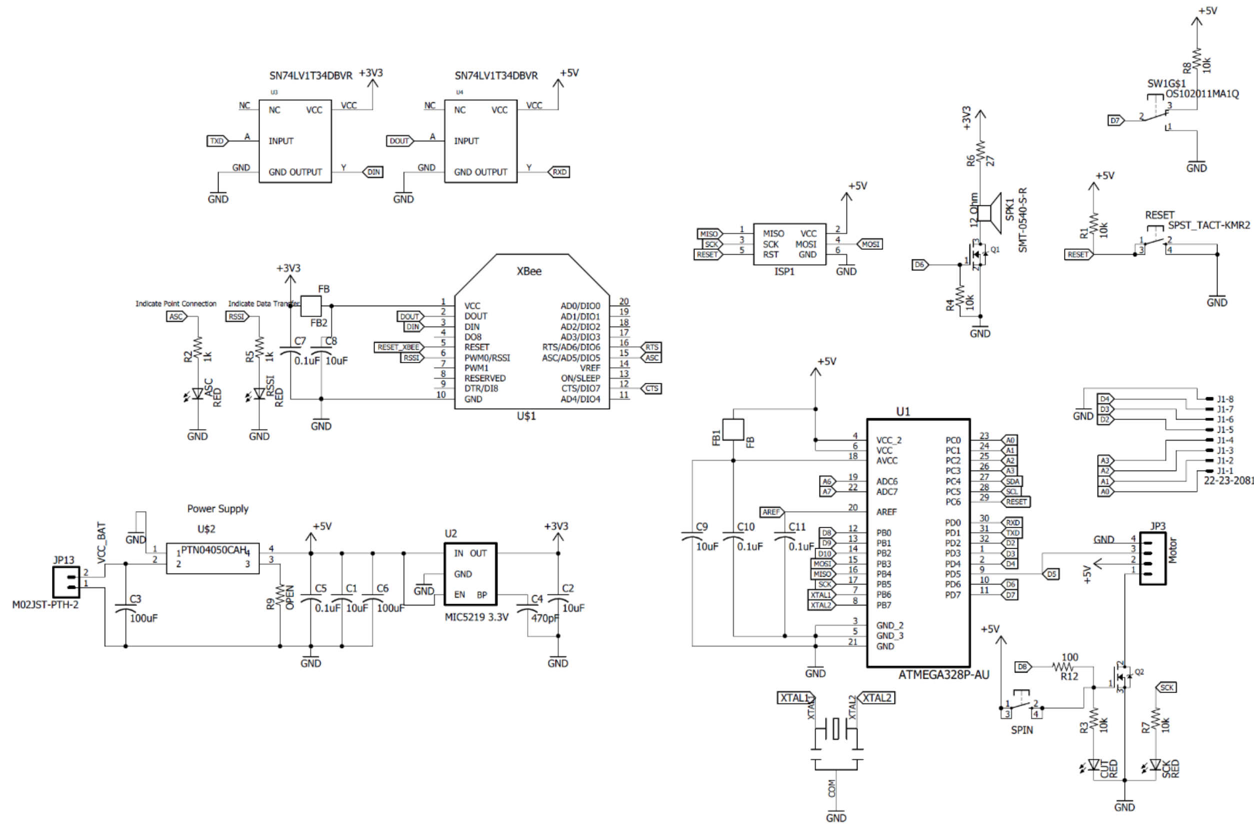
Current cut down hose clamped to 1” aluminum extrusion



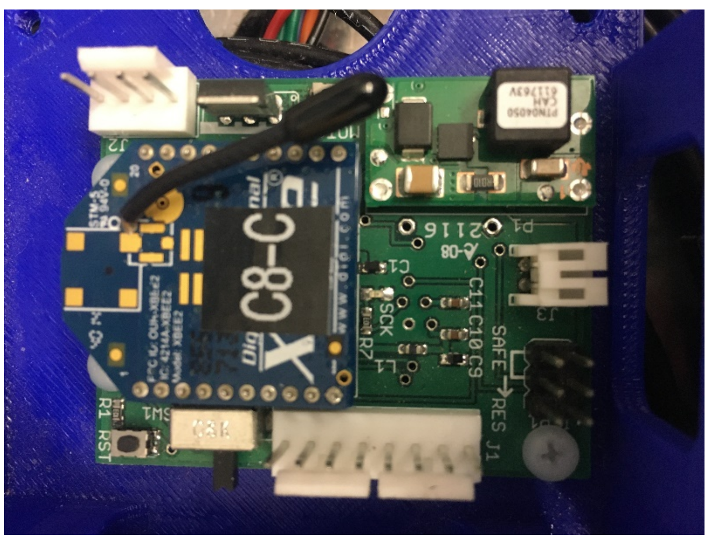
Solidworks model of future cutdown box with spring in the down position, will pop up after cut down is fired, as well as channels for hose clamp to run through and pull tabs for powering unit

1.5 Electrical Design

The payload interfaces a NAL 9602-LP ultra-low power asset tracker's digital input and output pins with a microcontroller in order to provide status and payload control. The microcontroller interfaces to a XBEE 2.4 GHz radio to transmit control signals to separate cutdown components on the HASP balloon payload. A DC-DC power supply converts the HASP power supply to the 5 volts required for the NAL 9602-LP asset tracker and microcontroller. The PTN04050CAH DC-DC converter is designed for a 3.7 volt input and will be replaced with the PTN78060W DC-DC converter which is designed for the HASP voltage input of 27-33 volts. Both DC-DC converter provide 5 volts and the necessary transient response for the NAL 9602LP when it switches in and out of transmit mode. An on board 3.3 volt low drop out regulator converters the 5 volts to the 3.3 volts required by the Xbee radio. Level shifters are utilized to convert digital signals between the two supplies when required. The multipurpose OCCAMs board has the ability to drive a small DC motor, provide audio feedback and provide LED feedback on status of the unit. Not all of these features are used in this design. Various switches are used to provide user input when necessary during testing and unit setup. The unit is designed to turn on and operate with no user input once in the system.

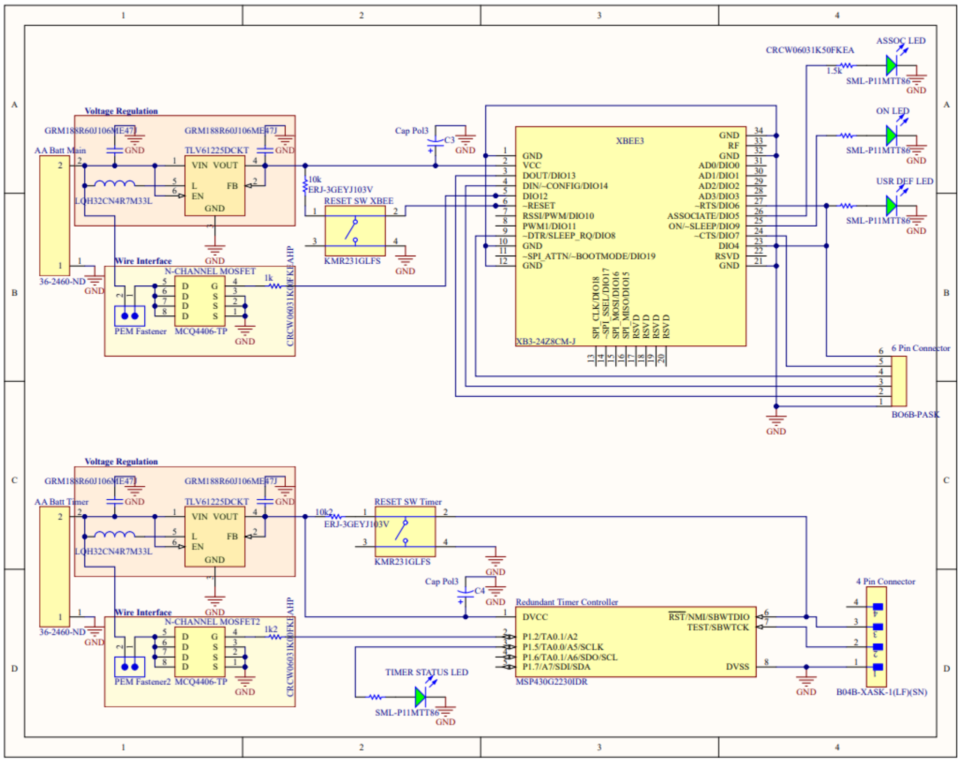


OCCAMS Schematic (before DC-DC modification)

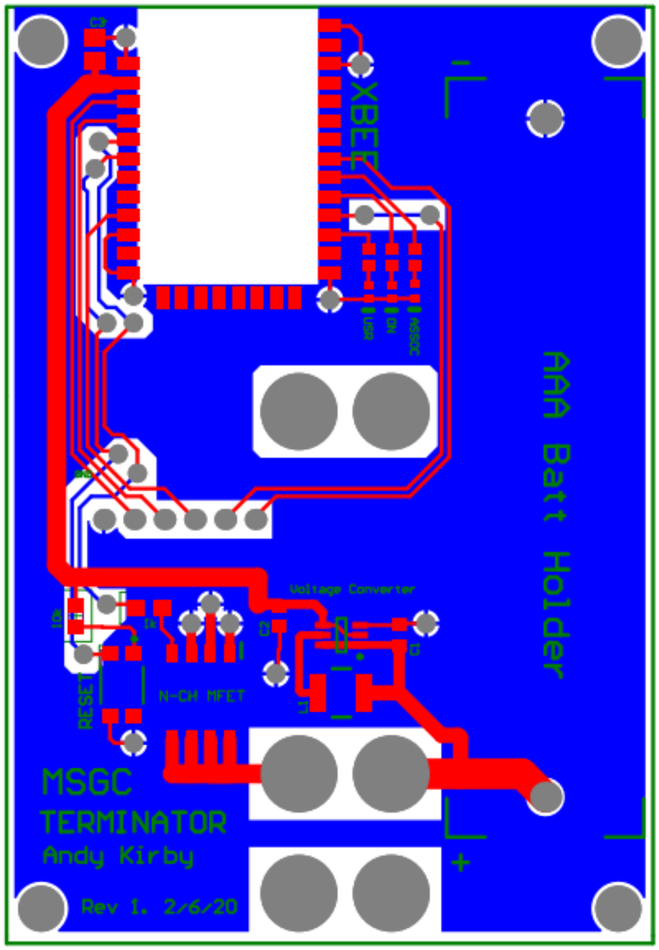


Picture of OCCAMS Board (before DC-DC modification)

The redundant cutdown mechanisms are housed on a single printed circuit board, each powered by standard commercial AA Energizer lithium L91 batteries. Step-up voltage regulators provide the 3.3-volt logic level to the microcontrollers. An XBEE 3 microcontroller monitors for 2.4 GHz communications from an XBEE radio interfaced to the NAL modem wireless link. The XBEE 3 controller is interfaced with several indicator LEDs, a reset switch, and connector for programming. A separate ultra-low-power microcontroller is used as a redundant cutdown controller (based on time since launch). A reset switch and programming port is included for the timer controller. Digital output pins on each microcontroller drive control signals to their respective MOSFETs, determining wire heating status. When active, the transistors short the battery across a mounted nichrome wire which burns through the balloon lead line. The balloon lead line runs through a line guide mechanism made from PEM nuts that are mounted to the printed circuit board and wrapped with bus wire. The nichrome wire length is also controlled by mounting it to additional PEM nuts mounted in the electrical path of the circuit to the battery and the MOSFET. Preliminary part selections are indicated in the attached preliminary schematics.

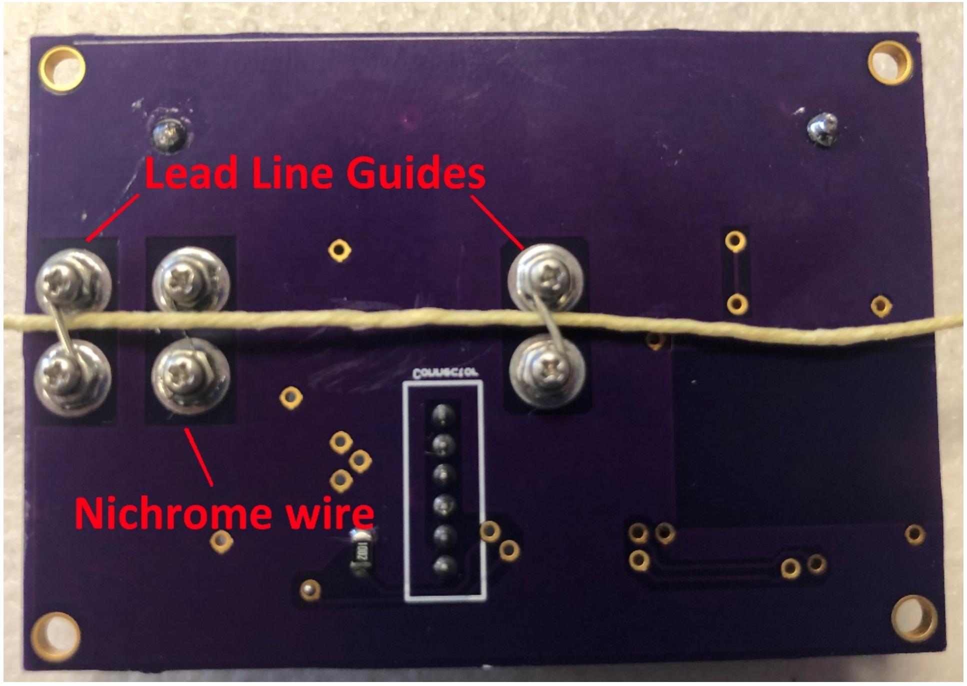


A preliminary circuit schematic for the cutdown board contains redundant wire cutting mechanisms and features programming ports for ease of use.



A preliminary board layout for the cutdown board (not containing the redundant, timer-based cutdown mechanism).

Cutdown Board (not containing the redundant, timer-based cutdown mechanism).



Cutdown Board showing lead line guides and nichrome wire (not containing the redundant, timer-based cutdown mechanism)

1.6 Thermal Control Plan

The termination units and associated GPS tracking system have been designed and extensively tested to successfully handle the environmental conditions experienced on short-duration flights using traditional latex sounding balloons. This system (tracking and termination) has also been successfully demonstrated on longer duration balloon flights, zero-pressure balloon on 2/15/16, 2/16/16, 7/22/20 and solar balloon 7/16/20 (IMEI 300234060252680 2016 flights and 300234065065560 2020 flights https://borealis.rci.montana.edu/tracking). The goal of the proposed project is to accumulate enough in-flight testing results to provide confidence in the system reliability for use with the long-duration daytime (8-hour lifetime – flight time plus safety factor) balloon flights to be conducted as part of 2023 and 2024 eclipse balloon project. By design the proposed HASP flight system will as closely as is permissible emulate what is envisioned for the eclipse project and will not have any active thermal management. As described below the components and enclosures are designed to function within environmental conditions anticipated for long-duration daytime high altitude balloon flights.

Insulated foam box with a white exterior to provide a solar shield to minimize radiative heating.

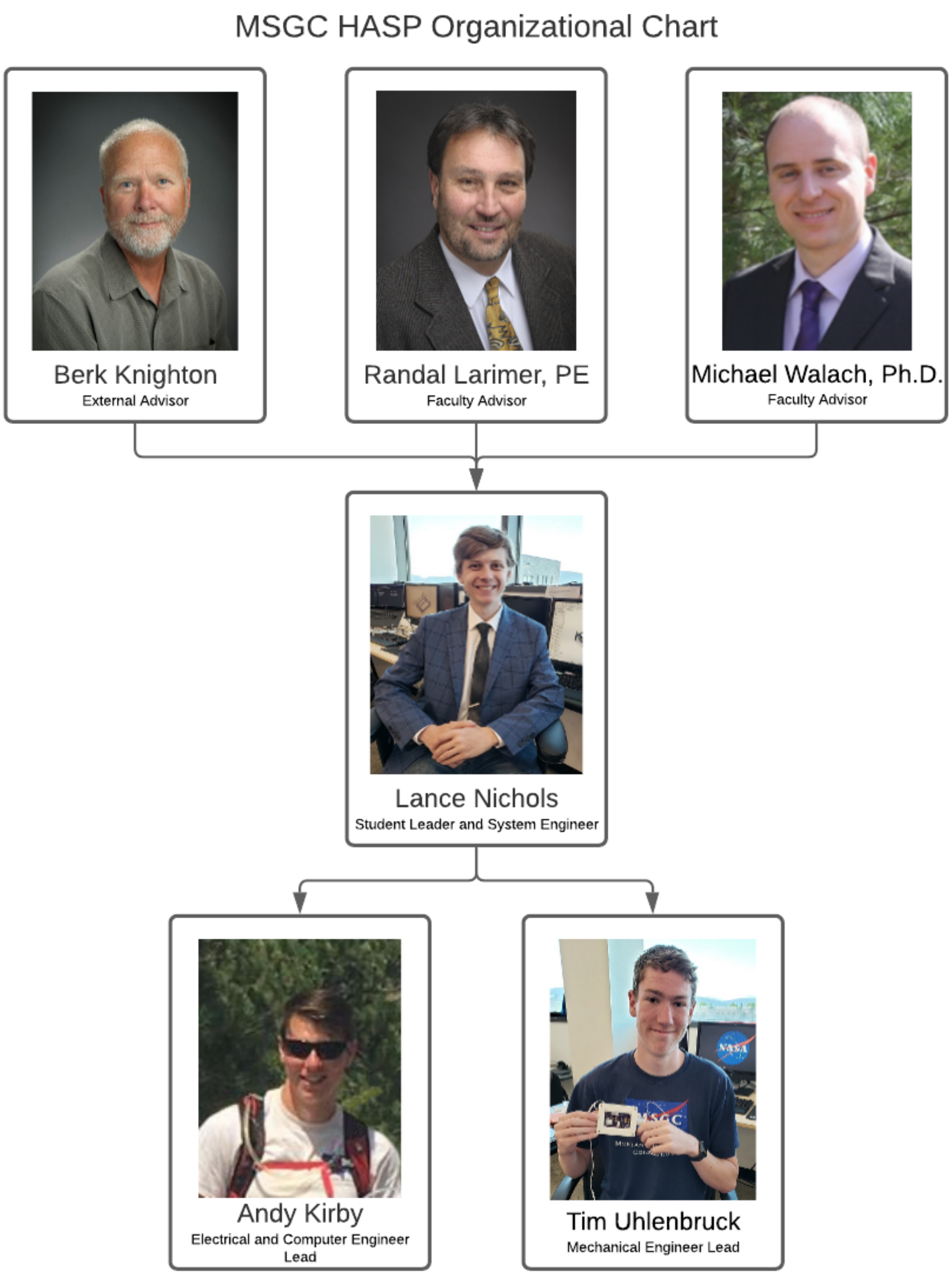
The termination systems are not designed for nighttime operation, but has been tested in-house to operate after thermal soaks 16 hours at -30 °C

3D printed enclosures are made from white ASA filament and withstand temperatures up to 100 °C without deformation.

Components were selected for Industrial temperature ranges of –40 C to +85 C

2. Team Structure and Management

2.1 Team Organization and Roles



Lance Nichols – Junior in Mechanical Engineering graduating May 2022
Lance.Donald.Nichols@gmail.com - 406-370-9012
Student Leader and System Engineer - Responsible for overall project management, making sure milestones are met and interfacing to HASP contacts. Responsible for system engineering and overall design, test and operation of the MSGC HASP 2021 payload. Will have final say on signing off on payload tests. Is the interface between mechanical design and electrical design. Responsible for overall operation of the payload.

Tim Uhlenbruck - Junior in Mechanical Engineering graduating May 2022
t.uhlenbruck@yahoo.com - 406-274-4677
Mechanical Engineer - Responsible for mechanical design, fabrication and testing of the small plate payload housing. Responsible for the mechanical design, fabrication and testing of the cutdown modules. Responsible for the mounting of the cutdown modules to the HASP gondola.

Andy Kirby – Senior in Electrical and Computer Engineering graduating May 2021
andy-kirby@live.com - 425-647-1745
Electrical and Computer Engineer - Responsible for the design and testing of the HASP power interface for the small plate payload. Responsible for the design, PCB layout, fabrication and testing of the cutdown modules. Responsible for programming and testing the functionality of the cutdown system.

2.2 Timeline and Milestones

Since we are modifying a current successful design for this project most of our project involves repackaging and testing. We should have the majority of work done by May 1. Detailed dates can be found in the appendix.

- Design and finalize Cutdown/Terminator Schematic
- Finalize Cutdown/Terminator parts selection
- Order Cutdown/Terminator parts
- Layout Cutdown/Terminator PCB
- Order Cutdown/Terminator PCB – 12 units
- Build Cutdown/Terminator PCB's – 8 flight units and 4 test units
- Generate Cutdown/Terminator firmware
- Program Cutdown/Terminator units – 12 units
- Test Cutdown/Terminator units – 12 units
- Change program if needed and re-program units -12 units
- Design and finalize Cutdown/Terminator mechanical housing
- Finalize mechanical parts selection
- Order Cutdown/Terminator parts
- 3D print required parts for 12 units
- Assemble Cutdown/Terminator units – 12 units
- Design and finalize Small Payload

- Finalize Small Payload parts selection
- Order Small Payload parts
- Design and finalize OCCAMS PCB
- Order OCCAMS PCB revision – 3 units
- Build OCCAMS PCB's – 1 flight unit and 2 test units
- Generate OCCAMS firmware
- Program OCCAMS units – 3 units
- Test OCCAMS units
- Change program if needed and re-program units – 3 units
- Build Small Payload units – 1 flight unit and 2 test units
- System Testing on Bench
- System Testing at Cold Temperatures
- System Testing at Hot Temperatures
- System Certification by Lance
- Package system for shipping to Palestine,TX
- Testing at Palestine, TX
- Flight at Fort Sumner, NM
- Attend required HASP meetings
- Generate required HASP reports

2.3 Anticipated Participation in Integration and Launch Operations

Our team plans on participating with all payload integration, testing and launch operations in Palestine and Fort Sumner. In the unfortunate case that COVID-19 will not allow our team to travel to Palestine and/or Fort Sumner detailed instructions will be provided to allow HASP personnel to conduct environmental testing, payload installation and all preflight operations. Inflight operations of the cutdown systems will be able to be performed remotely by us.

3. Payload Interface Specifications

3.1 Weight Budget

Nominal weights of current working versions:

Iridium system (modem, antennas, OCCAMS): 0.5 kg
Small Payload Structure (solar shield, aluminum plate): 0.1 kg
Total Small Payload Weight: 0.6 kg

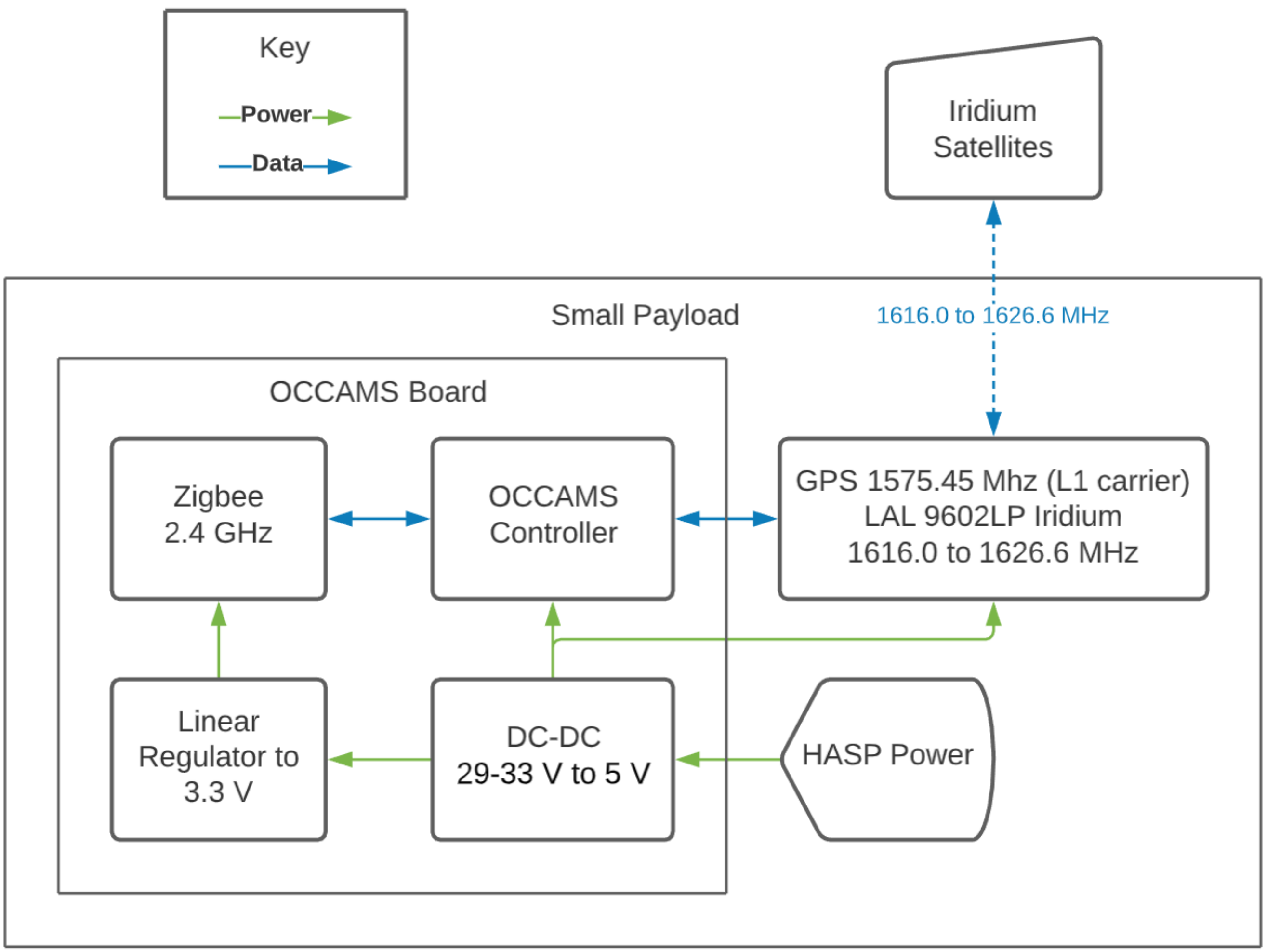
Individual Cutdown Units: 0.2 kg
Total of all 8 cutdowns: 1.6 kg

Total Weight: 2.2 kg

Given that the design is not finalized and increase of up to about half a kilogram is possible. However, the total weight will not surpass the 3 kg requirement. Based on theoretical calculations and approximations the final design will likely weigh 2.4 kg ± .1 kg

3.2 Power Budget

The small payload will utilize HASP power. The small payload consists of the NAL 9602LP modem, GPS antenna, Iridium antenna and the OCCAMS power and control board along with a XBEE/Zigbee radio module. The OCCAMS power and control board has a Texas Instruments PTN78060w DC-DC converter that is 85% efficient at our load level and has an input voltage range of 7-36 Vdc providing a 5 Vdc output at up to 3 Amps. This 5 volt output is used to power the NAL 9602LP modem which draws 200 mA average current.   The microcontroller used on OCCAMS is an Atmel ATMEGA328P operating at 5 volts and draws 10 mA. A 3.3 volt regulator is used to provide power to the XBEE radio module that draws 40 mA during transmit.



Small Payload Block Diagram

Current requirements determined from datasheets and unit measurements.

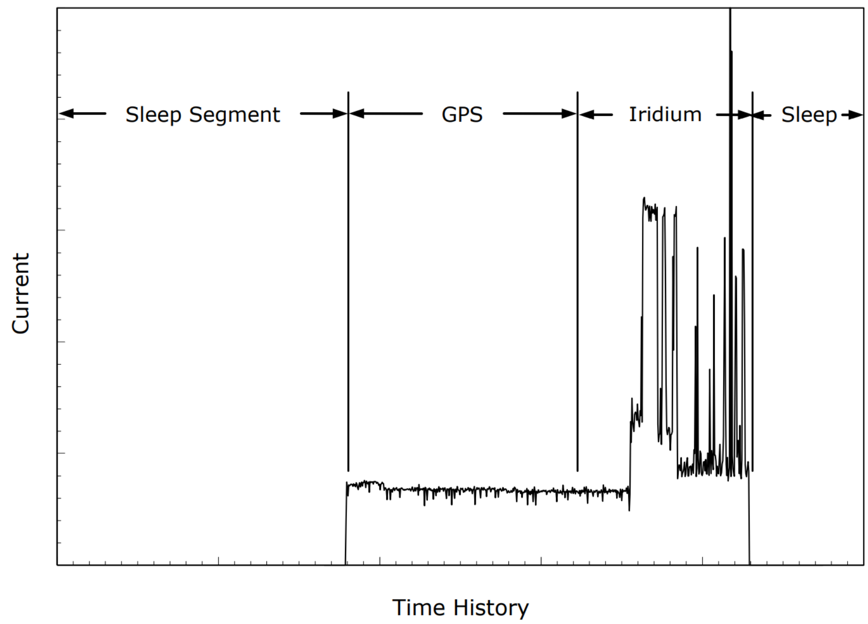
OCCAMS power and control board

XBEE radio module from datasheet
Transmit Current 3 volts @ 40 mA @ 8dBm (0.0063 watts)
Receive Current 3 volts@ 17 mA
Microcontroller from datasheet
Atmel ATmega328P 10 mA at 5 volts

NAL 9602LP – from Datasheet
Input Voltage: 3.6V to 5.5V or 6.5V to 32V (We use 5 volts for powering the NAL unit)
Avg Current (Report): 200mA @ 5V Input
Avg Current (Sleep): < 65µA @ 5V Input

Electrical Specifications
Input Voltage Range: +3.6VDC to +5.3VDC or +6.0VDC to +32VDC (We use 5 volts)
Main Input Voltage Ripple: < 40mV peak-to-peak
Transmit Current (Average): 200mA @ 5VDC
Transmit Current (Peak): 1.5A @ 5VDC
Receive Current (Average): 45mA @ 5VDC
Receive Current (Peak): 195mA @ 5VDC
Message Transfer Power (Average): <= 1.0W @ 5VDC
Current in Between Reports: Less than 65uA @ 5VDC
Power Input Type: DC power or LiIon battery
NOTE: The DC power requirement was measured at the 9602-LP multi-interface connector and not at the DC power supply. Users must take into account voltage drop across the power supply cable to ensure adequate current provided to the 9602-LP during SBD sessions. If input voltage does not stay above 3.0VDC during surge or high current demand, the 9602-LP will reset itself.
NOTE: The average current drawn during transmission may vary depending on the field of-view between the 9602-LP antenna and the Iridium satellite, the type of Iridium antenna used and the cable loss.

In tracking mode, the 9602-LP goes through three different power consumption segments: (1) the sleep (in between reports) segment, (2) GPS acquisition segment, and (3) SBD transmission segment. Figure below shows different stages of current drawn by the 9602 when in tracking mode. During the sleep segment, the 9602-LP goes into power-saving mode by shutting down all its internal circuits.



Sleep segment: 5 volts at 50uA gives 250 uW of power
GPS segment: 5 volts at 160 mA gives 800 mW of power
Iridium segment: 5 volts at 0.2 A average gives 1 W of average power
Note: these numbers are from the graphs in the NAL datasheet.

We report the GPS position of our payload at 10 second reporting interval the smallest interval for reporting. Since there is no time given on the above graph let's count the tic marks in each phase of operation. From this assume that the NAL 9602LP spends 0.5 of the time in the sleep segment, 0.28 of the time in GPS segment and 0.22 of the time in Iridium segment. Total power drawn for this interval is:
(0.250mWx0.5) + (800 mWx0.28) + (1000mWx0.22) = 444.125 mW or 0.444 W per interval.
At 5 volts this represents 88.8 mA per interval or report. This is not a reasonable number based on our experience with the NAL 9602LP and shows that the correct answer is two. Therefore we will use the data from actual flights for our power calculation.

From an extended field test of our payload on a July 22, 2015 flight, the unit reported for 18 hours with 30 second reporting with a 3.7V 6600mah battery (24.42 Wh). This flight had 1055 reports to the website, so 24.42Wh/1055 = 0.023Wh per report.
24.42Wh/18h = 1.36 Watts per hour average.

Total HASP power required 1.36W/ 30 volts = 0.0453 amps or 45.3 mA average current draw per hour. We are well under the 30 volts at 0.5 amp HASP limit.

3.3 Downlink Serial Data

No downlink of serial data is planned for our payload.

3.4 Uplink Serial Commanding

No uplink of serial data is planned for our payload.

3.5 Analog Downlink

No analog downlink is planned for our payload.

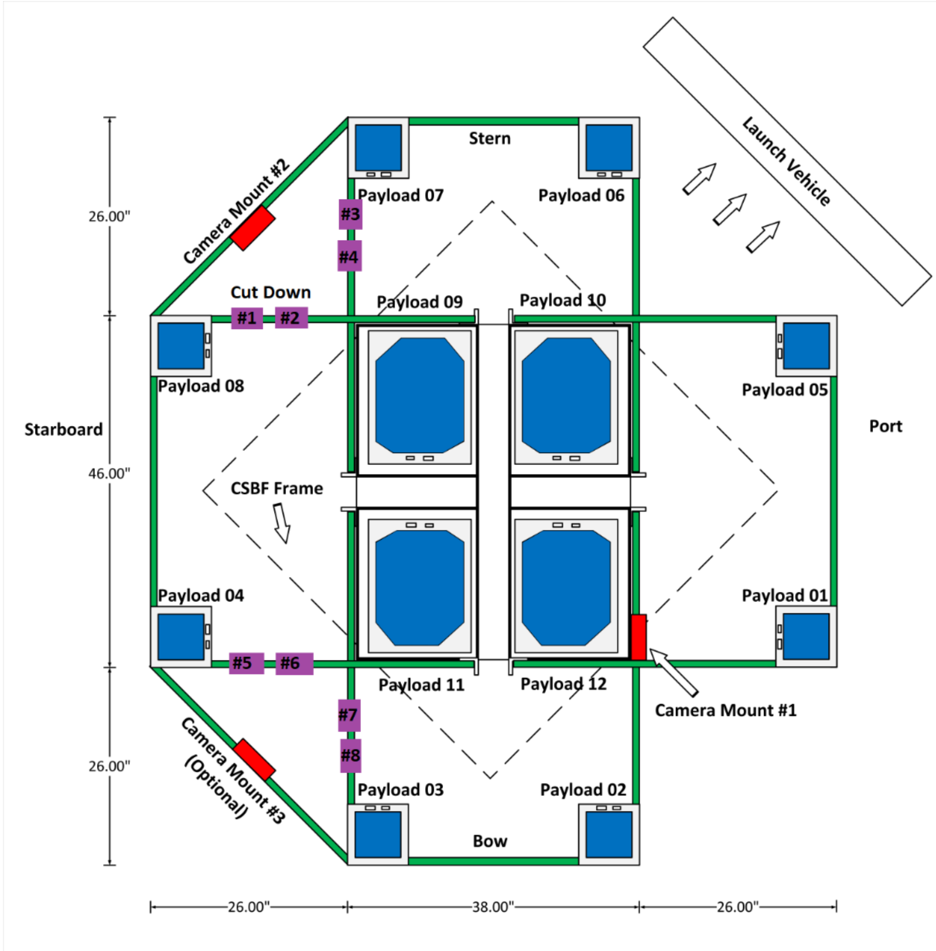
3.6 Discrete Commanding

No discrete commanding is planned for our payload.

3.7 Payload Location and Orientation Request

Our small payload would like an upward facing location away from significant metal structure of the HASP gondola.

Our cutdown systems should be mounted on the HASP gondola brackets facing up with hose clamps in such positions that they are in view of a HASP camera and clear of any interference that would not allow them to receive their 2.4 GHz wireless signal required to activate them. We would like payload spots 4 or 8 so our cutdowns and payload are close to each other without potential interference for their wireless communication.



Ideal cut down mounting locations (purple boxes)

3.8 Special Requests

The special requests that we have are: 1) Use of commercial off the shelf Energizer L91 AA lithium batteries as power sources for our cutdown/termination units 2) use of the NAL 9602-LP Iridium modem as our small payload, 3) use of Xbee/Zigbee radios to communicate between our small payload and our cutdown/termination units, and 4) specific mounting requirements of cutdown/termination units.

The individual cutdown units will be powered by two Energizer L91 AA battery operating independently.
Energizer Website datasheet:
https://data.energizer.com/pdfs/l91.pdf
Energizer Website Application Manual:
https://data.energizer.com/pdfs/lithiuml91l92_appman.pdf

Our payload will use the NAL 9602LP Iridium Modem for sending commands to our payload via email. The commands will be sent to the NAL 9602LP Iridium Modem and then sent to the individual cutdown units via a radio. XBEE/Zigbee radio module made by Digi.

XBEE/Zigbee Radio Modules:
From Digi Website:

https://www.digi.com/products/embedded-systems/digi-xbee/rf-modules/2-4-ghz-rf-modules/xbee3-zigbee-3#specifications

XBEE radio module
Transmit Current 40 mA @ +8dBm (0.0063 watts)
Transmit Power 8 dBm (0.0063 watts)
Receive Current 17 mA
Frequency 2.4 GHz in ISM Band
Protocol Zigbee 3.0
Interference Immunity DSSS (Direct Sequence Spread Spectrum)
Operating Temperature -40º C to 85º C (-40º F to 185º F)
Transceiver Chipset Silicon Labs EFR32MG SoC

NAL 9602-LP Iridium Modem
From NAL Website:
https://www.nalresearch.com/products/trackers-modems/960x-series/nal-9602-lp/#specs

Dimensions: 69 mm x 55 mm x 24 mm
(2.73" x 2.17" x 0.94")
Weight: 136 g (4.8 oz.)

Input Voltage: 3.6V to 5.5V or 6.5V to 32V
Avg Current (Report): 200mA @ 5V Input
Avg Current (Sleep): < 65µA @ 5V Input

I/O Interface: 15-Pin D-Sub
Antenna Interfaces: SMA Female
Software Interface: AT Commands through Serial

Operating Temp: –40°C to +85°C (–40°F to +185°F)
Operating Humidity: < 75% RH

Iridium Frequency: 1616.0 to 1626.5 MHz
GPS Frequency: 1575.42 MHz (L1 carrier)

Iridium RF Specifications:
Operating Frequency: 1616 to 1626.5 MHz
Duplexing Method: TDD
Input/Output Impedance: 50 W
Multiplexing Method: TDMA/FDMA
Iridium Radio Characteristics :
Average Power during a Transmit Slot (Max): 1.6W
Receiver Sensitivity at 50W (Typical): –117 dBm
Maximum Cable Loss Permitted: 2dB
Link Margin – Downlink: 13dB
Link Margin – Uplink: 7dB

GPS Receiver Performance Data:
Type of GPS Receiver: NEO-6Q from u-blox AG
Receiver Type: L1 frequency
C/A code
50-Channel
SBAS: WAAS, EGNOS, MSAS, GAGAN
Update Rate: 5Hz
Accuracy: Position 8.2 feet (2.5 meters) CEP
Position DGPS/SBAS 6.6 feet (2.0 meters) CEP
Acquisition (typical): Hot starts 1 second
Aided starts 1 second
Warm starts 28 seconds
Cold starts 28 seconds
Sensitivity: Tracking –160 dBm
Reacquisition –160 dBm
Cold starts –147 dBm
Operational Limits: COCOM restrictions apply
Altitude 164,000 feet (50,000 meters)
Velocity 1,640 feet/sec (500 m/sec)
One of the limits may be exceeded but not both
As long as power is provided to the 9602-LP, the GPS receiver will store ephemeris data in its memory before powering down (sleep between reports). The ephemeris data are valid up to two hours and can be used in future startup to improve time-to-first-fix. Unlike the 9601-DGS-LP, the 9602-LP does not need an extra back-up battery to retain ephemeris data.

Mounting Location
Our request for payload location is shown in section 1.4 and we request to be within the field of view of cameras 2 and 3. Our cutdown/termination units provide a visual indicator that can be monitored during flight.

4. Preliminary Drawings and Diagrams

Preliminary drawing and diagrams are imbedded throughout the proposal.

5. References

[1] 2011 AHAC Conference – Poster Presentation
This describes our first implementation of a hot wire cutter system for flight termination. Predates the Iridium modem and uses amateur radio for initiating the command.
Council G. & Riesland D. & Lutgen J., (2011) "Terminator—Flight Termination System for High Altitude Ballooning", *Academic High Altitude Conference*2011(1). doi: https://doi.org//ahac.8127

[2] 2020 AGU Presentation: ED013-04 STEM Student Engagement Using High Altitude Ballooning During Eclipses ***Randal Larimer***[1]*, Walter B Knighton*[1]*, James Flaten*[2]*, T Gregory Guzik*[3]*, Douglas J Grainger*[4] *and Angela Colman Des Jardins*[1]*, (1)Montana State University, Bozeman, MT, United States, (2)University of Minnesota Twin Cities, Aerospace Engineering*

and Mechanics Department, Minneapolis, MN, United States, (3)Louisiana State University, Physics and Astronomy, Baton Rouge, LA, United States, (4)Louisiana State University, Department of Physics and Astronomy, Baton Rouge, LA, United States

[3] 2014 AHAC Conference Presentation – Oral Presentation
This describes the initial work on the 9602LP Iridium modem, website and termination control. Miller S. & Basta T. & Motley J. & Murray N. & Larimer R. & Knighton B., (2014) "Repurposing an Iridium Network Satellite Modem into a Two-Way Balloon Tracking and Communications System", *Academic High Altitude Conference*2014(1). doi: https://doi.org//ahac.8158

Appendix

2021
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
HASP
Terminator
Design and finalize Cutdo...
Finalize Cutdown/Termin...
Order Cutdown/Terminat...
Layout Cutdown/Termina...
Order Cutdown/Terminat...
Cutdown/Terminator Par...
Build Cutdown/Terminato...
Cutdown/Terminator Bo...
Generate Cutdown/Termi...
Program Cutdown/Termi...
Test Cutdown/Terminator...
Change program if neede...
Cutdown/Terminator Bo...
Design and finalize Cutdo...
Finalize mechanical parts ...
Order Cutdown/Terminat...
3D print required parts fo...
Cutdown/Termination B...
Assemble Cutdown/Termi...
Cutdown/Terminator Uni...
Small Payload
Design and finalize Small ...
Finalize Small Payload par...
Order Small Payload parts
Build Small Payload Boxes
Payload Boxes Maunufac...
Design and finalize OCCA...
Order OCCAMS PCB revis...
OCCAMS Parts Received
Build OCCAMS PCB's - 1 fl...
OCCAMS Boards Populat...
Generate OCCAMS firmw...
Program OCCAMS units - ...
Test OCCAMS units
Change program if neede...
OCCAMS Boards Bench ...
Build Small Payload units ...
Payload Units Assembled
System
System Testing on Bench
System Bench Operational
System Testing at Hot Te...
System Testing at Cold T...
System Temperature Op...
System Certification by L...
Certification Complete
Package system for shippi...
Testing at Palestine, TX
Pass Testing at Palestine
Flight at Fort Sumner, NM
Complete Flight
Generate required HASP reports
Attend required HASP meetings
Design and finalize Cutdown/Terminator Schematic
Finalize Cutdown/Terminator parts selection
Order Cutdown/Terminator parts
Layout Cutdown/Terminator PCB
Order Cutdown/Terminator PCB - 12 units
Cutdown/Terminator Parts Received
Build Cutdown/Terminator PCB's - 8 flight units and 4 test units
Cutdown/Terminator Boards Populated
Generate Cutdown/Terminator firmware
Program Cutdown/Terminator units - 12 units
Test C...
Change program if needed and re-program units -12 units
Cutdown/Terminator Boards Bench Operational
Design and finalize Cutdown/Terminator mechanical housing
Finalize mechanical parts selection
Order Cutdown/Terminator parts
3D print required parts for 12 units
Cutdown/Termination Boxes Manufactured
Assemble Cutdown/Terminator units - 12 units
Cutdown/Terminator Units Assembled
Design and finalize Small Payload
Finalize Small Payload parts selection
Order Small Payload parts
Payload Boxes Maunufactured
Design and finalize OCCAMS PCB
Order OCCAMS PCB revision - 3 units
OCCAMS Parts Received
Build OCCAMS PCB's - 1 flight unit and 2 test units
Generate OCCAMS firmware
Program OCCAMS units - 3 units
Test ...
Change program if needed and re-program units - 3 units
OCCAMS Boards Bench Operational
Build Small Payload units - 1 flight unit and 2 test units
Payload Units Assembled
System Testing on Bench
System Bench Operational
System Testing at Hot Temperatures
System Testing at Cold Temperatures
System Temperature Operational
LN
System Certification by Lance
Certification Complete
Packa...
Testing at Palestine, TX
Pass Testing at Palestine
Flight at Fort Sumner, NM
Complete Flight
Generate required HASP reports
Attend required HASP meetings

TN2011-001-V1.0

GENERAL DESCRIPTION OF MODEL 9602-LP

Version 1.0

February 25th, 2013

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TABLE OF CONTENTS

GLOSSARY

AES	Advanced Encryption Standard
BIS	Bureau of Industry and Security
CEP	Circular Error Probable
DGPS	Differential Global Positioning System
DoD EMSS	DoD Enhanced Mobile Satellite Services
DTE	Data Terminal Equipment
DSN	Defense Switch Network
EAR	Export Administration Regulations
FDMA	Frequency Division Multiple Access
GND	Ground
GPS	Global Positioning System
GUI	Graphical User Interface
ID	Static Identifier
ISU	Iridium Subscriber Units
LED	Light Emitting Diode
LiIon	Lithium Ion
LNA	Low Noise Amplifier
LP	Low Power
NOC	Network Operation Center
OFAC	Office of Foreign Asset Controls
PMS	PECOS Message Structure
PSTN	Public Switch Telephone Network
PWR	Power
RHCP	Right Hand Circular Polarization
RUDICS	Router-Based Unrestricted Digital Internetworking Connectivity Solution
SBAS	Satellite Based Augmentation System
SBD	Short Burst Data
SMA	Sub-Miniature Version A
SMS	Short Message Service
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
VSWR	Voltage Standing Wave Ratio

1.0 PURPOSE

This document describes the electrical and mechanical interfaces of the 9602-LP. The 9602-LP is a pocket-size, low-cost, satellite tracker designed to operate with the Iridium low-Earth orbit satellite network. It is self-contained relying on an extremely low power consumption micro-controller for operation. The 9602-LP measures 2.73” x 2.17” x 0.94”, weighs less than 5 ounces and can be attached to high value, un-tethered or non-powered assets such as shipping containers, barges, railcars, trailers, buoys or even to a person. It can also be used to track environmentally demanding platforms including helicopters, fixed wing aircraft, unmanned aerial vehicles, rockets, high altitude balloons, ships, speed-boats, ground vehicles and remote unattended sensors. With the exception of smaller form-factor and wide input voltage range, model 9602-LP is functionally compatible with the 9601-DGS-LP.

The 9602-LP comprises of an Iridium 9602 transceiver module, a built-in 50-channel GPS receiver and low power micro-controllers. The 9602-LP allows only short-burst data (SBD) connectivity to the Iridium satellite network. It does not support voice, circuit switched data, or short message service (SMS). It can transmit messages in NAL Research’s defined formats compatible with models 9601-DGS and 9601-DGS-LP. The 9602-LP can also transmit in PECOS Message Structure (PMS). The PMS complies with the Blue Force Tracking Data Format Specification. The 9602-LP supports 256-bit AES encryption algorithm. NAL Research can enable the 9602-LP to utilize the DoD EMSS (Enhanced Mobile Satellite Services) Gateway when requested by an authorized user.

> **IMPORTANT:** EMSS-enabled 9602-LP must first be provisioned (signed up for airtime) with EMSS SBD Service before testing or field use. Accessing the DoD EMSS Gateway is not authorized until the 9602-LP is provisioned. Unauthorized attempts to access the DoD EMSS Gateway will result in immediate disabling of the offending device, which must then be returned to NAL Research for repair. See https://sbd.pac.disa.mil for more information regarding EMSS service provisioning.

When a data terminal equipment (DTE) is connected to the 9602-LP with SatTerm software installed (or any terminal emulator software), the DTE can be used to setup the operating parameters of the 9602-LP via a serial connection. A DTE can be a desktop computer, a laptop computer or a PDA.

2.0 GENERAL SPECIFICATIONS

2.1 Mechanical Specifications

Dimensions:	2.73” L x 2.17” W x 0.94” D (69 mm x 55 mm x 24 mm)
Weight:	4.8 oz. (136 g)
Enclosure:	Hard anodized aluminum/EMI shielding
	Waterproof version of the enclosure is available (Model 9602-BTI)
Multi-Interface Connector:	15-Pin D-Sub
Iridium Antenna:	SMA female
GPS Antenna:	SMA female
OFF/ON Switch:	Push Button
Emergency Switch:	Guarded Button and/or External via Multi-Interface Connector
Status LED Displays:	Power, GPS, Iridium, SBD status and Emergency

2.2 Iridium RF Specifications

Operating Frequency:	1616 to 1626.5 MHz
Duplexing Method:	TDD
Input/Output Impedance:	50 Ω
Multiplexing Method:	TDMA/FDMA

2.3 Iridium Radio Characteristics

Average Power during a Transmit Slot (Max):	1.6W
Receiver Sensitivity at 50Ω (Typical):	–117 dBm
Maximum Cable Loss Permitted:	2dB
Link Margin – Downlink:	13dB
Link Margin – Uplink:	7dB

2.4 Electrical Specifications

Input Voltage Range:	+3.6VDC to +5.3VDC or +6.0VDC to +32VDC
Main Input Voltage Ripple:	< 40mV peak-to-peak
Transmit Current (Average):	200mA @ 5VDC
Transmit Current (Peak):	1.5A @ 5VDC
Receive Current (Average):	45mA @ 5VDC
Receive Current (Peak):	195mA @ 5VDC
Message Transfer Power (Average):	<= 1.0W @ 5VDC
Current in Between Reports:	Less than 65μA @ 5VDC
Power Input Type:	DC power or LiIon battery

NOTE: The DC power requirement was measured at the 9602-LP multi-interface connector and not at the DC power supply. Users must take into account voltage drop across the power supply cable to ensure adequate current provided to the 9602-LP during SBD sessions. If input voltage does not stay above 3.0VDC during surge or high current demand, the 9602-LP will reset itself.

NOTE: The average current drawn during transmission may vary depending on the field-of-view between the 9602-LP antenna and the Iridium satellite, the type of Iridium antenna used and the cable loss.

2.5 Environmental Specifications

Operating Temperature Range:	–40°F to +185°F (–40°C to +85°C)
Operating Humidity Range:	≤ 75% RH
Storage Temperature Range:	–40°F to +185°F (–40°C to +85°C)
Storage Humidity Range:	≤ 93% RH

NOTE: Operating temperature range based on a duty-cycled usage model with the stand-alone 9602 transceiver sending one SBD message per hour and is otherwise turned off during the hour.

2.6 Data I/O Specifications

Short-Burst Data Mobile-Originated:	340 bytes per message
Short-Burst Data Mobile-Terminated:	270 bytes per message
Hardware Interface:	3-Wire RS232
Software Interface:	AT commands

2.7 Related Hardware

Antennas:	SYN7391 Series, SAF2040 Series, SAF5340 Series, SAF5350 Series, SAF4070-IG, SAF7352-IG and SAF5270-G
AC Power Adapter:	LA-3098 (100–240VAC, 47–60Hz input)
Car Adapter:	LA-7021 (12VDC car battery input)
Power Cable:	HRC-24-12, HRC-24-12A

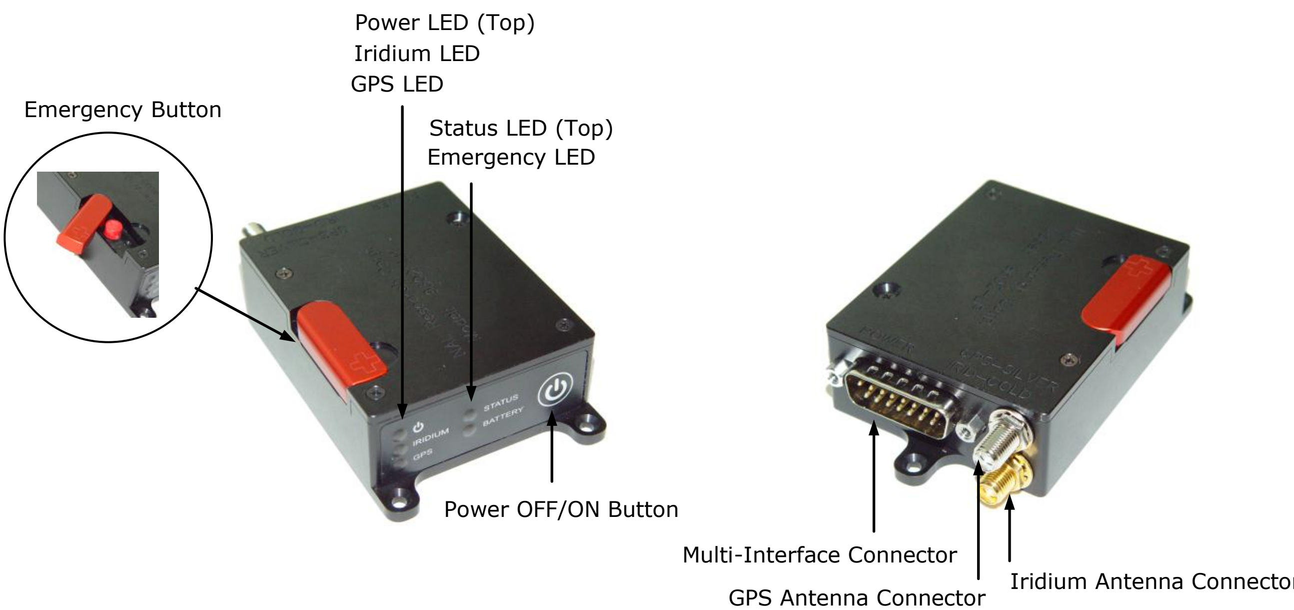


Figure 1. Iridium Satellite Tracker Model 9602-LP.

3.0 GPS RECEIVER PERFORMANCE DATA

Type of GPS Receiver:	NEO-6Q from u-blox AG	
Receiver Type:	L1 frequency	
	C/A code	
	50-Channel	
	SBAS: WAAS, EGNOS, MSAS, GAGAN	
Update Rate:	5Hz	
Accuracy:	Position	8.2 feet (2.5 meters) CEP
	Position DGPS/SBAS	6.6 feet (2.0 meters) CEP
Acquisition (typical):	Hot starts	1 second
	Aided starts	1 second

	Warm starts	28 seconds
	Cold starts	28 seconds
Sensitivity:	Tracking	–160 dBm
	Reacquisition	–160 dBm
	Cold starts	–147 dBm
Operational Limits:	COCOM restrictions apply	
	Altitude	164,000 feet (50,000 meters)
	Velocity	1,640 feet/sec (500 m/sec)
	One of the limits may be exceeded but not both	

As long as power is provided to the 9602-LP, the GPS receiver will store ephemeris data in its memory before powering down (sleep between reports). The ephemeris data are valid up to two hours and can be used in future startup to improve time-to-first-fix. Unlike the 9601-DGS-LP, the 9602-LP does not need an extra back-up battery to retain ephemeris data.

4.0 MULTI-INTERFACE CONNECTOR

The multi-interface connector on model 9602-LP is a standard male 15-pin miniature D-Sub type (DB-15). The connector comprises of four interfaces with the pin assignments shown in Table 1. These interfaces include:

- External DC power input
- 3-wire RS232 serial data interface
- TTL/CMOS I/Os
- Reserved RS232 serial data interface

PIN #	SIGNAL	DESCRIPTION	INTERFACE
1	EXT_PWR	External power input (+3.6VDC to +5.3VDC)	DC Power (+)
2	EXT_GND	External power input (GND)	DC Power (GND)
3	Tx1	RS232 Input	RS232 Data
4	Rx1	RS232 Output	RS232 Data
5	Signal_GND	Signal Ground, 0V signal reference and return	RS232 GND
6	EMERGENCY	External TTL/CMOS Input S0	0 – 5V TTL
7	TTL	TTL/CMOS Output 0	0 – 5V TTL
8	TTL	TTL/CMOS Output 1	0 – 5V TTL
9	EXT_PWR	External power input (+6.0VDC to +32.0VDC)	DC Power (+)
10	Rx2	Reserved	RS232 Data
11	Tx2	Reserved	RS232 Data
12	TEST	External TTL/CMOS Input S1	0 – 5V TTL
13	TTL	External TTL/CMOS Input S3	0 – 5V TTL
14	TTL	External TTL/CMOS Input S2	0 – 5V TTL
15	TTL	TTL/CMOS Output 2	0 – 5V TTL

Table 1. Pin Assignments for the 9602-LP Multi-Interface Connector.

4.1 External DC Power Input

DC power interface comprises of two DC power inputs and a ground input as summarized in Table 1. The 9602-LP accepts either +3.6VDC to +5.3VDC input through pin#1 or +6.0VDC to +32VDC input through pin#9. The 9602-LP is shipped with hardware set for +3.6VDC to +5.3VDC input. It can be changed to +6.0VDC to +32VDC input through an internal jumper—POWER MUST BE DISCONNECTED BEFORE RESETING THE JUMPER. The jumper can be found by removing the modem's top plate. With the 9602-LP held in the position shown in Figure 2 (DB15 connector to the left), the 9602-LP is set for 3.6VDC to +5.3VDC when the red jumper is on the middle and top pins and is set for +6.0VDC to +32VDC when the jumper is on the middle and bottom pins. Each pin is also labeled with 5V and 32V to the left of the top and bottom pins, respectively. Both the power pins on the multi-interface connector and their corresponding voltage settings on the jumper must be used for the unit to power up properly. **NOTE:** User MUST remember not to apply voltage higher than 5.3VDC on pin 1 (or accidently swap voltage between pins 1 and 9). The 9602-LP will be damaged beyond repair with warranty voided if this were to occur.

Figure 2. Power Input Setting for the 9602-LP.

> **IMPORTANT:** User can remove the 9602-LP's top plate to set the jumper but not for repair or services. The warranty is voided if the 9602-LP is disassembled for any reason other than to set the jumper.

Cables used to supply power to the 9602-LP should be kept as short as possible to prevent significant voltage drop, which can cause the 9602-LP to malfunction during an SBD session. Power reset by the 9602-LP during an SBD transmission is an indicative of the DC power source unable to sustain voltage above 3.0VDC at peak current demand. Plots of DC power requirement for the 9602-LP are found in Appendix A.

4.2 RS232 Serial Data Interface

The 9602-LP supports 3-wire serial interface to a host DTE through the multi-interface connector. The serial connection comprises of a transmit (Tx) line on pin 3, a receive (Rx) line on pin 4 and a signal GND on pin 5 as described in Table 1. The 9602-LP does not support auto-baud and the default baud rate is factory set at 19.2 kbits/sec. The baud rate can be reconfigured with the +IPR command ranging from 4.8kbits/sec to 115.2kbits/sec.

The serial port allows a connected DTE to configure the 9602-LP using NAL Research's defined AT commands and any terminal emulator software. These AT commands can be found in the manual "AT Commands for Model 9602-LP" TN2011-002-V1.0. Instead of trying to memorize various functions of AT commands, NAL Research recommends the use of SatTerm graphical user interface (GUI) software to configure the 9602-LP.

4.3 TTL/CMOS Inputs/Outputs

The 9602-LP has four TTL/CMOS inputs and three TTL/CMOS outputs. All I/Os are brought out to the multi-interface connector. SatTerm should be used to configure these I/Os as shown in Figure 3 under the I/O tab. The four CMOS/TTL inputs, denoted as S0 through S3, have internal pull ups which allow the inputs to float as high. The inputs can be configured as emergency, test, or general input with a trigger on a rising and/or falling edge. The trigger will activate the special functionality of the input type. Emergency configured inputs will enable the Emergency Tracking mode when triggered. Test configured inputs will enable the Test Tracking mode. General configured inputs will queue the transmission of an Input Report (see Appendix C in “AT Commands for Model 9602-LP” TN2011-002-V1.0). Regardless of the type or trigger configuration, the value of the input will be included in any version 5 GPS report sent. By default, S0 is configured as an emergency input triggered by a falling edge and S1 is configured as a test input triggered by a falling edge. S0 is shared with the on board emergency button. This means both the guarded emergency button on the 9602-LP and S0 can be used to activate Emergency Tracking.

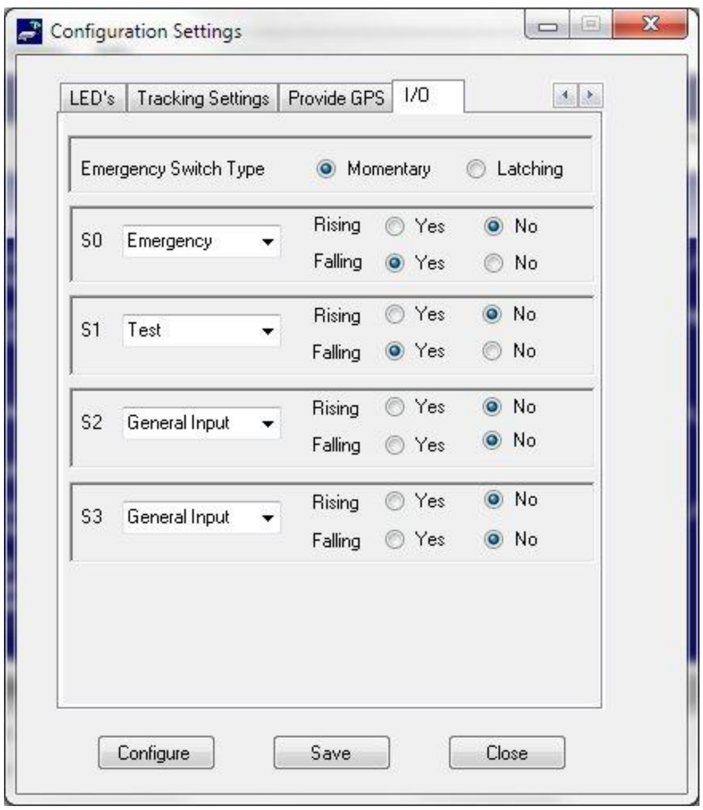


Figure 3. SatTerm Setup Window for I/Os.

Under the default configuration, Emergency Tracking can be triggered at any time by a quick press and release of the Emergency button (momentary switch). Once enabled, holding the Emergency button longer than three seconds takes the 9602-LP out of Emergency Tracking. When Emergency Tracking is active the Emergency LED will illuminate. The Emergency trigger can further be customized using the AT command ^EST. This command specifies the type of emergency switch as either momentary (default) or latching (similar to the toggle switch on the 9601-DGS-LP). The momentary switch type functions as described above, but when set to latching, Emergency tracking is enabled only when the trigger is active. For example, setting the emergency trigger to the falling edge and the switch type to latching will cause emergency tracking to enable when the input level is pulled from high to low and then it will disable when the input level returns to high.

The AT command ^PR controls input value reporting. When ^PR is enabled and a pin changes, an unsolicited response, ^PV, will be sent on the serial port indicating the values of the input pins. Setting the outputs is controlled by the AT command ^Pn. Outputs can also be set by remote update. For detailed information regarding I/Os, users are referred to the manual "AT Commands for Model 9602-LP".

5.0 CONFIGURATION SETTINGS

5.1 Modes of Operation

The 9602-LP can be in one of two operating modes at power up: (1) Command mode, or (2) Tracking mode. When in Command mode, AT commands can be entered to configure the 9602-LP's operating profiles or the 9602-LP can be operated as a 9602-G (standard SBD-modem with GPS). As a reminder, developers are encouraged to use SatTerm GUI software to set up the 9602-LP instead of using AT commands. When in Tracking mode, the 9602-LP automatically transmits GPS reports defined by parameters in the active operating profile (see description below). There are three different types of Tracking modes—Normal Tracking, Emergency Tracking and Test Tracking. The 9602-LP is factory-set for AT^START0 to power up in Command mode and can be reset to power up in Tracking mode by the AT^START1 command. After the 9602-LP is powered up, the AT^TRK command can be used to switch from Command mode to Tracking mode and switching from Tracking mode back to Command mode is done with the +++ escape sequence. The flow chart in Figure 4 describes operating modes of the 9602-LP.

There are three types of operating profiles—active operating profile, factory-default operating profile and user-defined operating profile. The active operating profile is the set of parameters currently in use by the 9602-LP. There are two user-defined operating profiles, profiles 0 and 1, available for the 9602-LP. Each user-defined operating profile can be edited and saved at anytime through the AT command &Wn. The factory-default operating profile is stored permanently on the 9602-LP's memory and cannot be changed by the user. Profiles 0 and 1 are initially set as the factory default profile.

At power up and as a default, the 9602-LP loads user-defined operating profile 0 into the active operating profile. However, either one of the two user-defined operating profiles can be designated as the active operating profile at power up through the use of the AT&Yn command. During power up, the factory-default operating profile can be loaded (soft reset) into the active operating profile using the AT&Fn command. The active operating profile will revert back to the user-defined operating profile designated under the AT&Yn command at power reset. Similarly, the active operating profile can be soft reset with either one of the two user-defined operating profiles during power up with the ATZn command. Again, the active operating profile will revert back to the user-defined operating profile designated under the AT&Yn command at power reset.

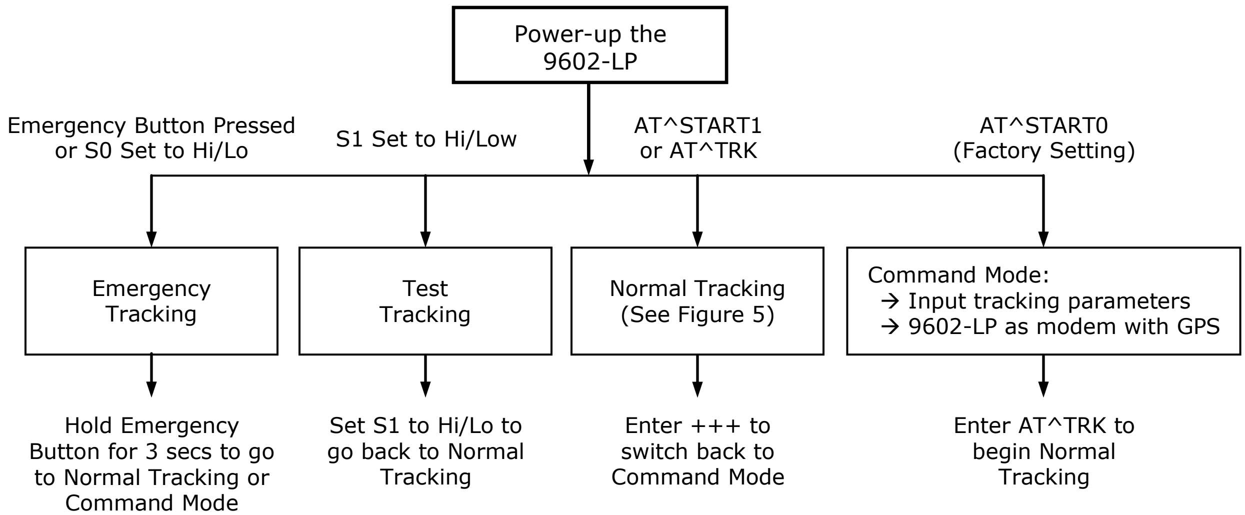


Figure 4. Different Operating Modes of the 9602-LP.

Normal Tracking Mode

Normal Tracking is the mode when the 9602-LP is configured to power up with AT^START1 command or after transitioning from Command mode to Tracking mode with the AT^TRK command. Normal Tracking offers a wide range of unique settings as shown in Figure 5. Each setting can be tailored to meet specific applications. For example, the 9602-LP can be pre-programmed to transmit reports at a fixed interval, to transmit reports triggered by the internal motion sensor, to transmit reports triggered by the Emergency switch or to transmit reports triggered by external devices. The "Callable (No)" option is implemented when lowest power consumption is required because of limited battery capacity. Or "Same Place Skip Reports" is chosen so that the 9602-LP does not repeatedly send the same location information back to a command center. The remaining of this section describes Normal Tracking settings.

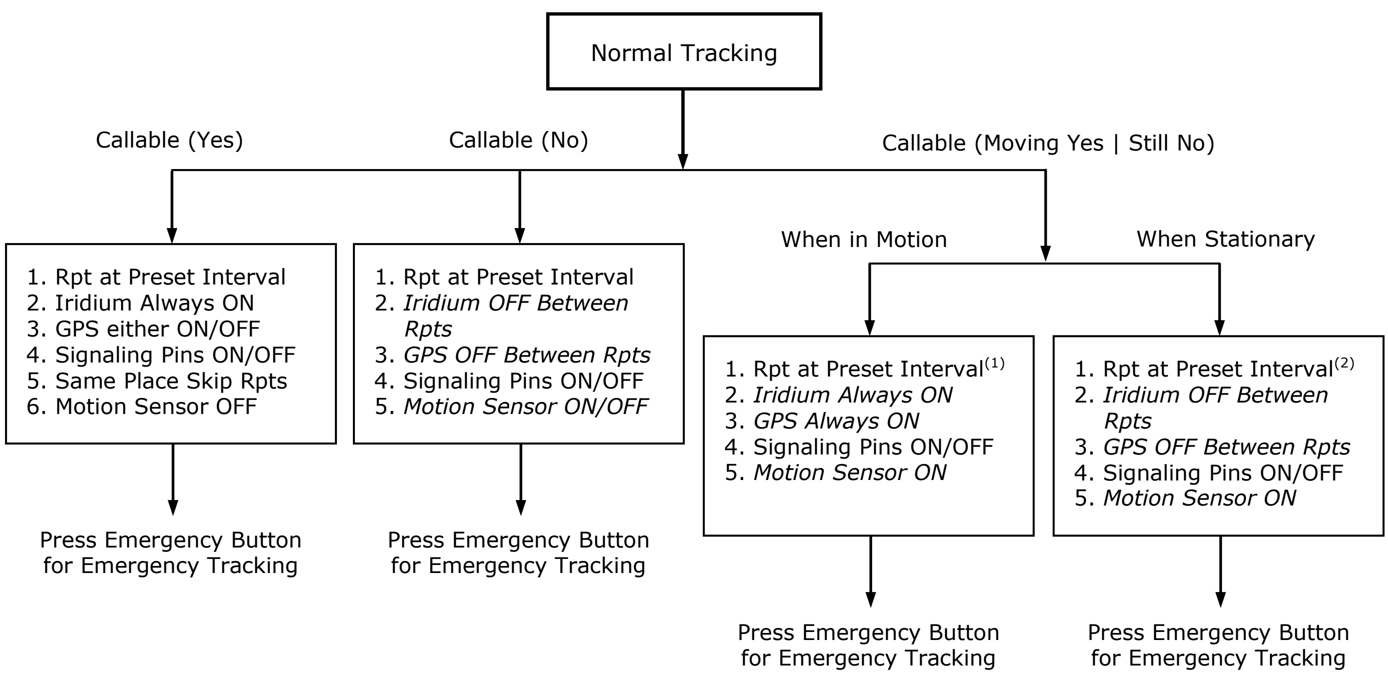


Figure 5. Block Diagram of Normal Tracking Mode of the 9602-LP.

During Normal Tracking and "Callable" is set to "Yes", the 9602-LP will automatically transmit GPS reports at a preset interval ranging from continuous to one report every seven days. The Iridium RF board will be ON in between reports allowing the 9602-LP's operating profile to be re-configured remotely in real-time. Since the Iridium RF board is ON at all times, the 9602-LP will consume the most power in between reports (~110mA at 5VDC). The GPS receiver can be left either ON or OFF in between reports to reduce power by ~40mA at 5VDC. Any of the four input pins (S0 through S3) on the multi-interface connector can be selected to trigger immediate transmission of GPS report(s) when a rising edge or a falling edge of a TTL/CMOS input signal is detected. Once the last GPS report is sent, the 9602-LP goes back to Normal Tracking. The "Same Place Skip Reports" option prevents GPS reports from being transmitted if the 9602-LP does not move outside a defined radius. Under "Callable (Yes)" option, the motion sensor signal is ignored by the tracker.

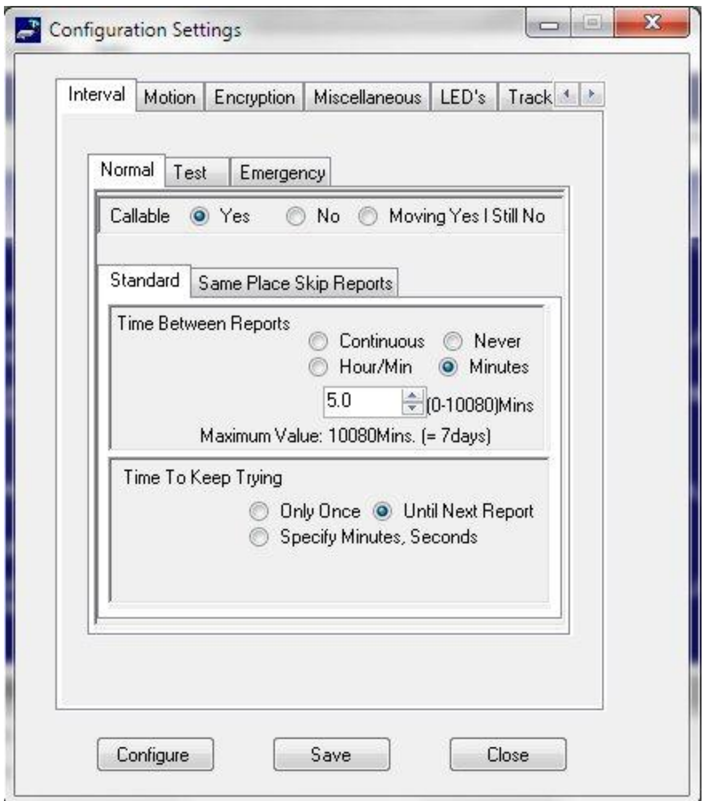


Figure 6. SatTerm Setup Window for Normal Tracking and "Callable (Yes)".

During Normal Tracking and "Callable" is set to "No", the 9602-LP will automatically transmit GPS reports at a preset interval ranging from continuous to one report every seven days. All internal circuits of the 9602-LP are turned OFF in between reports including the GPS receiver, GPS antenna's LNA, Iridium RF board, DC-DC converters and serial interfaces. The only active components are the microcontroller and the motion sensor. The 9602-LP will draw the lowest current in between reports of around 60μA at 5VDC. The 9602-LP will not respond to any entered commands including the +++. The +++ command will work only while the tracker is waiting for GPS acquisition or is transmitting a report. Updated operating profile sent to the 9602-LP from a command center will remain at the Iridium gateway until the 9602-LP wakes up and retrieves it. Any of the four input pins (S0 through S3) on the multi-interface connector can be selected to trigger immediate transmission of GPS report(s) when a rising edge or a falling edge of a TTL/CMOS input signal is detected. Once the last GPS report is sent, the 9602-LP goes back to Normal Tracking.

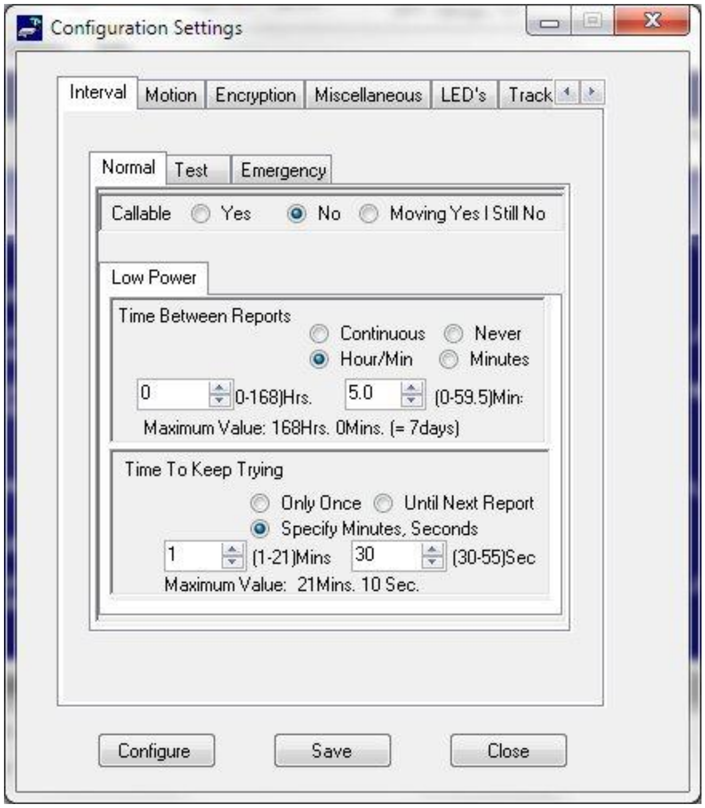


Figure 7. SatTerm Setup Window for Normal Tracking and "Callable (No)".

With "Callable" set to "No" and "Awake on Motion" option selected, the 9602-LP can be triggered by an internal motion sensor to send GPS report. The 9602-LP has a built-in motion sensor that works regardless of how the 9602-LP is mounted or aligned. It is sensitive both to tilt (static acceleration) and vibration (dynamic acceleration). When in motion, the sensor produces continuous on-off contact closures (a series of TTL level logic or pulse train) as it chatters open and closed. The signal level is fed directly into the 9602-LP's micro-controller. When at rest, it normally settles in a closed state.

Three parameters must be provided when choosing the "Awake on Motion" option— "Minutes of Motion Before Waking", "Sensitivity" and "Motion Sensor Wait". "Minutes of Motion Before Waking" is a user-defined duration within which *valid motion* must exist before the 9602-LP sends a GPS report. For example, a car must experience continuous motion for three minutes before a GPS report is sent. Otherwise, a slight bump by a person or by a gust of wind does not initiate a report. The duration of "Minutes of Motion Before Waking" is divided into one-minute blocks. "Sensitivity" is defined as the number of motion sensor on-off contact closures the 9602-LP must detect in each of the one-minute block for motion within that block to be considered *valid motion*. All contiguous one-minute blocks must have *valid motion* before a GPS report is sent. At any time a block has an *invalid motion*, the "Minutes of Motion Before Waking" timer is reset and the motion detection process starts over again. After *valid motion* is detected and a successful GPS report is sent, the 9602-LP goes back to sleep with all circuits OFF. It will ignore the motion sensor input signal for "Motion Sensor Wait" minutes. All other parameters and I/O pins are still observed by the 9602-LP.

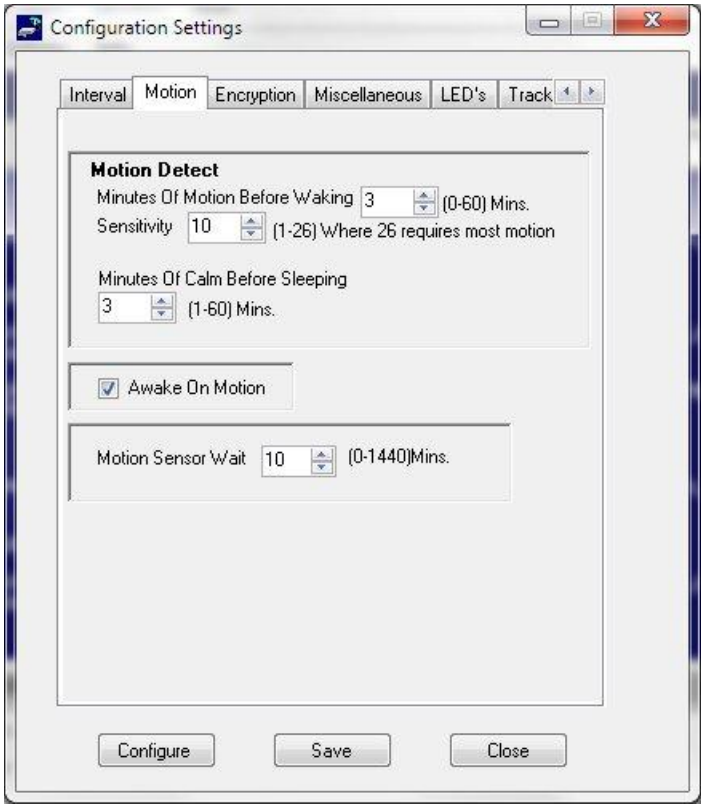


Figure 8. SatTerm Setup Window for Normal Tracking and "Awake on Motion".

The third Normal Tracking option is "Callable (Moving Yes | Still No)". This is a hybrid between the "Callable (Yes)" and "Callable (No)" configurations. When in motion the 9602-LP uses a set of "Callable (Yes)" parameters to send GPS reports and when not in motion the 9602-LP uses a set of "Callable (No)" parameters to send GPS reports. The goal is to allow users the flexibility to define different set of parameters for different operating conditions. For example, a stationary vehicle only needs to send position report perhaps once a day. However, when in motion a higher reporting frequency is required.

The setup parameters for "Callable (Moving Yes | Still No)" and "not in motion or Low Power" are shown in Figure 9. These parameters are very similar to the standard "Callable (No)" option except there is no "Awake on Motion". The 9602-LP uses "Minutes of Motion Before Waking" and "Sensitivity" to determine if *valid motion* is observed by applying the same approach described previously. Once *valid motion* is determined, the 9602-LP switches to "Callable (Moving Yes | Still No)" and "in motion" mode.

The setup parameters for "Callable (Moving Yes | Still No)" and "in motion or Motion" are similar to the "Callable (Yes)" option except the motion sensor is active. The 9602-LP uses "Minutes of Motion Before Waking" and "Sensitivity" to determine if *valid motion* is observed by applying the same approach described above. If *valid motion* is not detected before the "Minutes of Calm Before Sleeping" expires, the 9602-LP switches back to "not in motion or Low Power" mode.

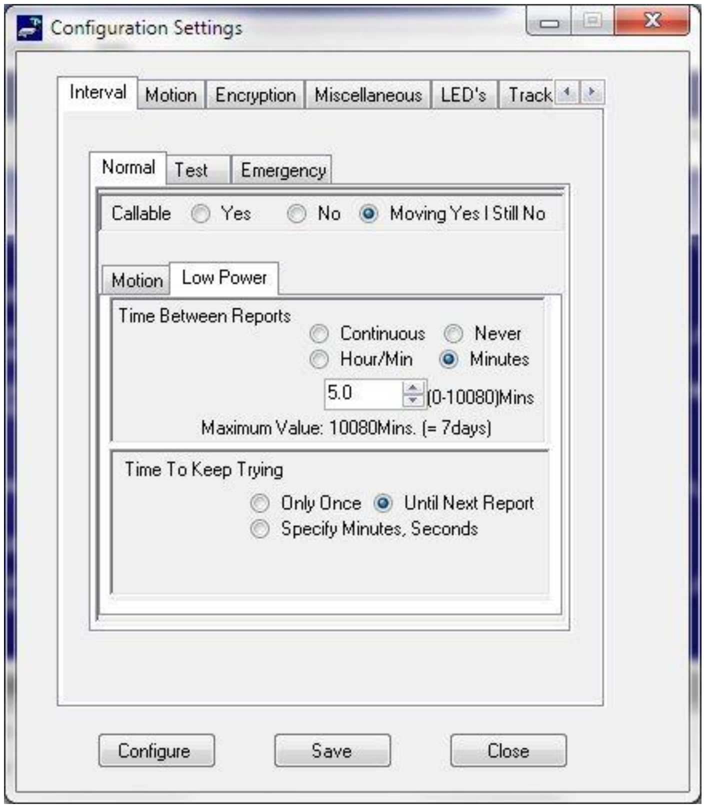


Figure 9. SatTerm Setup Window for Normal Tracking and "Callable (Moving Yes | Still No)".

Emergency and Test Tracking Modes

Emergency Tracking can be triggered by the Emergency button or by Input S0. Test Tracking can be triggered by Input S1. Emergency Tracking and Test Tracking operate similar to Normal Tracking in that they have individually configurable reporting parameters. While in Emergency Tracking, the 9602-LP does not respond to +++ escape sequence and at least one "report send attempt" must be completed before transitioning back to Normal Tracking. The Emergency GPS reports have a special data bit activated to alert the recipient of the message type. The 9602-LP allows GPS reports to be saved on its non-volatile memory when an Iridium satellite is not available.

5.2 Encryption Setting

The 9602-LP can send GPS reports in AES 256-bit encrypted format. Figure 10 displays SatTerm encryption setting window. The GUI allows the Crypto Officer Password to be changed, the encryption to be enabled or disabled, and the encryption key or decryption key to be set or changed.

A factory-default Crypto Officer Password is initially set and saved into the 9602-LP. This default Password must be changed before any encryption properties can be set or changed. To change the default Password, click on the "Change" button to open the "Change Crypto Officer Password" window. Then complete the form. The default Password should be displayed as the "Old Password". When done, click on the "Send" button.

Once the default Password has been changed, the encryption and decryption keys will need to be set in order to use encryption for the first time. In the "Change Encryption Settings" window, check "Use Encryption" and choose the option "Use". Then check "Encryption Key" and enter the key two times. Next check the "Decryption Key" and enter the key two times. When done, click the "Send" button. The message "Update Made" will be displayed.

After the default Crypto Officer Password has been changed and the Encryption and Decryption Keys have been set, encryption properties can be modified via the "Change Encryption Settings" window using the current Crypto Officer Password.

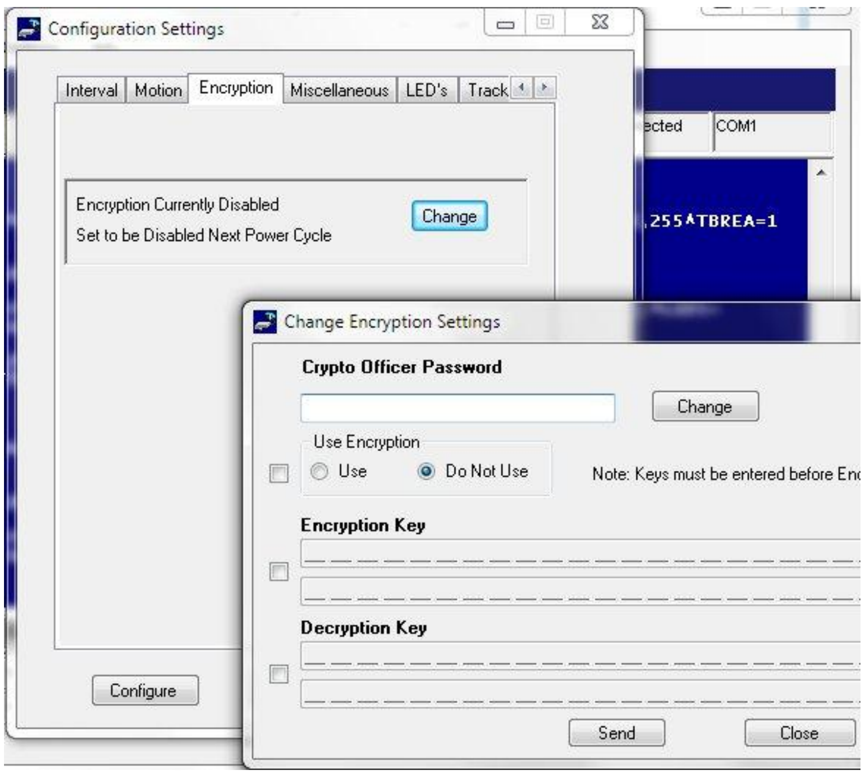


Figure 10. SatTerm Setup Window for AES-256 Bit Encryption.

5.3 Miscellaneous Settings

The Miscellaneous tab offers four settings. "Remote Update Password" sets the required password when a remote update to the current active operating profile is made from a command center while the 9602-LP is in the field. The <password> entered must be 8 characters in length and all printable characters are allowed. The factory-set password is 12345678 and there is no requirement to change this password. "Identifier in Reports" option allows a unique static identifier of up to 50 characters (platform identifier of the 9602-LP) to be entered and added to the GPS report. The power up text can either be displayed or hidden with the "Startup Information" option.

The 9602-LP has a single power on/off button. With the correct internal voltage jumper setting, the 9602-LP is default to power up automatically when DC power is first applied to either pin 1 or pin 9 on the multi-interface connector. It can be turned off/on again by momentarily holding down the power button and release. Using AT command ^IPS, the 9602-LP can also be set to power up by pressing the power button when DC power is first applied to pin 1 or pine 9. If the device is sleeping in between reporting cycles, pressing the power button will turn the 9602-LP on for 10 seconds. During this time tracking mode can be exited by sending +++.

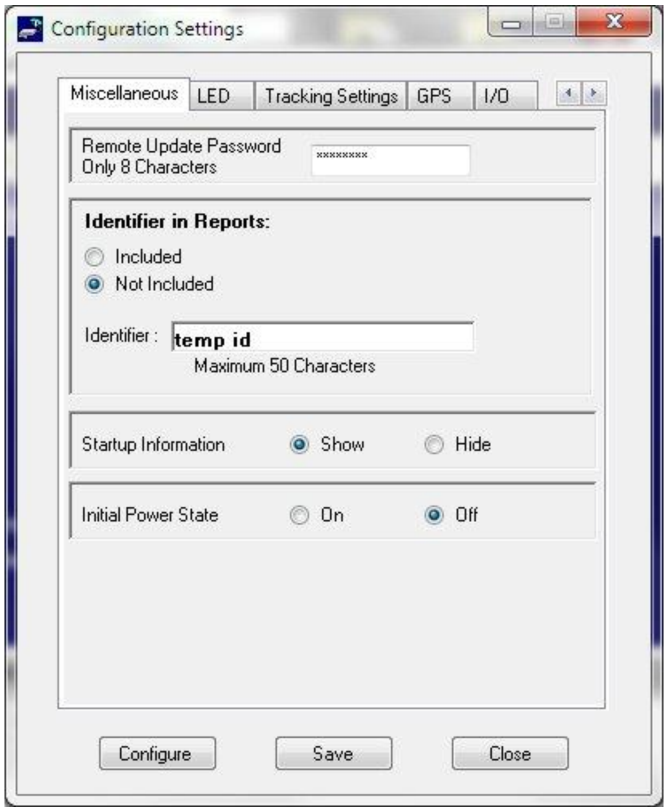


Figure 11. SatTerm Setup Window for Miscellaneous Options.

5.4 LED Settings

The 9602-LP has five status LEDs. These include power indicator, Iridium signal strength, GPS availability, SBD transmission status and Emergency mode alert. They offer users a quick visual check to ensure proper operations. These LEDs provide the following information during Normal tracking mode:

- Power LED: lights up when power is applied to the 9602-LP and power-on button is pressed.
- GPS LED: stays solid when there is a valid GPS position fix, blinks when there is 2D fix or using dead reckoning, and stays off when unable to obtain a position fix. Users have to watch closely for the LED since it can briefly stay on.
- Iridium LED: stays solid when the Iridium signal strength is between 3–5 bars, blinks when the Iridium signal strength is between 1–2 bars, and stays off when the Iridium signal strength is at

light up very briefly and users might not be able to see if not watched closely.

0 bars. Since the Iridium modem is on over a short period during a location report, this LED will light up very briefly and users might not be able to see if not watched closely.

- Status LED: when first entering Tracking Mode, the LED will not light up. This LED stays solid if the last SBD transmission had a valid GPS fix and successfully received by the gateway, blinks if the last SBD transmission was unsuccessfully sent or did not have a valid GPS fix but one was sent since the unit was turned on, and stays off if no SBD transmission with a valid GPS fix was sent to the gateway.
- Emergency LED: lights up when the Emergency button is pressed or the Input S0 is activated.

During Command Mode or while operating the 9602-LP as a 9602-G modem, the LEDs display information in the same manner as during Normal tracking mode. In addition, the Status LED provides:

- Status LED: when first entering the Command mode, this LED will not light up. If the last SBD session does not have an error the LED stays solid. An error occurs when a transmitted SBD message is not being acknowledged by the Gateway or if a message received from the Gateway contains an error(s). The LED blinks only after the 9602-LP is powered up with the last SBD session having an error but the next SBD session is error-free.

For those applications where prolonging battery life is essential, the LEDs can be turned OFF using the ^LEDS AT command or using the SatTerm LED's tab as shown in Figure 12. The 9602-LPs are shipped with all LEDs set to on.

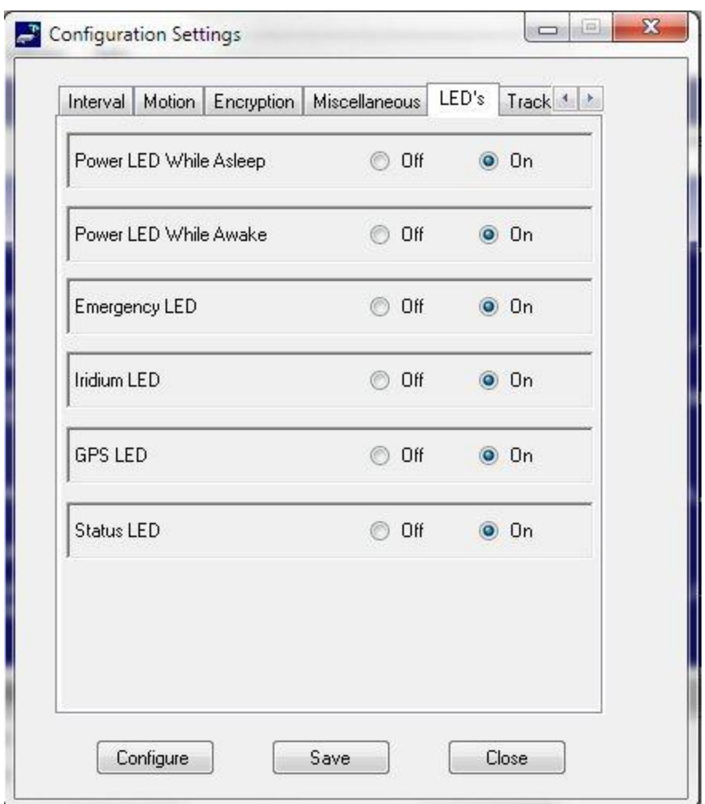


Figure 12. SatTerm Setup Window for LEDs.

5.5 Tracking Settings

The Tracking Settings tab offers multiple settings. “Emergency Report Flood” sets how many GPS reports will be sent out continuously when first entering Emergency Tracking. After <n> GPS reports have been sent, the pre-programmed reporting interval will take effect. “Remote Message Format” sets format of the messages that will be sent to the command center. “GPS Always ON” forces the GPS receiver to stay on in between reports allowing hot-start each time the 9602-LP wakes up. “Start-Up Mode” sets the power-up mode of the 9602-LP.

The 9602-LP allows GPS reports to be saved on its non-volatile memory with “Data Log Tracking” option turned on. When its memory is full, the oldest reports are over-written. SatTerm can be used to retrieve all position reports at a later time through the multi-interface serial port.

When the “Block Invalid Reports” is enabled and a tracking mode is selected, reports with invalid GPS fix will not be sent. “Test Report Flood” sets how many GPS reports will be sent out continuously when first entering Test Tracking. After <n> GPS reports have been sent, the pre-programmed reporting interval will take effect.

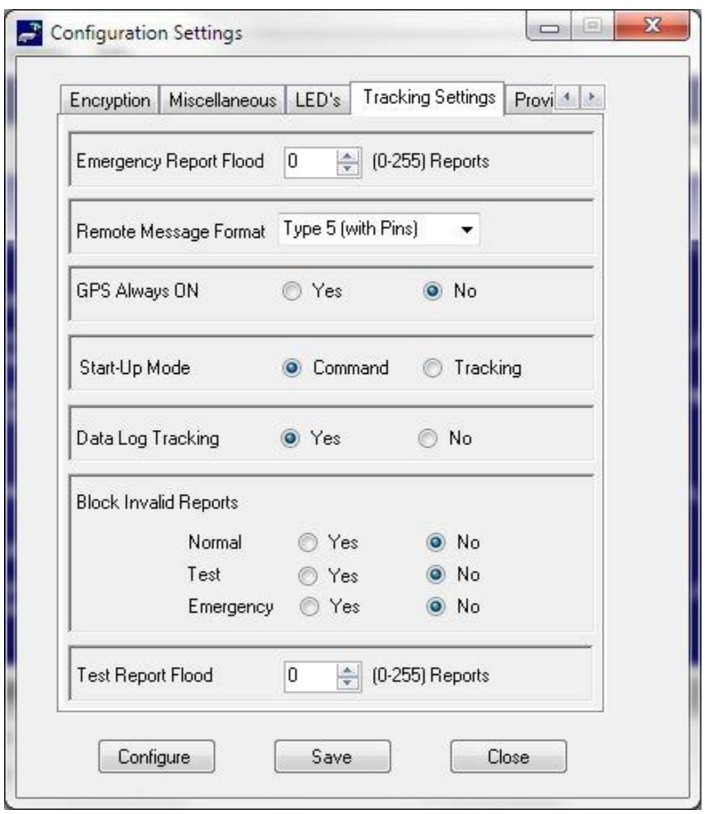


Figure 13. SatTerm Setup Window for Tracking Options.

5.6 GPS Settings

The GPS tab offers users the option to obtain GPS information from the 9602-LP serial port while the unit is in command mode or tracking mode (similar to the command ^PG). Both GPS NMEA formats and updating (streaming) rate can be defined.

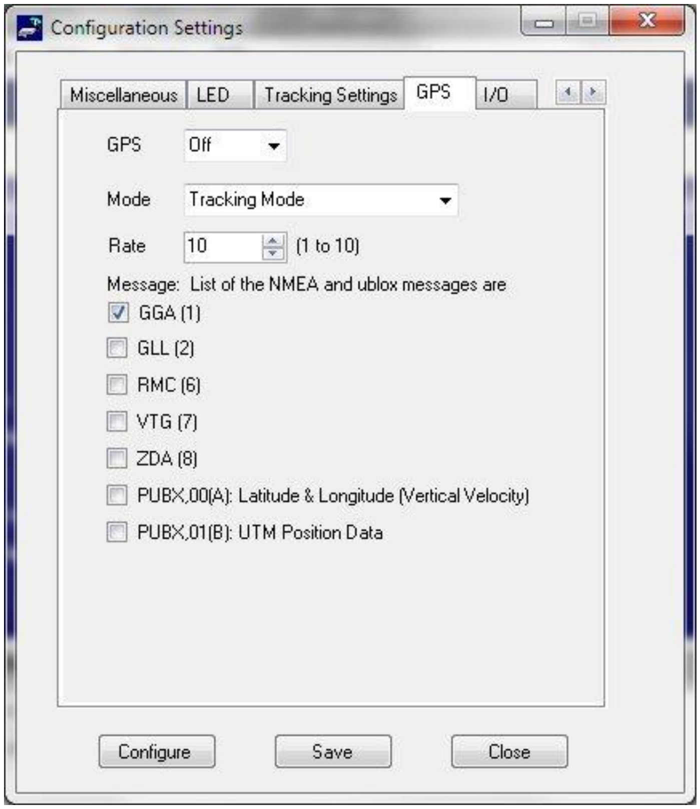


Figure 14. SatTerm Setup Window for GPS Options.

6.0 MOTION SENSOR

The 9602-LP has a built-in sensor that can reliably detect motion. It is truly an omni-directional movement sensor and will function regardless of how the 9602-LP is mounted or aligned. It is sensitive to both tilt (static acceleration) and vibration (dynamic acceleration). The sensor produces a series of TTL level logic or pulse train. The signal level is fed directly into the 9602-LP's micro-controller to "wake up" the 9602-LP out of sleep mode when activity is sensed and to transmit location report.

The 9602-LP's motion sensor can be enabled or disabled through an AT command (^MSA). When enabled, the motion sensor has a user-defined time out to prevent false alarm. The user-defined time out is the duration in which the 9602-LP must remain in motion before the signal level is asserted to the micro-controller. Additional motion sensor settings can be found in the AT manual. The motion sensor draws approximately 4μA at 4VDC power input regardless of whether it is software enabled or not.

7.0 IRIDIUM ANTENNA CONNECTOR

The 9602-LP uses a single SMA female 50-ohm antenna connector for both transmission and reception of the Iridium signals. The mating SMA male connectors are readily available from many RF hardware vendors/suppliers. Cable and connector losses between the 9602-LP and the antenna are critical and must be kept to less than 2dB at the operating frequency of 1616 to 1626.5 MHz.

NAL Research offers several types of antennas for use with the 9602-LP. These antennas include the fixed mast, mobile magnetic/permanent mount and portable auxiliary. For low-cost and applications where small form-factor and light-weight are required, NAL Research highly recommends model SYN7391-C as shown in Figure 15.

Figure 15. NAL Research's Antenna SYN7391-C.

If custom-designed antenna is required, it must meet the specifications shown in Table 2 below.

PARAMETER	VALUE
Measurement Frequency Range	1616 to 1626.5 MHz
Return Loss (Minimum)	9.5 dB
Gain	0.0 dBic (weighted average minimum)
VSWR	1.5 : 1
Minimum 'Horizon' Gain	–2.0 dBic (82° conic average)
Nominal Impedance	50 Ohms
Polarization	Right Hand Circular (RHCP)
Basic Pattern	Omni directional and hemispherical

Table 2. Recommended Iridium Antenna's Design Specifications.

8.0 GPS ANTENNA CONNECTOR

The 9602-LP tracker uses an SMA female connector for the GPS antenna. Any active antenna accepting a bias voltage of 3VDC is appropriate. However, the low-noise amplifier (LNA) gain should not exceed 30dB. NAL Research offers a magnetic mount GPS antenna as well as dual Iridium/GPS antennas for use with the 9602-LP. For low-cost and applications where small form-factor and light-weight are required, NAL Research highly recommends model SAF7352-IG as shown in Figure 16.

Figure 16. NAL Research's Antenna SAF7352-IG.

IMPORTANT: GPS antenna should only be connected to or disconnected from the 9602-LP when it is not powered. DO NOT CONNECT OR DISCONNECT THE GPS ANTENNA WHEN

THE 9602-LP IS POWERED. The internal GPS receiver calibrates the noise-floor on power-up, and by connecting the GPS antenna after power-up can result in prolonged acquisition time and possibly damage the GPS receiver. To test GPS signal reacquisition, physically blocking the signal to the antenna rather than disconnecting and reconnecting the antenna is recommended.

IMPORTANT: Never feed external supply voltage into the active GPS antenna. Always use the bias voltage supplied by the 9602-LP via the SMA antenna connector to power an active GPS antenna. Feeding voltage to the GPS antenna other than the provided bias voltage will damage the 9602-LP.

9.0 POWER CONSUMPTION

This section gives users some insight to the electrical power profile of the 9602-LP. It does not describe every situation and permutation possible. It should be used as a starting point for the users to continue their own development design. The actual usage profile can vary for a number of reasons:

1. Poor visibility of the sky where clear line of sight is not available between the 9602-LP and satellite.
2. The higher the antenna VSWR the higher the current consumed.
3. And manufacturing variation from device to device.

Power consumption of the 9602-LP can be divided into distinct operating segments: (1) power up, (2) standby, (3) sleep between reports, (4) GPS acquisition, and (5) SBD report transmission. At power up in command mode, typical in-rush current of ~3A-4A over a few milliseconds is mainly due to the current drawn by the 9602 (see Figure 17).

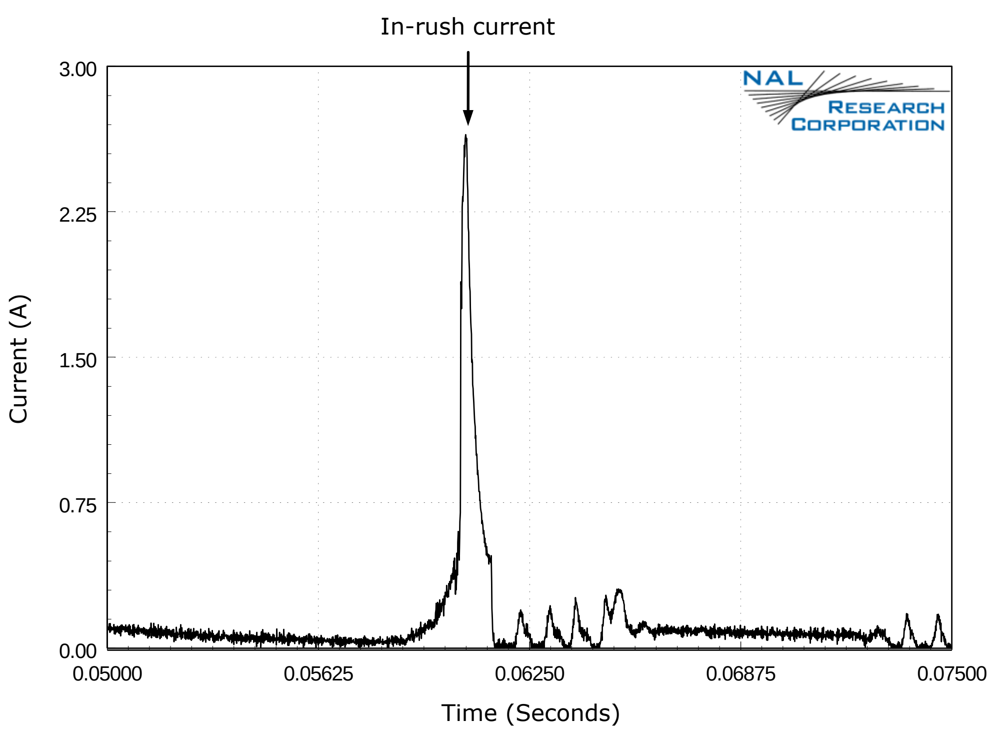


Figure 17. In-Rush Current Spike during Power-Up in Command Mode at 5VDC Input.

At standby in command mode, current is measured when all circuits are on. The average current drawn during standby with 3.6VDC – 5VDC input and 6VDC – 32VDC are shown in Figures 18 and 19, respectively.

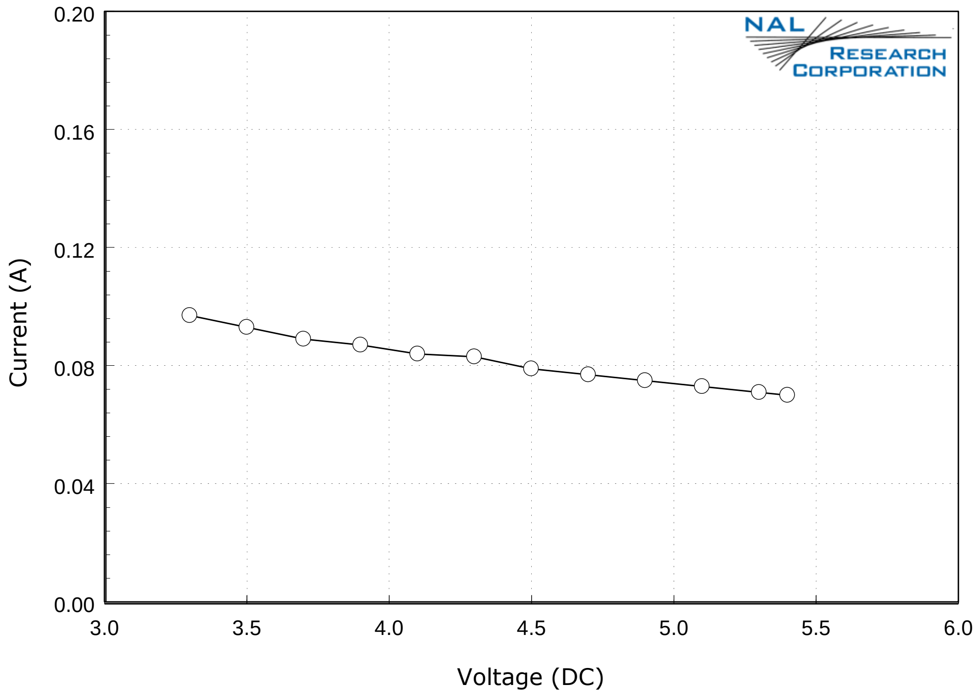


Figure 18. Average Current during Standby with 3.5VDC to 5VDC Input.

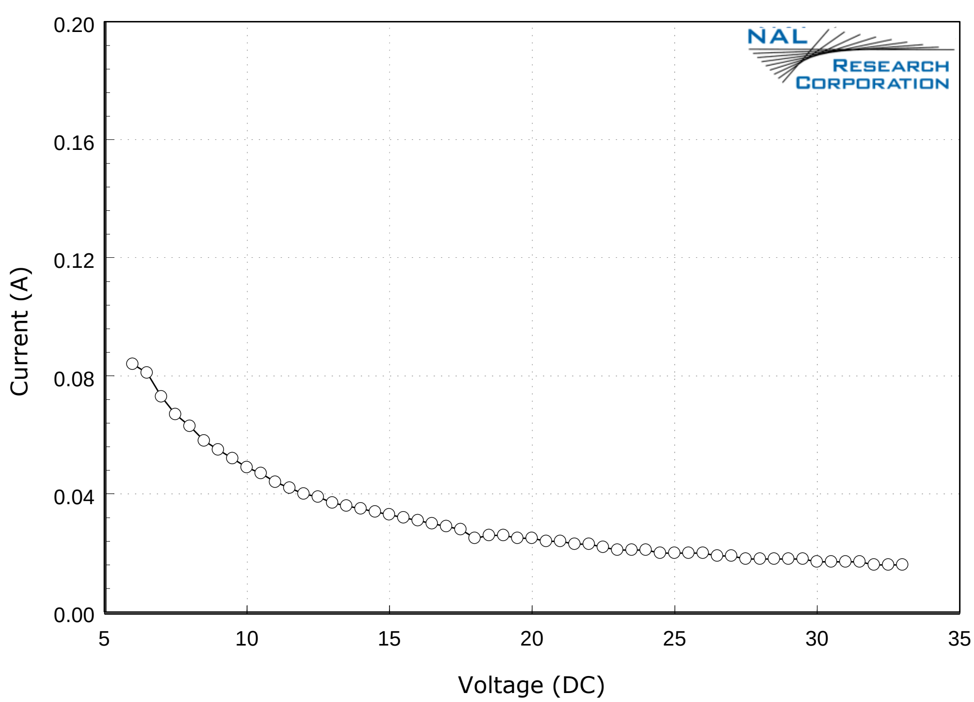


Figure 19. Average Current during Standby with 6VDC to 32VDC Input.

Figure 20 shows the average power consumption by the 9602-LP at standby in command mode for the entire voltage range.

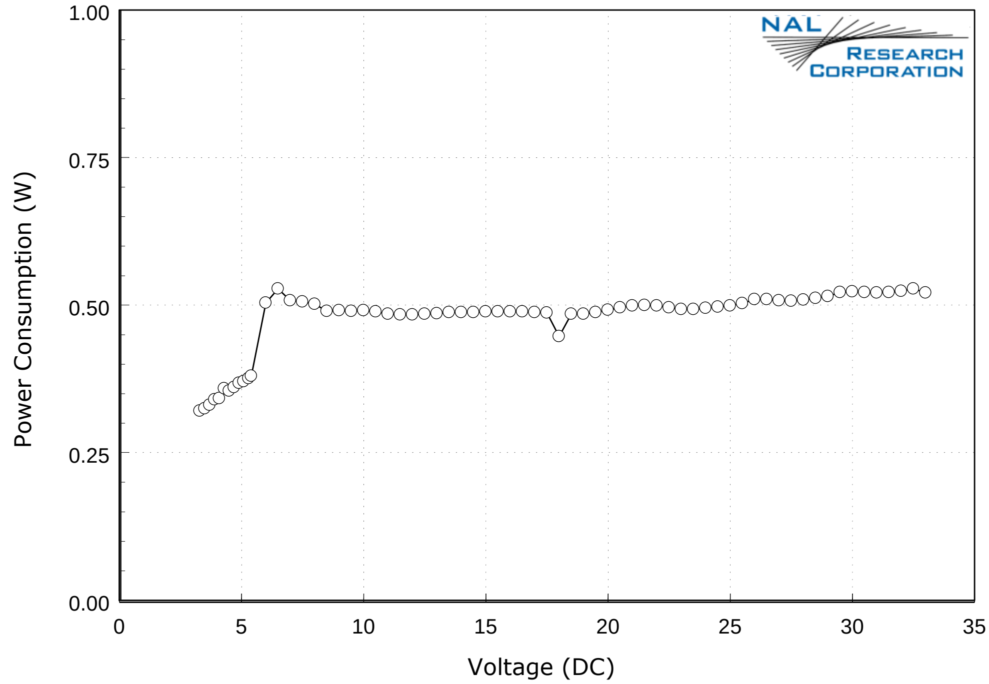
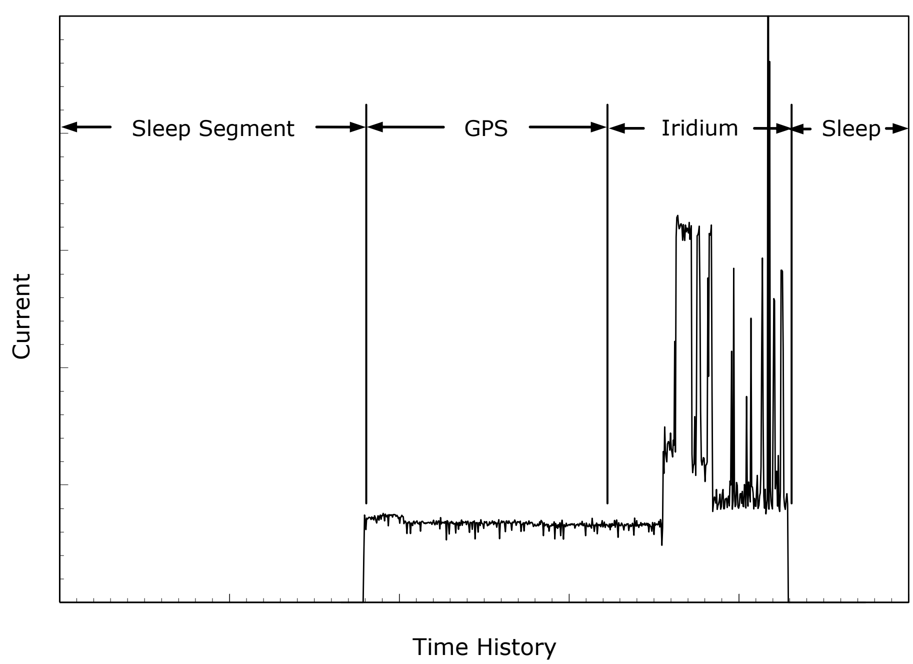


Figure 20. Average Power Consumption during Standby with 3.5VDC to 32VDC Input.

In tracking mode, the 9602-LP goes through three different power consumption segments: (1) the sleep (in between reports) segment, (2) GPS acquisition segment, and (3) SBD transmission segment. Figure below shows different stages of current drawn by the 9602 when in tracking mode. During the sleep segment, the 9602-LP goes into power-saving mode by shutting down all its internal circuits.



The average current drawn by the 9602-LP during sleep with 3.6VDC–5VDC input is shown in Figure 21.

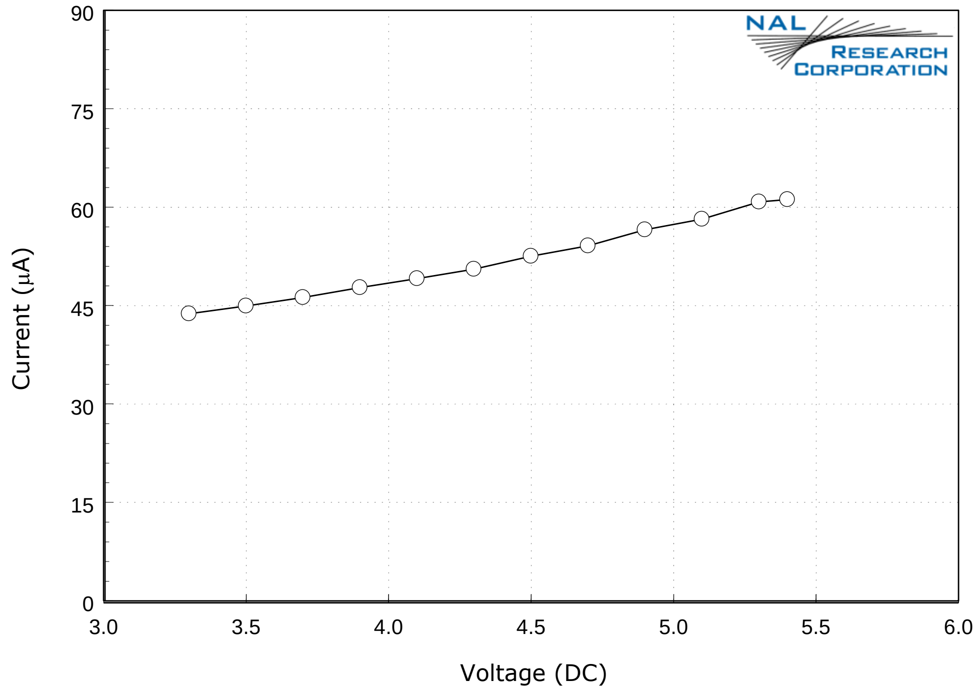


Figure 21. Average Current during Sleep with 3.5VDC to 5VDC Input.

The average current drawn by the 9602-LP during sleep with 6VDC – 32VDC is shown in Figure 22. Due to limitation of our signal analyzer, current drawn for voltages above 15VDC in the μA range could not be measured. The dashed line is resulted from curve fitting (cubic spline) of the data.

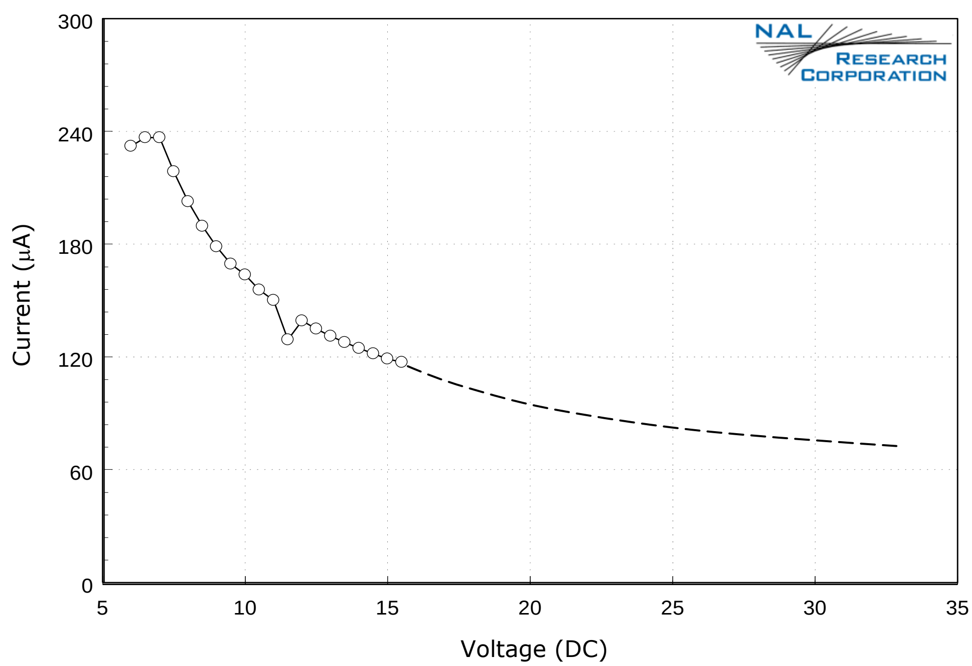


Figure 22. Average Current during Sleep with 6VDC to 32VDC Input.

Figure 23 shows the average power consumption by the 9602-LP during sleep for the entire voltage range.

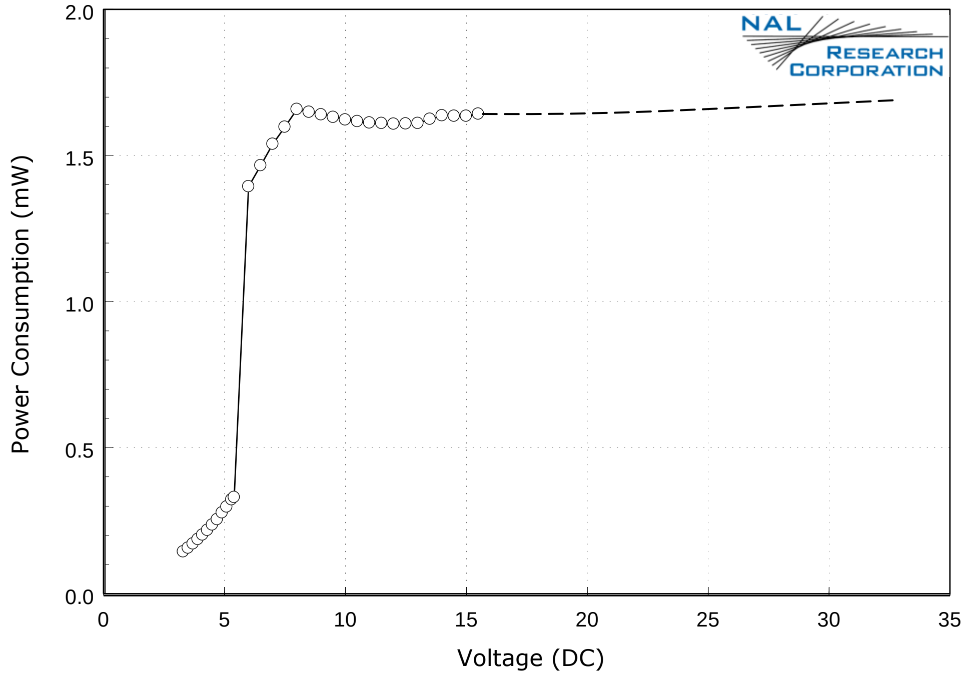


Figure 23. Average Power Consumption during Sleep with 3.5VDC to 32VDC Input.

During the GPS acquisition segment, the average current drawn by the 9602-LP with 3.6VDC – 5VDC input and 6VDC – 32VDC are shown in Figures 24 and 25, respectively. The GPS acquisition time can range from 1 second (hot starts) to 28 seconds (cold starts).

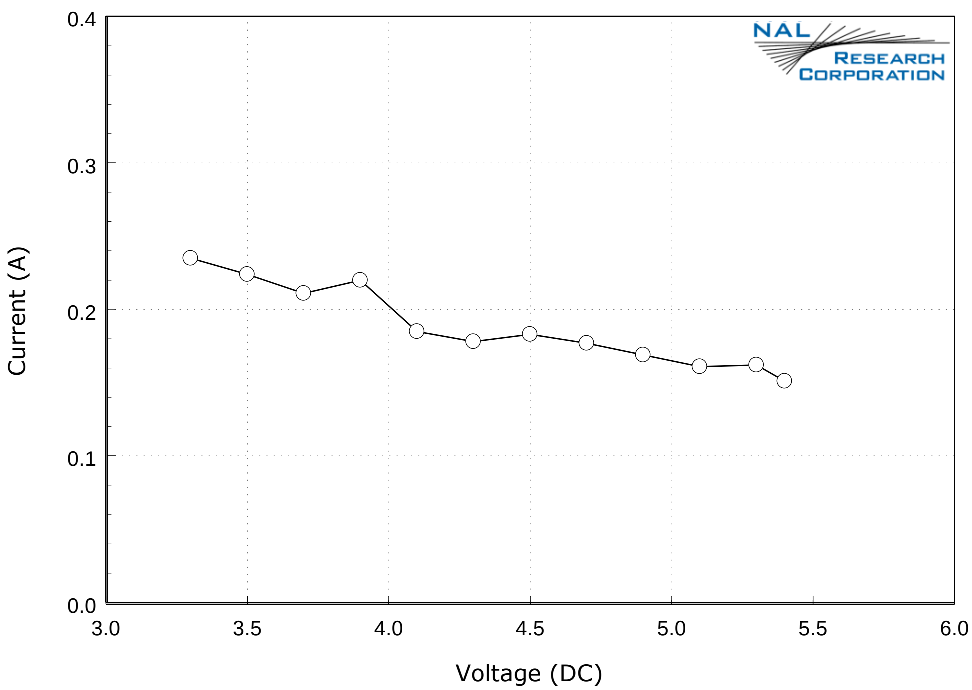


Figure 24. Average Current during GPS Acquisition with 3VDC to 5VDC Input.

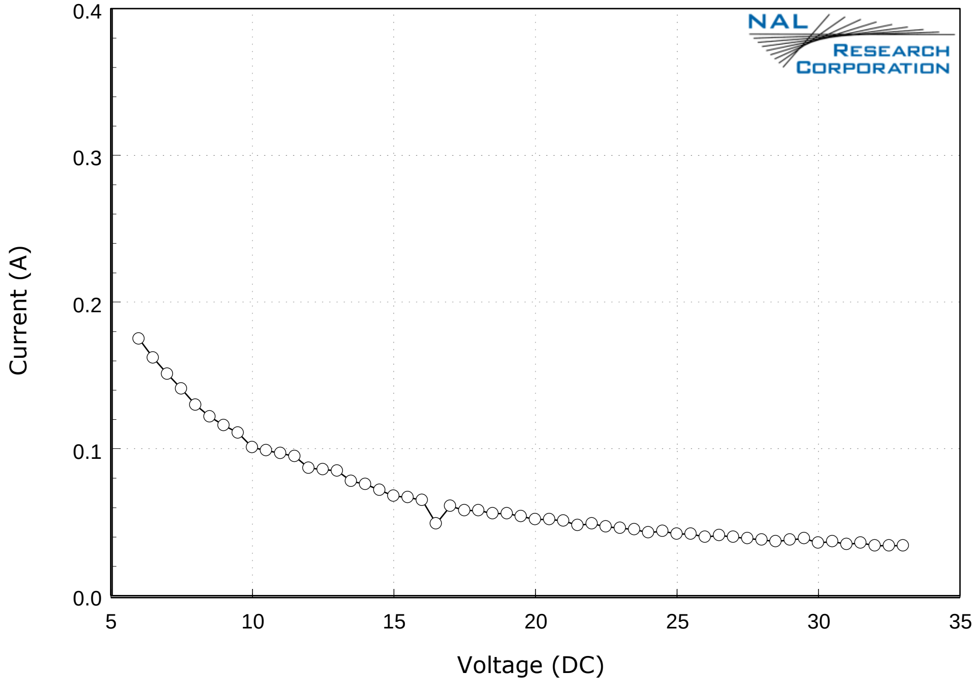


Figure 25. Average Current during GPS Acquisition with 6VDC to 32VDC Input.

Figure 26 shows the average power consumption by the 9602-LP during GPS acquisition for the entire voltage range.

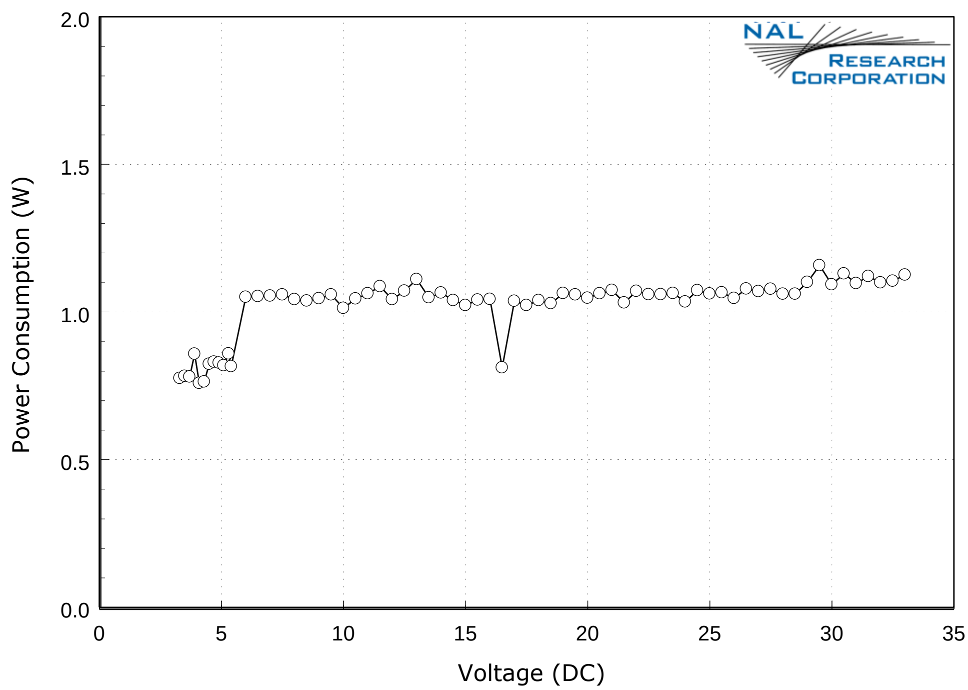


Figure 26. Average Power Consumption during GPS Acquisition with 3.5VDC to 32VDC Input.

During the SBD transmission segment, the average current drawn by the 9602-LP with 3.6VDC – 5VDC input and 6VDC – 32VDC are shown in Figures 27 and 28, respectively.

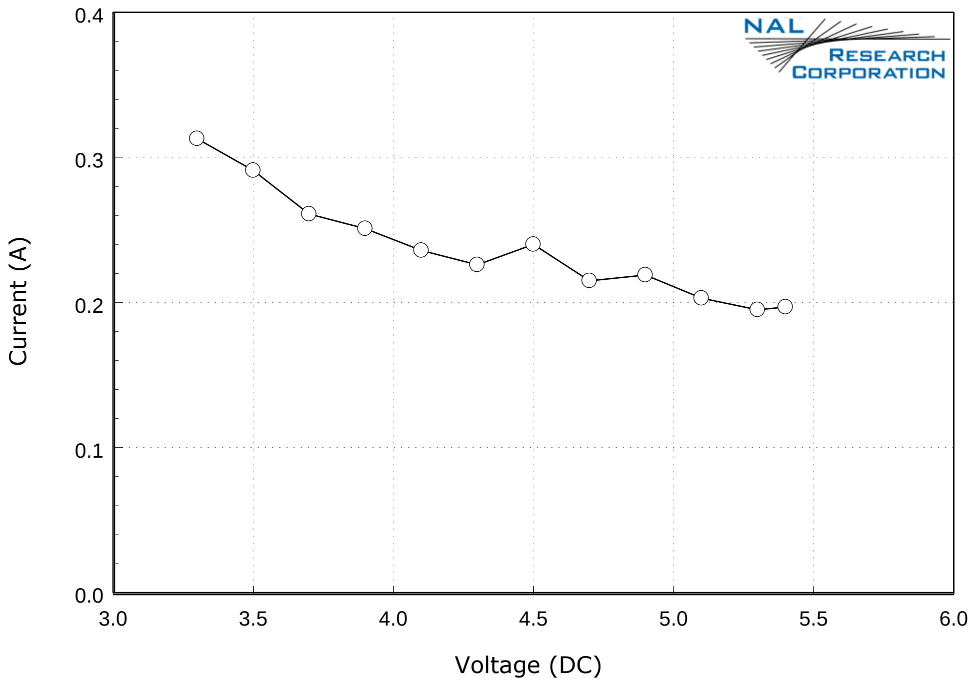


Figure 27. Average Current during SBD with 3VDC to 6VDC Input.

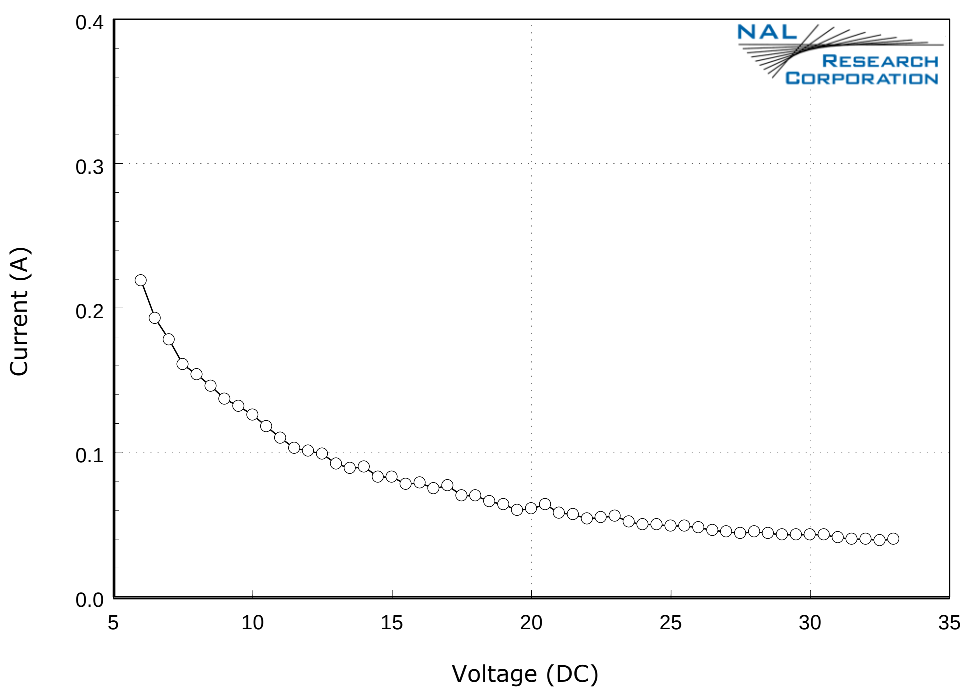


Figure 28. Average Current during SBD with 6VDC to 32VDC Input.

Figure 29 shows the average power consumption by the 9602-LP during SBD transmission on for the entire voltage range.

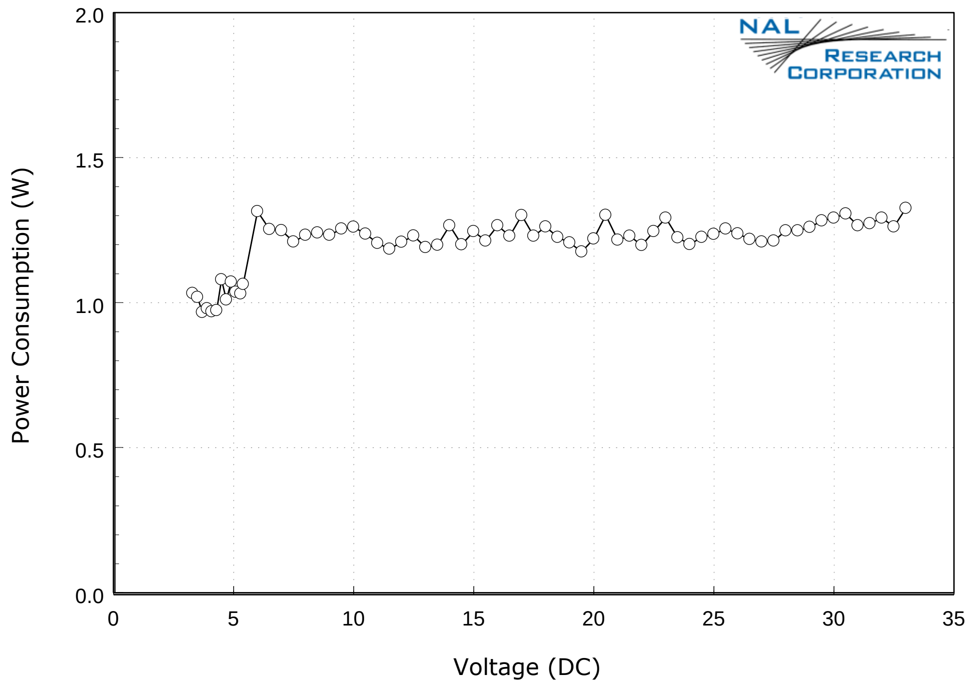


Figure 29. Average Power Consumption during SBD Transmission with 3.5VDC to 32VDC Input.

All the plots above show that the 9602-LP is more efficient (consumes less power) when operates in the 3.6VDC to 5.3VDC input range especially in between reports. It should be noted that the actual current profiles may vary for a number of reasons and users are again reminded to optimize their setup to attain the lowest possible power consumption. Some of the setup parameters to be carefully observed include:

1. Have a clear view of the sky for both the GPS and Iridium antennas—poor visibility of the sky is when a clear line-of-sight is not available between the 9602-LP and the satellites.
2. Keep the Iridium antenna's VSWR low—the higher the antenna VSWR the higher the current consumed by the 9602-LP.
3. Keep the antenna cables' loss to less than 3dB—the higher the antenna cable loss the higher the current consumed by the 9602-LP.
4. Select active GPS antennas with low-power consumption LNAs—a GPS antenna LNA with 30dB gain is sufficient.
5. Keep the power cable between the 9602-LP and the power source as short as possible.

10.0 LIST OF KNOWN ISSUES

a. ^TBR=68401 (never send) is not implemented
b. ^BIGR cannot be set by remote update
c. Waking from motion with ^CAL0 may not cause a report to be sent
d. ^WMF does not accept values 6 and 7
d. ^ERF=? and ^TRF=? display the wrong range

11.0 TECHNICAL SUPPORT

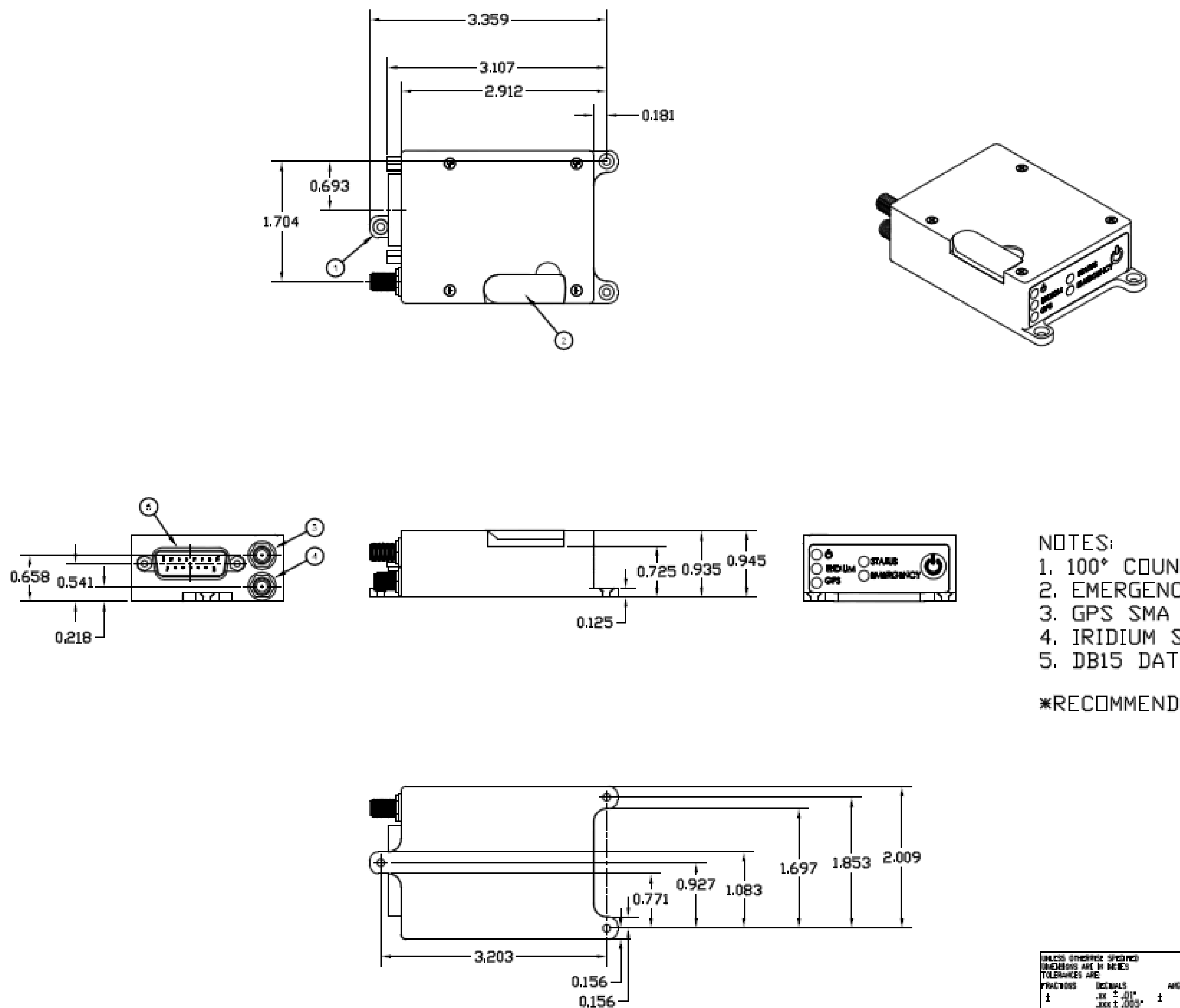
For technical support, please contact us at:
Phone: 703-392-1136 Ext. 200 or
E-mail: contact@nalresearch.com

Technical documents are also available to download on NAL Research's website
www.nalresearch.com

DWG. NO. 92358	SH. 1	REV. 1.1

DWG REV	A
BD REV	
A/W REV	

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED
	1.0	INITIAL RELEASE	02/07/2011	D. GAIBROIS
	1.1	TORQUE INFORMATION ADDED	2/15/2013	D. GAIBROIS



NOTES:
1. 100° COUNTERSINK FOR # 4 SCREW, UNTHREADED (X4)
2. EMERGENCY SWITCH ACCESS
3. GPS SMA CONNECTION, COLOR: SILVER
4. IRIDIUM SMA CONNECTION, COLOR: GOLD
5. DB15 DATA CONNECTION

*RECOMMENDED SMA MATING TORQUE: 8 IN-LBS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .01" .XXX ± .005" ANGLES ±
MATERIAL
FINISH

CONTRACT NO.	
APPROVALS	DATE
DESIGNER E. RODERICK	2/15/2013
CHECKER	
PROJ. ENG.	
APPROVED D. GAIBROIS	2/15/2013

NAL RESEARCH CORP.

DRAWING NAME
9602-LP

C	CAGE CODE	DWG NO. 92358	REV 1.1
SCALE 1:1		SHEET 1 OF 1	

92358 SH. 1 REV. 1.1

CAD DRAWING FILE NAME: 9602-LP
CAD GENERATED DRAWING, MANUAL CHANGES NOT ALLOWED

APPENDIX A: STANDARDS COMPLIANCE

The 9602 transceiver is designed to meet the regulatory requirements for approval for FCC, Canada, and CE assuming an antenna with a gain of ~3 dBi and adequate shielding. The 9602 transceiver is tested to the regulatory and technical certifications shown in table below.

Regulatory Approvals	**Radio Tests**	**EMC Tests**	**Mechanical/ Electrical Tests**
CE	ETSI EN 301 441 V1.1.1 (2000-05)	ETSI EN 301 489-1 V1.8.1 (2008-04) ETSI EN 301 489-20 V1.2.1 (2002-11)	EN60950-1:2006 Part 1
FCC	FCC CFR47 Parts 2, 15, and 25	EN61000-4-2: 1995/A2: 2001 Part 4.2 EN61000-4-3: 2002 Part 4.3 EN61000-4-4: 2004 EN61000-4-6: 1996/A1: 2001 Part 4.6 EN55022: 2006	
Industry Canada	Industry Canada RSS170 Issue 1, Rev 1, November 6, 1999		

APPENDIX B: EXPORT COMPLIANCE INFORMATION

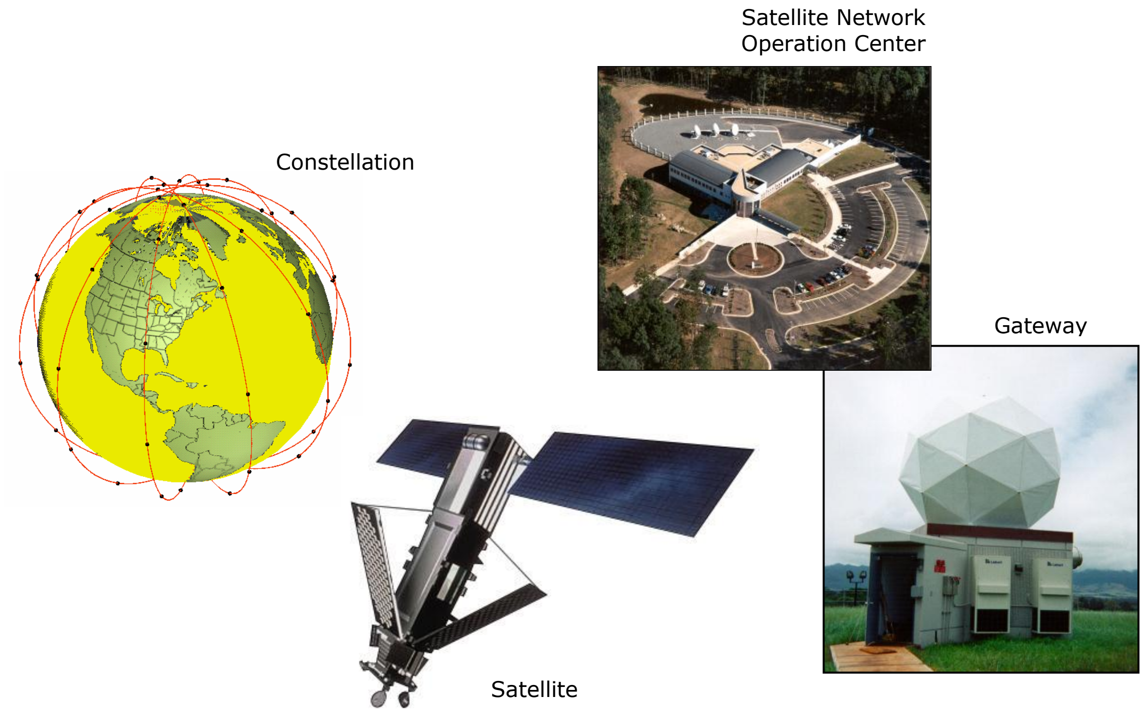
The 9602-LP is controlled by the export laws and regulations of the United States of America (U.S.). It is the policy of NAL Research to fully comply with all U.S. export and economic sanction laws and regulations. The export of NAL Research products, services, hardware, software and technology must be made only in accordance with the laws, regulations and licensing requirements of the U.S. Government. NAL Research customers must also comply with these laws and regulations. Failure to comply can result in the imposition of fines and penalties, the loss of export privileges, and termination of your contractual agreements with NAL Research.

The export and re-export of NAL Research products and services are subject to regulation by the Export Administration Regulations (15 CFR 730-744), as administered by the U.S. Department of Commerce, Bureau of Industry and Security ("BIS"). See: http://www.bxa.doc.gov for further information on BIS and the Export Administration Regulations (EAR). Additional export restrictions are administered by the U.S. Department of the Treasury's Office of Foreign Asset Controls ("OFAC"). See: http://www.ustreas.gov/ofac for further information on OFAC and its requirements.

APPENDIX C: DESCRIPTION OF THE IRIDIUM NETWORK

C.1 Description of the Iridium Network

The Iridium satellite network is owned and operated by Iridium Satellite LLC (ISLLC). It was constructed as a constellation of 66 satellites in low-earth orbit, terrestrial gateways and Iridium subscriber units (ISU). An ISU can either be an Iridium satellite phone or any of the modems. The satellites are placed in an approximate polar orbit at an altitude of 780 km. There are 6 polar planes populated with 11 satellites per orbit constituting the 66 satellite constellation. The near polar orbits of the Iridium constellation provide truly real-time and global coverage from pole-to-pole.



The Iridium is designed to operate in the band of 1616 to 1626.5 MHz although the exact frequencies used depend on the local regulating authorities and issued licenses in any particular region. Each satellite projects 48 beams on the surface of earth, which may be viewed as providing coverage cells on the ground similar to terrestrial systems. Each beam is approximately 600 km in diameter. The 66-satellite constellation has the potential to support a total of 3,168 spot beams; however, as the satellite orbits converge at the poles, overlapping beams are shut down. The satellite footprint is ~4,700 km in diameter. Under each footprint, a satellite is power limited to ~1,100 simultaneous circuits.

The Iridium network uses a time domain duplex (TDD) method and transmits and receives in an allotted time window within the frame structure. Since the system is TDD, the ISU transmit and receive in the same frequency band. The access technology is a FDMA/TDMA (frequency division multiple access/time division multiple access) method whereby an ISU is assigned a channel composed of a frequency and time slot in any particular beam. Channel assignments may be changed across cell/beam boundaries and is controlled by the satellite. The system will provide an average link margin of 13.1 dB.

Although there are multiple gateways, a user is registered to a single gateway. The gateways perform call connection setup and administrative duties such as billing and resource management. The satellite constellation provides connectivity between users, from a user to the Iridium system gateway, and between gateways. Within the Iridium network architecture, the satellites are cross-linked which allows ISU to ISU communication independent of gateway intervention once the call connection is established.

There are currently two commercial Iridium gateways located in Arizona, United States and Fucino, Italy. The U.S. government owns and operates an Iridium gateway located in Hawaii, United States. Each gateway generates and controls all user information pertaining to its registered users, such as user identity, geo-location and billing items. The gateway also provides connectivity from the Iridium system to the terrestrial based networks such as the PSTN.

C.2 Description of the Iridium Network Data Capabilities

For data communications, the Iridium network supports five different modes of operation as shown in Figure D1—dial-up data service, direct Internet connection, short-burst data (SBD), short-messaging service (SMS) and router-based unrestricted digital internetworking connectivity solution (RUDICS).

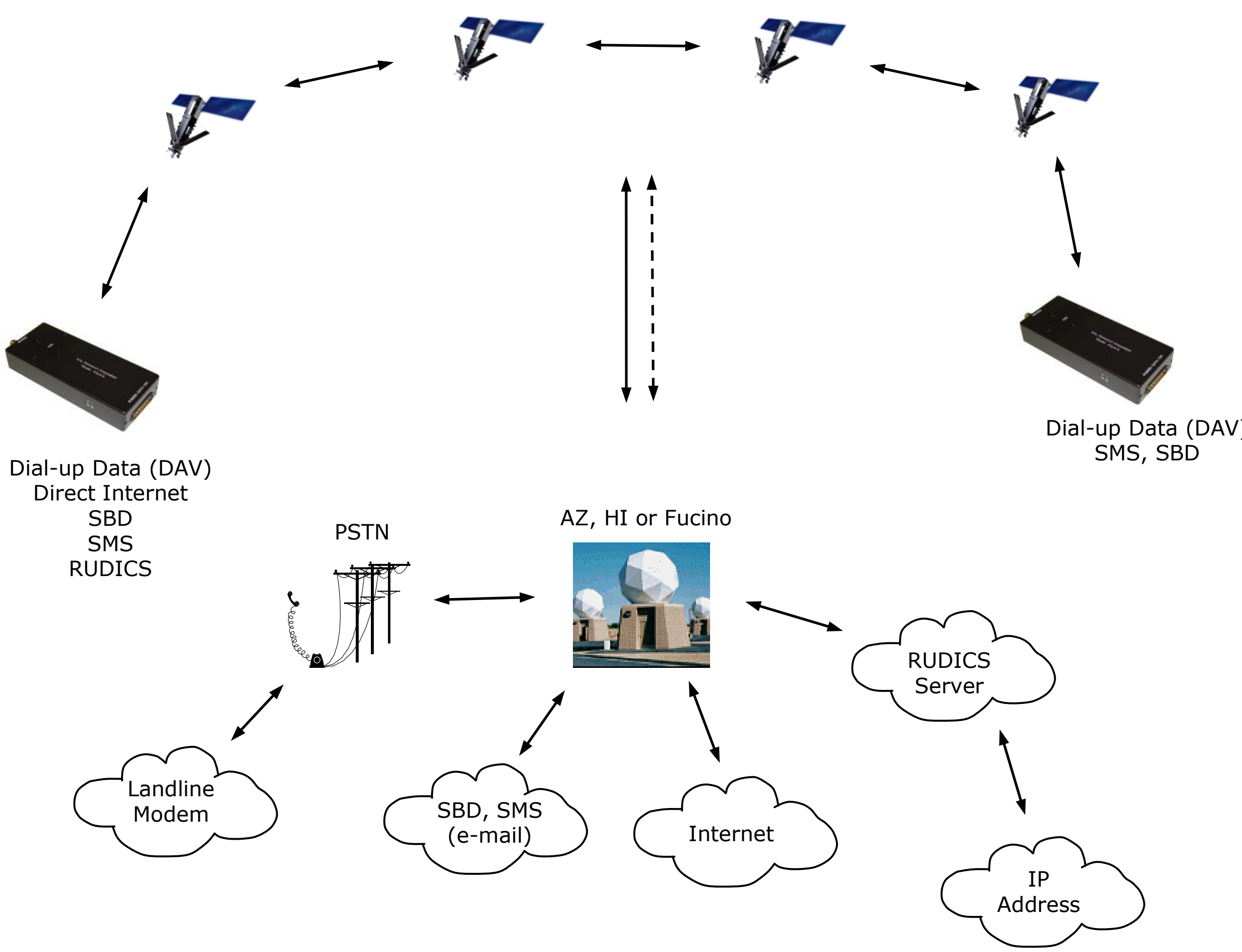


Figure D1. Iridium Network Data Capabilities.

C.3 Dial-Up Data Service

Dial-up data service provides connectivity through the Iridium satellite network to another Iridium modem, to the public switch telephone network (PSTN), to the Defense Switch Network (DSN), to a remote LAN (e.g., a corporate network) or to an Internet Service Provider (ISP) at a nominal data rate of 2.4 kilobits per second (Kbps). The connection time involving user authentication and handshaking (or modem training) can range from 15 to 30 seconds. For an Iridium-to-Iridium call, dial-up data service offers an additional option known as data after voice or DAV. Similar to a voice call, a DAV call is routed directly from one Iridium modem to another Iridium modem without going through the gateway.

Many desktop and laptop computers are equipped with either an internal or external modem to perform dial-up data applications across the landline telephone network (PSTN). On these computers, terminal emulator software or a dial-up networking connection can be configured to a specific modem with a phone number to dial, user identification and password. The modem can then be used to call another computer, a remote LAN or an Internet service provider as shown in Figure D2. The handshaking and protocols are established between the modems independent of the landline.

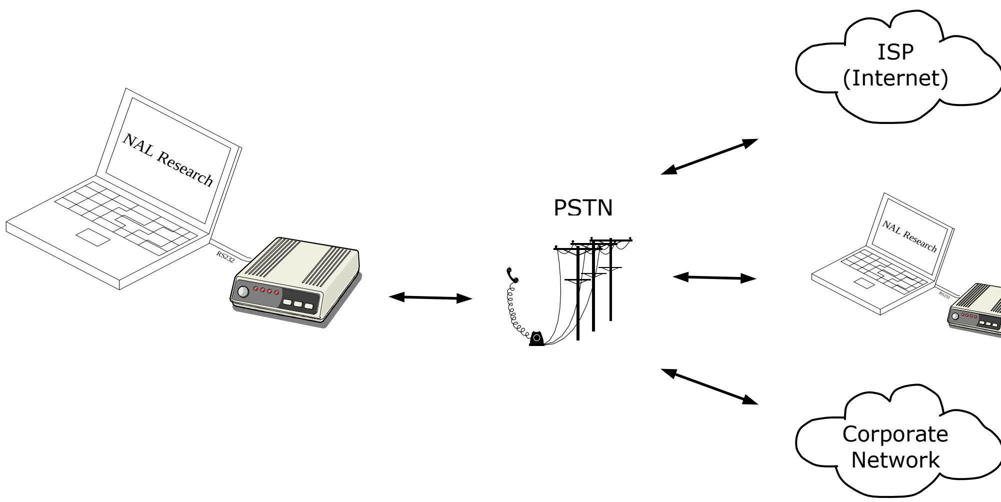


Figure D2. PSTN Dial-Up Connectivity.

The Iridium dial-up data service functions in much the same way as the PSTN dial-up connectivity. From the perspective of a computer, the Iridium modem is just another external modem. The only difference is that the dialed telephone number must conform to the international dialing pattern used by Iridium. When a data call is placed, the Iridium modem actually dials and initiates a connection with the Iridium gateway through the Iridium satellite constellation. Since the Iridium modem is requesting to establish a data connection, the switch at the gateway routes the call through another modem. The modem at the Iridium gateway then dials into and connects to another modem at the other end. Figure D3 illustrates how an Iridium dial-up data service call is routed. The handshaking and protocols established between the modems independent of the Iridium network.

For those ISU-to-ISU dial-up calls where data transmission delay is critical such as the application of TCP/IP protocol, DAV should be considered in the design. This option eliminates the Iridium gateway once authentication and registration is completed allowing ISU-to-ISU communication without the gateway in the loop.

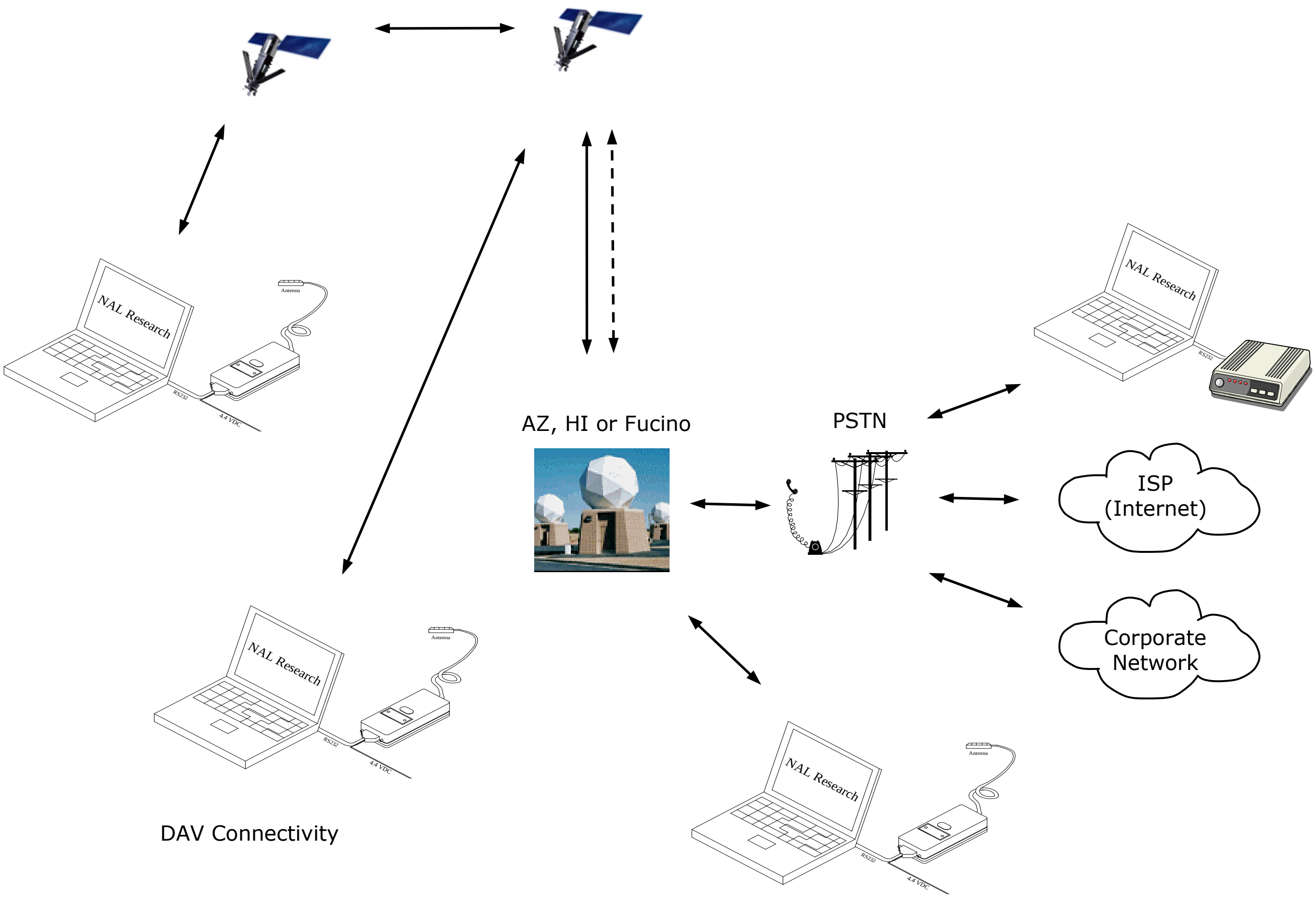


Figure D3. Iridium Dial-Up Data Service.

C.4 Direct Internet Connection

The Iridium Direct Internet service allows users to connect to the Internet via the Iridium gateway without having to sign up with an Internet service provider. This service utilizes a dedicated Apollo Server at the Iridium gateway, which provides high-speed connectivity to the Internet and optimizes server-to-Iridium modem communications. The dial-up networking setup is similar to the dial-up networking setup for landline telephone. The only difference is that the dialed telephone number is an international number provided by Iridium. Figure B3 illustrates how Iridium Internet (NIPRNet) call is routed.

Direct Internet service can be enhanced using Windows-based emulated point-to-point protocol (PPP) called the Apollo Emulator. With the use of the Apollo Emulator software instead of Microsoft Windows® dial-up networking, Direct Internet service can reduce connection time and improve data throughput. In addition, the Apollo Emulator offers a feature called Smart Connect™, which manages airtime by seamlessly connecting and disconnecting a user through the Iridium system. Airtime charges accumulate only while the call is connected. Improved effective data throughput is achieved through the use of user-transparent data compression. The channel rate is still 2.4 Kbps. However, 10 Kbps effective throughput can be achieved depending on content (graphics and images will result in lower effective throughput).

C.5 Short-Burst Data (SBD)

SBD is a simple and efficient bi-directional transport capability used to transfer messages with sizes ranging from zero (a mailbox check) to 1960 bytes. SBD takes advantage of signals within the existing air interface, without using the dedicated traffic channels. As a result, small amounts of data can be transferred more efficiently than those associated with circuit-switched data calls. Messages that originate from an Iridium modem can be delivered to a variety of destinations. Commonly, data are delivered across terrestrial communications networks (NIPRnet and Internet) to servers and applications that process data from one or multiple fielded Iridium modems. SBD service also supports the transfer of messages to Iridium modems, where messages may originate from terrestrial sources. Delivery methods and options are initially configured when the Iridium modem is first purchased and may be easily modified via web pages at a later time.

C.6 Short Messaging Service (SMS)

SMS is a mechanism to deliver short data messages over the Iridium satellite network to the NIPRNet/Internet. Iridium SMS service incorporates a subset of the GSM SMS features. Each SMS message can be up to 160 text characters (7-bit coded) in length. The text characters are based on a 7-bit alphabet, which is encoded and transmitted as 8-bit data, hence the 140 octet (byte) maximum message size.

SMS service is a store and forward method of transmitting messages to and from an Iridium modem. The short message from the modem is stored in a central Short Message Center (SMSC) which then forwards it to the destination. In the case that the recipient is not available, the SMSC will attempt to deliver the SMS until it is delivered or the validity period expires. SMS supports a limited confirmation of message delivery. The sender of the short message can request to receive a return message notifying them whether the short message has been delivered or not. With this option, the originator gets a confirmation that the message was delivered to the SMSC. Unlike standard GSM, the Iridium SMS can only acknowledge that the message was delivered to the SMSC and not the end-destination.

SMS messages can be sent and received simultaneously while a voice call is in progress. This is possible because SMS messages travel over and above the radio channel using the signaling path, whereas the voice call uses a dedicated “traffic” radio channel for the duration of the call.

C.7 RUDICS

RUDICS is an enhanced gateway termination and origination capability for circuit switched data calls across the Iridium satellite network. When an Iridium modem places a call to the RUDICS Server located at the Iridium Gateway, the RUDICS Server connects the call to a pre-defined IP address allowing an end-to-end IP connection between the Host Application and the Iridium modem. There are three key benefits of using RUDICS over the conventional PSTN circuit switched data connectivity or mobile-to-mobile data solutions: (1) elimination of analog modem training time, (2) increased call connection quality, reliability, and maximized throughput and (3) protocol independence.

C.8 Iridium Geo-Location

The Iridium network makes calculations of the geographical location (geo-location) of an ISU each time a call is placed. The technique employed to determine the geo-location of an ISU is based on measurements of the ISU and satellite propagation delay and Doppler frequency shift. These measurements are used to estimate cosines of spherical angles that identify the ISU's location relative to the satellite by the gateway.

The Iridium network can locate an ISU to within 10 km only about 78% of the time. The so-called error ellipse can have a large eccentricity with the major axis oriented in the azimuth dimension and the minor axis oriented in the radial dimension. The position of the ISU in the radial dimension relative to the satellite can almost always be determined to within 10 km with just one measurement. Errors in the azimuth dimension relative to the satellite are largest along the satellite's ground path and tend to increase with distance from the satellite. Geo-location errors in the east-west dimension, therefore, are sometimes more than 100 times greater than in the north-south dimension.

DIGI XBEE 3 ZIGBEE 3.0

Easy-to-add connectivity in a compact, low-power, low-profile footprint

Digi XBee® 3 modules accelerate time to market for designers, OEMs and solution providers by quickly enabling wireless connectivity and easy-to-add functionality. Building on industry-leading technology, pre-certified Digi XBee 3 modules offer the flexibility to switch between multiple frequencies and wireless protocols as needed.

Digi XBee 3 Zigbee 3.0 offers a fully interoperable ecosystem covering all vertical markets including building automation, smart energy, digital health, intelligent lighting, and others.

With Digi Remote Manager®, Digi XBee 3 modules can be easily configured and controlled from a simple, central platform. Built-in Digi TrustFence® security, identity and data privacy features use more than 175 controls to protect against new and evolving cyber threats. MicroPython and Digi XCTU® software tools simplify adding functionality, configuration and testing.

From edge computing to future migration, Digi XBee modules offer size, weight, power and performance advantages ideal for scalable device connectivity. A versatile addition to the expanding Digi XBee Ecosystem of wireless modules, adapters and software, the Digi XBee 3 Series is engineered to accelerate development and deployment.

SIZE AND FLEXIBILITY

- At 13 mm x 19 mm, the new Digi XBee® 3 micro form factor allows for more compact and portable applications
- Digi XBee 3 is one module for all protocols including: Zigbee, 802.15.4, DigiMesh® and BLE, all configurable via Digi XCTU®

PROGRAMMABILITY

- Eliminate the need for an external microcontroller and create smart end nodes using MicroPython
- Bluetooth® Low Energy for beaconing, connecting to Bluetooth sensors and local configuration using the Digi XBee Mobile app

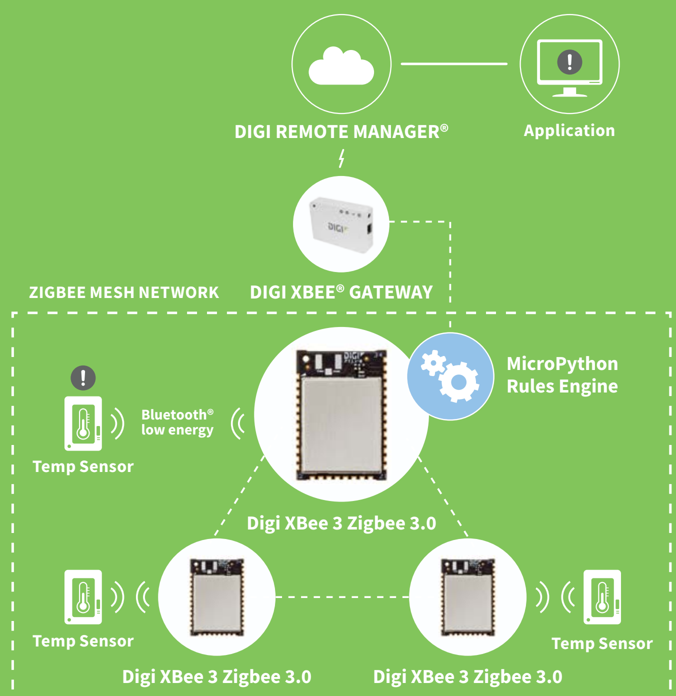
SECURITY

- Intrinsic IoT security with Digi TrustFence®, a layered approach securing the edge device, through the gateway, into and out of the IoT

RELATED PRODUCTS AND SERVICES

Development Kits | Digi XCTU® | Digi TrustFence® | Digi Remote Manager® | Digi Design Services

APPLICATION EXAMPLE



SPECIFICATIONS	Digi XBee® 3 Zigbee 3.0	Digi XBee® 3 PRO Zigbee 3.0
PERFORMANCE		
TRANSCEIVER CHIPSET	Silicon Labs EFR32MG SoC	
DATA RATE	RF 250 Kbps, serial up to 1 Mbps	
INDOOR/URBAN RANGE*	Up to 60 m (200 ft)	Up to 90 m (300 ft)
OUTDOOR/RF LINE-OF-SIGHT RANGE*	Up to 1200 m (4000 ft)	Up to 3200 m (2 miles)
TRANSMIT POWER	+8 dBm	+19 dBm
RECEIVER SENSITIVITY (1% PER)	-103 dBm Normal Mode	
FEATURES		
SERIAL DATA INTERFACE	UART, SPI, I^2C	
CONFIGURATION METHOD	API or AT commands, local or over-the-air (OTA)	
FREQUENCY BAND	ISM 2.4 GHz	
FORM FACTOR	Micro, through-hole, surface mount	
INTERFERENCE IMMUNITY	DSSS (Direct Sequence Spread Spectrum)	
ADC INPUTS	(4) 10-bit ADC inputs	
DIGITAL I/O	15	
ANTENNA OPTIONS	Through-hole: PCB Antenna, U.FL Connector, RPSMA Connector SMT: RF Pad, PCB Antenna, or U.FL Connector Micro: U.FL Antenna, RF Pad, Chip Antenna	
OPERATING TEMPERATURE	-40° C to 85° C (-40° F to 185° F)	
DIMENSIONS (L X W X H)	Through-hole: 2.438 x 2.761 cm (0.960 x 1.087 in) SMT: 2.199 x 3.4 x 0.305 cm (0.866 x 1.33 x 0.120 in) Micro: 13 x 19 x 2 mm (0.533 x 0.76 x 0.087 in)	
PROGRAMMABILITY		
MEMORY	1 MB / 128 KB RAM (32KB are available for MicroPython)	
NETWORKING AND SECURITY		
PROTOCOL	Zigbee® 3.0	
ENCRYPTION	128/256 bit AES	
RELIABLE PACKET DELIVERY	Retries/acknowledgements	
IDS	PAN ID and addresses, cluster IDs and endpoints (optional)	
CHANNELS	16 channels	
POWER REQUIREMENTS		
SUPPLY VOLTAGE	2.1 to 3.6 V	
TRANSMIT CURRENT	40 mA @ 8 dBm	135 mA @ 19 dBm
RECEIVE CURRENT	17 mA	
POWER-DOWN CURRENT	2 micro Amp @ 25° C (77° F)	
REGULATORY APPROVALS		
FCC, IC (NORTH AMERICA)	Yes	Yes
ETSI (EUROPE)	Yes	No
RCM (AUSTRALIA)	Yes	Yes
ANATEL (BRAZIL)	Yes	Yes
TELECK MIC (JAPAN)	Yes	No
KCC (SOUTH KOREA)	Yes	No

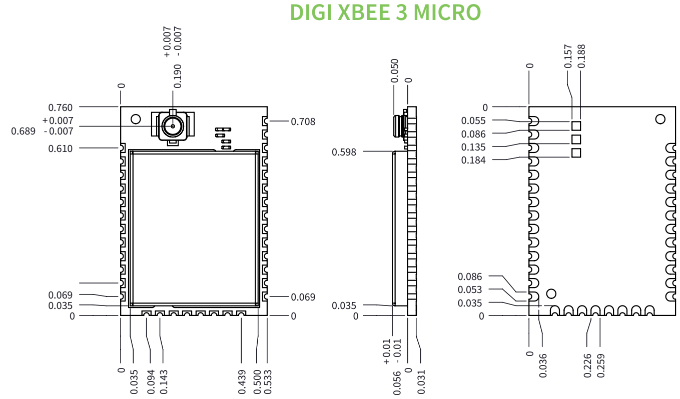
*Range figure estimates are based on free-air terrain with limited sources of interference. Actual range will vary based on transmitting power, orientation of transmitter and receiver, height of transmitting antenna, height of receiving antenna, weather conditions, interference sources in the area, and terrain between receiver and transmitter, including indoor and outdoor structures such as walls, trees, buildings, hills, and mountains.

PART NUMBERS	DESCRIPTION
XB3-24Z8RM-J	Digi XBee 3 Zigbee 3.0, 2.4 GHz, Micro, RF Pad Ant, MMT
XB3-24Z8UM-J	Digi XBee 3 ZigBee 3.0, 2.4 GHz, Micro, U.FL Ant, MMT
XB3-24Z8CM-J	Digi XBee 3 ZigBee 3.0, 2.4 GHz, Micro, Chip Ant, MMT
XB3-24Z8RM	Digi XBee 3 PRO ZigBee 3.0, 2.4 GHz, Micro, RF Pad Ant, MMT
XB3-24Z8UM	Digi XBee 3 PRO ZigBee 3.0, 2.4 GHz, Micro, U.FL Ant, MMT
XB3-24Z8CM	Digi XBee 3 PRO ZigBee 3.0, 2.4 GHz, Micro, Chip Ant, MMT
XB3-24Z8ST-J	Digi XBee 3, 2.4 Ghz Zigbee 3.0, SMA Ant, TH MT
XB3-24Z8UT-J	Digi XBee 3, 2.4 Ghz Zigbee 3.0, U.FL Ant, TH MT
XB3-24Z8PT-J	Digi XBee 3, 2.4 Ghz Zigbee 3.0, PCB Ant, TH MT
XB3-24Z8ST	Digi XBee 3 PRO, 2.4 Ghz Zigbee 3.0, SMA Ant, TH MT
XB3-24Z8UT	Digi XBee 3 PRO, 2.4 Ghz Zigbee 3.0, U.FL Ant, TH MT
XB3-24Z8PT	Digi XBee 3 PRO, 2.4 Ghz Zigbee 3.0, PCB Ant, TH MT
XB3-24Z8RS-J	Digi XBee 3, 2.4 Ghz Zigbee 3.0, RF Pad Ant, SMT
XB3-24Z8US-J	Digi XBee 3, 2.4 Ghz Zigbee 3.0, U.FL Ant, SMT
XB3-24Z8PS-J	Digi XBee 3, 2.4 Ghz Zigbee 3.0, PCB Ant, SMT
XB3-24Z8RS	Digi XBee 3 PRO, 2.4 Ghz Zigbee 3.0, RF Pad Ant, SMT
XB3-24Z8US	Digi XBee 3 PRO, 2.4 Ghz Zigbee 3.0, U.FL Ant, SMT
XB3-24Z8PS	Digi XBee 3 PRO, 2.4 Ghz Zigbee 3.0, PCB Ant, SMT
A24-HABUF-P5I	Antenna - 2.4 GHz, half wave dipole, 2.1 dBi, U.FL female, articulating
A24-HASM-450	Antenna - 2.4 GHz, half wave dipole, 2.1 dBi, RPSMA male, articulating
A24-HASM-525	Antenna - 2.4 GHz, half wave dipole, 2.1 dBi, RPSMA male, articulating
DC-ANT-24DT	Antenna - Wi-Fi, table-top mount, 2450 Mhz, 0.5 m cable

PRODUCT DIMENSIONS

ACTUAL SIZE

DIGI XBEE 3 MICRO



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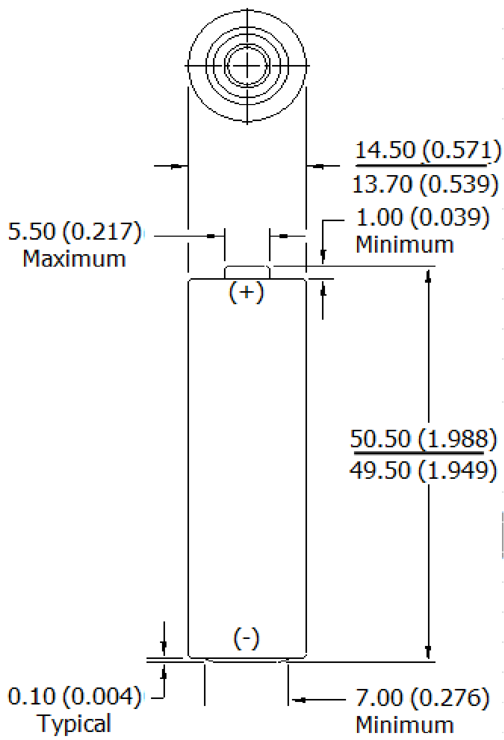
Energizer

ENERGIZER L91

Ultimate Lithium

Industry Standard Dimensions

mm (inches)



Specifications

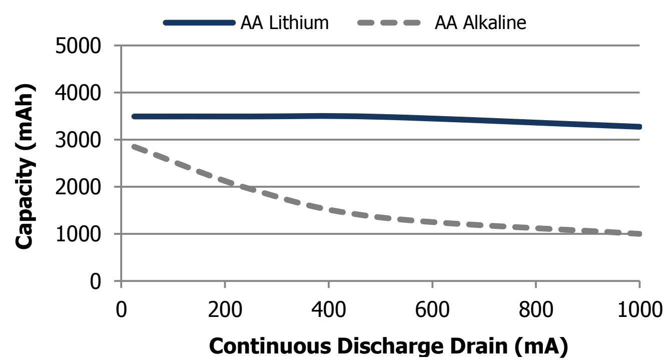
AA

Classification:	"Cylindrical Primary Lithium"
Chemical System:	Lithium/Iron Disulfide (Li/FeS_2)
Designation:	ANSI 15-LF, IEC-FR14505 (FR6)
Nominal Voltage:	1.5 Volts
Sizing Compatibility	E91 NH15 1215
Storage Temp:	-40°C to 60°C (-40°F to 140°F)
Operating Temp:	-40°C to 60°C (-40°F to 140°F)*
Typical Weight:	15 grams (0.5 oz.)
Typical Volume:	8.0 cubic centimeters (0.49 cubic inch)
Max Discharge:	2.5 amps continuous
(single battery only)	4.0 amps pulse (2 sec on / 8 sec off)
Lithium Content:	Less than 1 gram
Typical IR:	120 to 240 milliohms (depending on method)
Shelf Life:	20 years at 21°C
More Details:	On-Line Catalog-Application Manual (Li/FeS_2)
Shipping:	Please refer to PSDS Document
Certifications:	SGS US 800045; II 1G Ex ia IIC Ga Baseefa 14ATEX0107U

***All data shown tested at 21°C unless otherwise stated.**

Milliamp-Hours Capacity

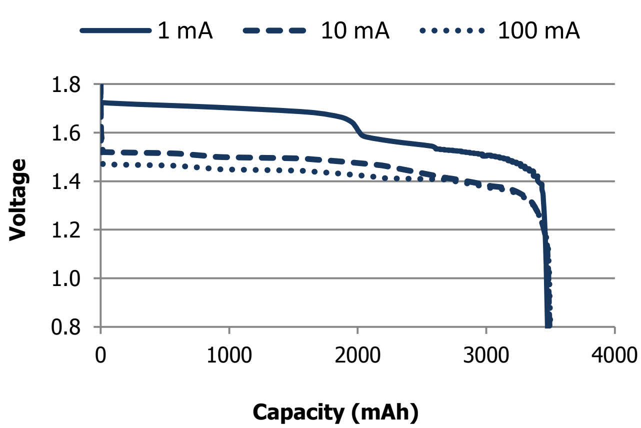
Constant Current Discharge to 0.8 Volts



(alkaline shown for comparison)

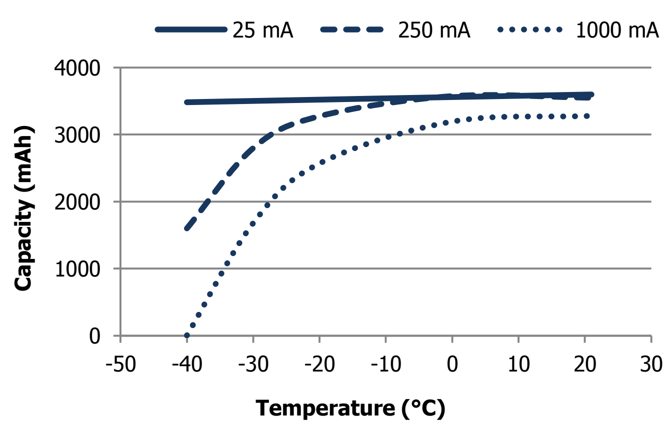
Discharge Profile

Constant Current Discharge



Temperature Effects on Capacity

Constant Current Discharge



Important Notice

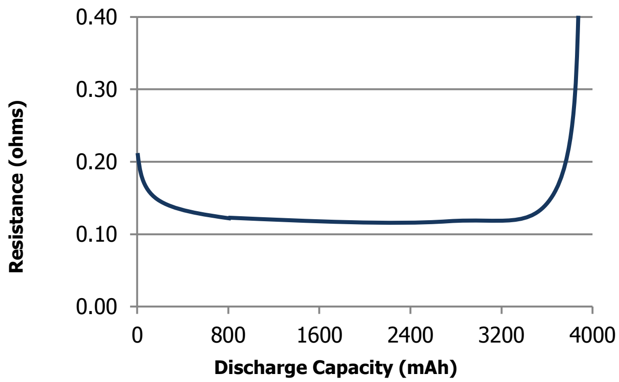
This datasheet contains typical information specific to products manufactured at the time of its publication.
Contents herein do not constitute a warranty and are for reference only.

ENERGIZER L91

AA

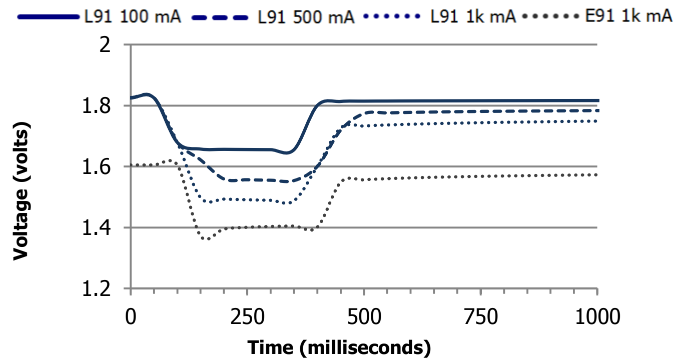
Internal Resistance Profile

Cell Ohmic Resistance - Dual Pulse Method



Pulse Response

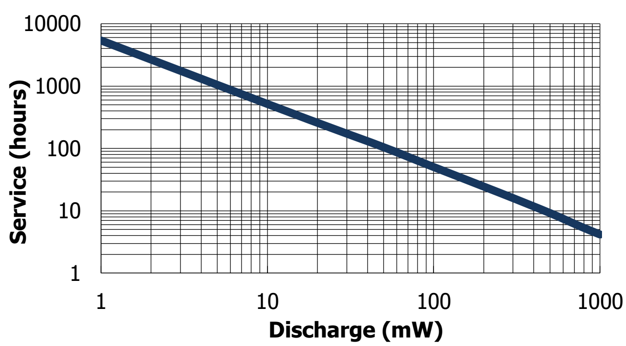
Open Circuit Voltage - 100/500/1k mA Pulse



(E91 AA alkaline shown for comparison)

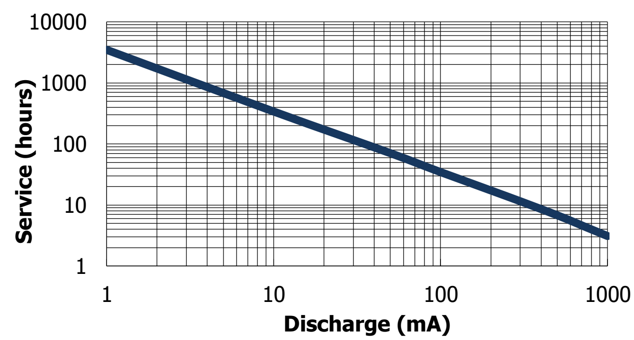
Constant Power Performance

Typical Characteristics to 0.8 Volts



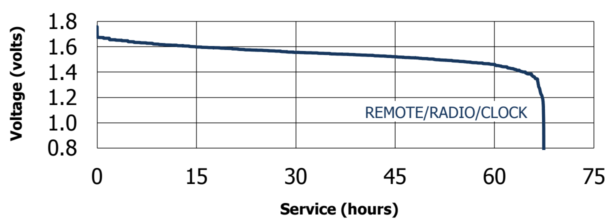
Constant Current Performance

Typical Characteristics to 0.8 Volts



Application Tests

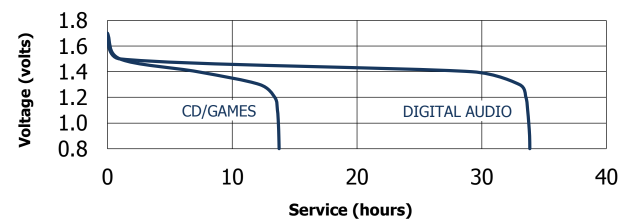
REMOTE/RADIO /CLOCK
50 mA 1 hr/8 hrs day



Application Tests

CD/GAMES
250 mA 1 hr/day

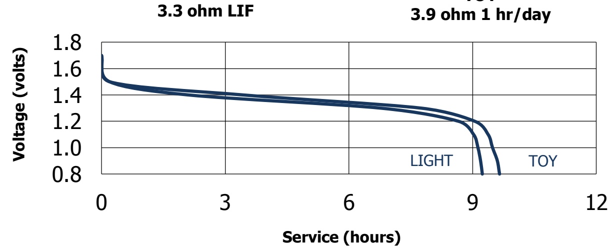
DIGITAL AUDIO
100 mA 1 hr/day



Application Tests

PORTABLE LIGHTING
3.3 ohm LIF

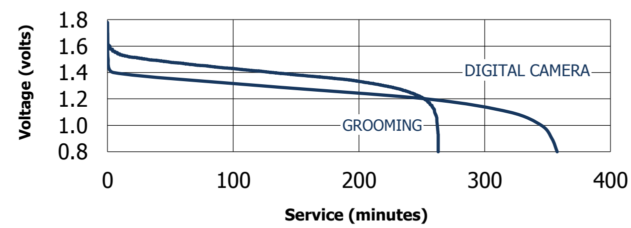
TOY
3.9 ohm 1 hr/day



Industry Standard Tests

PERSONAL GROOMING
750 mA 2 min/hr 8 hrs/day

DIGITAL CAMERA
1.5/.65K mW 2/.1/27.9s 10X



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Introduction:

Energizer® lithium iron disulfide differs from alkaline batteries in chemistry and construction. They are built in a spiral construction featuring two long, thin electrodes rolled together to form a jellyroll shape. This shape provides almost 20 times more interfacial surface area than a standard alkaline. This large interface helps to meet the power demands of many of today's devices. Lithium is the lightest, most active metal. When this powerful metal is paired with iron disulfide, this energy is available at a voltage suitable for 1.5 volt applications.

AA "Ultimate"
Lithium 4-Pack

Energizer® successfully produced the first commercially available "AA" size 1.5 volt lithium battery in 1989. The 1.5 volt "AAA" size followed in 2004.

Electrodes in lithium iron disulfide batteries are isolated from one another by a highly engineered microporous polymer membrane. This membrane allows ions to move easily during normal use, but restricts this movement in certain abuse situations to ensure superior product performance and safety. Lithium iron disulfide batteries contain a non-aqueous electrolyte designed to operate even in extreme temperatures from as low as -40°C up to +60°C. They also include a resettable overcurrent safety device that protects the user by switching the battery off if it is misused in devices.

Some of the advantages of the lithium iron disulfide ($LiFeS_2$) system over the alkaline chemistry are:

- Direct drop-in compatibility in applications using primary 1.5 volt "AA" and "AAA" battery sizes.
- Far greater power than other primary battery types.
- Provides longer service than other primary battery types in moderate to heavy

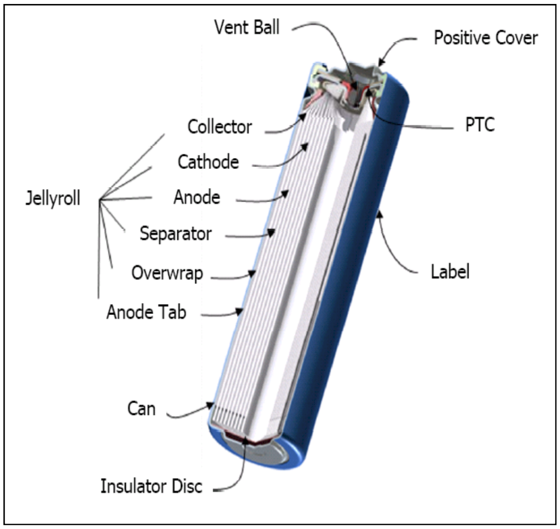
drain applications.

- Greater service advantage over other primary battery types at low temperature extremes operating at -40°C.
- Higher operating voltage and flatter discharge curve than other primary battery types.
- Superior leakage resistance compared to other primary battery types.
- Outstanding service maintenance when stored at ambient conditions.
- Considerably lighter than other battery types.
- Good service maintenance after high temperature storage up to +60°C.
- No added mercury, cadmium, or lead.

As power demands of new devices continue to increase and high drain devices become more prevalent with consumers, *Energizer®* lithium iron disulfide batteries provide the optimum performance consumers demand.

Battery Description:

Cylindrical lithium iron disulfide batteries use lithium for the anode, iron disulfide for the cathode, and a lithium salt in an organic solvent blend as the electrolyte. A cutaway (Fig. 1) of a typical cylindrical LiFeS_2 battery is illustrated in the following diagram:
Click here for larger view



Anode - lithium metal
Cathode – iron disulfide on an aluminum foil substrate
Separator – polyolefin
Electrolyte – lithium salt / organic solvent
Jellyroll construction – spiral wound multiple layers of anode/separator/cathode material to produce a high surface area for high power cell design
Vent ball – safety mechanism that provides internal pressure release
Positive and negative contact surfaces - nickel-plated steel
Non-conductive plastic film label - electrically insulates the battery
Positive Temperature Coefficient (PTC) – over current safety device

(Fig. 1) Typical Cylindrical Lithium Iron Disulfide Battery

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The term "lithium battery" refers to many different chemistries utilizing lithium as the anode but differing in cathode material, electrolyte, and construction. They may be classified in several ways, but one convenient method is by the cathode material and voltage. Using an iron disulfide cathode gives a battery with a nominal voltage of 1.5 volts. Most other lithium batteries are 3.0 volt systems using cathodes comprising either solids (manganese dioxide or carbon monofluoride) or highly toxic liquids (sulfur dioxide or thionyl chloride). Finally, lithium batteries should not be confused with lithium ion rechargeable batteries. Lithium ion batteries do not contain metallic lithium.

Under rating current drain rates (~200mA), typical of many commercial devices, the "AA" size $LiFeS_2$ battery has a specific energy density of ~297 Wh/kg compared to a comparable size alkaline of ~143 Wh/kg.

The characteristics that make lithium an exceptional electrode material for high energy density batteries include, low electrode potential and very high conductivity. It is soft and malleable and can be extruded into thin foils. Lithium reacts with water and for this reason must be used with a non-aqueous electrolyte.

The choice of cathode materials is critical when considering voltage, high energy density, high rate performance, and electrolyte compatibility. Other considerations include low cost, environmentally friendly, and stability. The choice of FeS_2 as a cathode material is unique because the chemical reaction with lithium results in an open circuit voltage (OCV) of 1.8 volts. Other cathode materials combined with lithium will produce battery voltages above 2.0 volts.

Although the higher OCV of the $LiFeS_2$ system is 1.8 volts, the nominal or rated voltage is 1.5 volts which makes it a suitable replacement for alkaline and nickel systems. The battery voltage will drop when it is placed under load. For this reason, the higher OCV will typically not damage electronic components, but device designers should take into consideration that the OCV of fresh batteries can range from 1.79 to 1.83V. $LiFeS_2$ batteries fully meet the ANSI specification for a 1.5V battery. When a drain has been applied to the battery, the OCV drops dramatically and then slowly recovers with time. The OCV for a battery can be misleading. A "good" battery will generally have an OCV >1.74 volts. Any battery with an OCV <1.70 (after it has been allowed to recover) is completely discharged. Although an alkaline battery may read "good" at 1.6 volts, this reading on a $LiFeS_2$ battery indicates the product has been discharged. The jellyroll battery design gives the battery excellent high rate performance. The non-aqueous electrolyte used in $LiFeS_2$ battery provides excellent low temperature performance.

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Under high temperature operating or storage, it is not uncommon to experience some electrolyte odor. This odor is due to transmission of ethers (i.e. 1, 2-dimethoxyethane and 1, 3-dioxolane) through the seal. The odor threshold for these organics is on the order of a few parts per million, which does not indicate leakage. The ethers can have a noticeable odor, but the actual amount of vapors present is very low. Potential exposure is well below the American Conference of Governmental Industrial Hygienists (ACGIH) time weighted average limit and other industry standards.

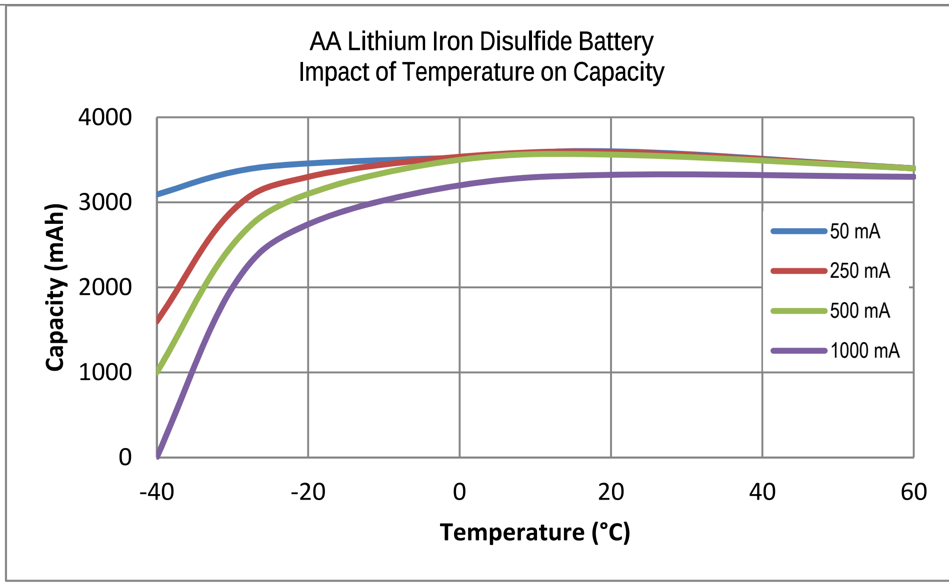
The overall discharge reaction of the LiFeS_2 construction takes place in two steps. The first step: $2Li+FeS_2 \rightarrow Li_2FeS_2$. The second step follows: $2Li+Li_2FeS_2 \rightarrow Fe+2Li_2S$. Typically the two step discharge can be seen at low drain rates of approximately ten milliamps or less and during higher drains at elevated temperatures.

The discharge characteristics of batteries can vary depending upon whether they are discharged at a constant resistance, constant current, or constant power drain. Due to the unique characteristics of the lithium chemical system, the battery will maintain a high average operating voltage compared to other systems throughout the life of the discharge. This is particularly important for constant power devices that can better take advantage of the higher voltage. As the battery voltage decreases, the current drain increases to maintain constant power to the device. Therefore, the higher voltage of lithium iron disulfide lowers the current drain on the battery and longer run times.

Temperature Effects on Performance:

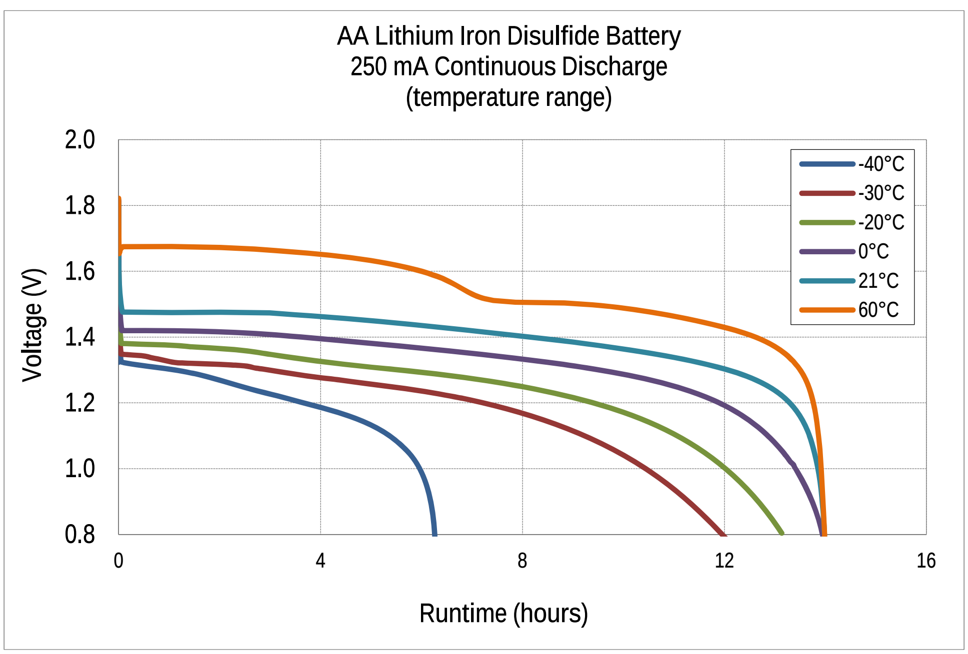
Lithium iron disulfide (LiFeS_2) batteries have a much lower sensitivity to temperature compared to other chemical systems. The recommended operating temperature range is -40°C to +60°C (-40°F to +140°F). As with all battery systems, service life is reduced as the discharge temperature is lowered below room temperature (Fig. 2).

Batteries generate power through chemical reactions and these typically run much more slowly at lower temperatures. However, even at -40°C, the LiFeS_2 batteries perform well at the rating drain 200 mA. LiFeS_2 batteries can deliver approximately full rated capacity at -40°C if they are discharged at 25 mA. Thus, at these rates, the batteries give comparable performance over the entire 100°C operating range.



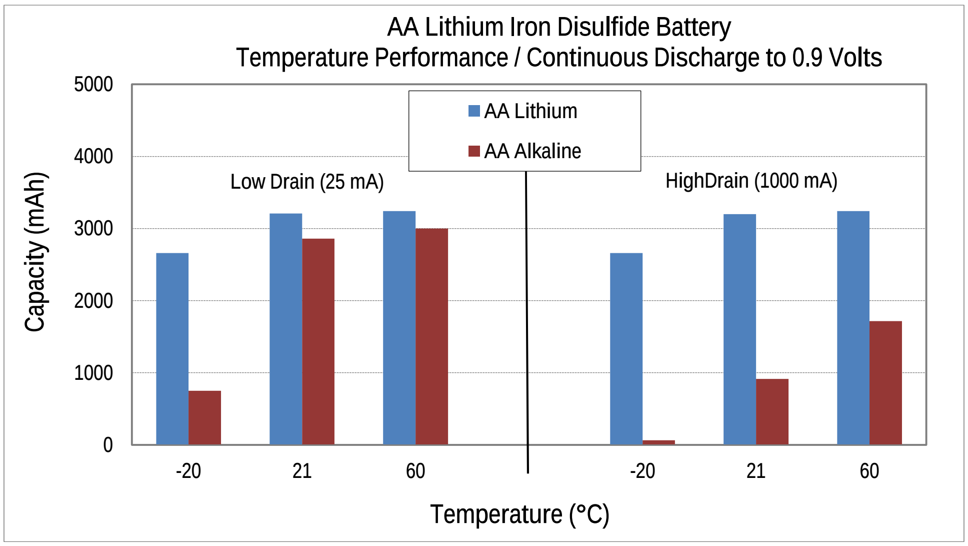
(Fig. 2) Temperature Effect on Capacity

Cold temperatures also lower the operating voltage thereby reducing the energy output (Fig 3). Battery capacity is not lost due to cold temperature use, rather it is more difficult to access the battery's full potential due to the slowing of the electrochemical reactions, reducing capacity at high drain rates.



(Fig. 3) Temperature Effect on Performance

When comparing cold temperature performance of the $LiFeS_2$ battery versus an alkaline based aqueous system, the $LiFeS_2$ system is affected much less across a range of drain rates (Fig. 4) and operates at temperatures where alkaline batteries do not run at all. This is due to the use of a non-aqueous electrolyte and the high surface area jellyroll construction. In particular, *Energizer*® patented electrolyte has the unique property of actually increasing in conductivity as the temperature drops, in contrast to electrolytes used in other lithium batteries.



(Fig. 4) Temperature Effect on Performance versus Alkaline

Conversely, warm temperatures can boost battery performance in very high drain continuous applications that increase the battery temperature (Fig.5).

In some applications there may be further limits on the maximum discharge temperature due to current limiting safety features of the battery. The $LiFeS_2$ battery utilizes a PTC (positive temperature coefficient over current safety device) that is designed to reversibly shut down the battery at high temperatures.

Both ambient temperature and the internal battery heating that occurs during discharge will affect the operation of the PTC.

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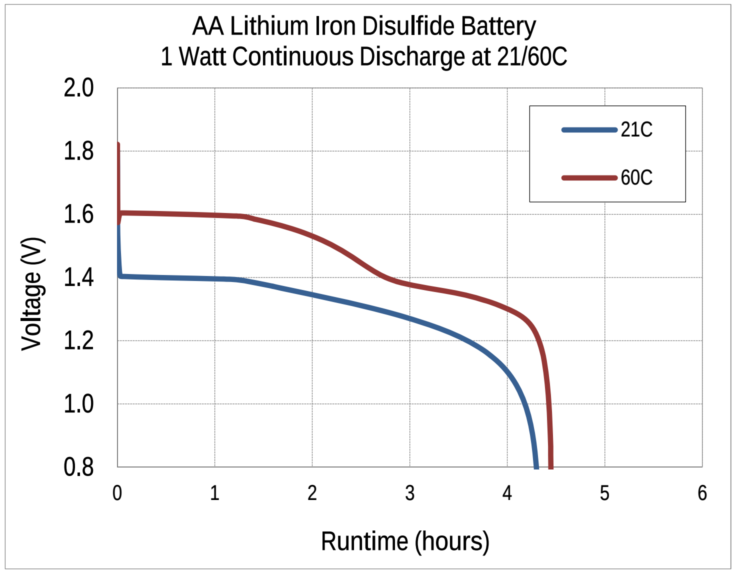
The higher the rate of discharge (a heavy drain or load on the battery), the more heat is generated that could cause the PTC to activate. In low to moderate drain applications, less than 500 mA, the heat dissipates and should not activate the PTC. However, a high ambient temperature combined with a high drain application increases the likelihood of PTC activation. Moreover, many applications use power intermittently and this can greatly mitigate any temperature rise and prevent PTC activation. While PTC activation in these rare scenarios may be a nuisance, the PTC is critical to battery safety.



(Fig. 5) Elevated Temperature Effect on Performance

The batteries and device should once again perform normally once the battery has time to cool down.

Device manufacturers must consider all of the following that can affect internal heating of $LiFeS_2$ batteries during discharge.

- Surrounding air temperature
- Thermal insulating properties of the battery container
- Heat generated by equipment components
- Cumulative heating effects of multiple batteries
- Discharge rate(s) and duration(s)
- Frequency and length of rest periods

Comparison to other Chemical Systems:

Lithium iron disulfide batteries have a higher operating voltage than alkaline and rechargeable nickel metal hydride (NiMH) batteries and flatter discharge profile versus alkaline. These characteristics result in higher energy density (Wh/L) and specific

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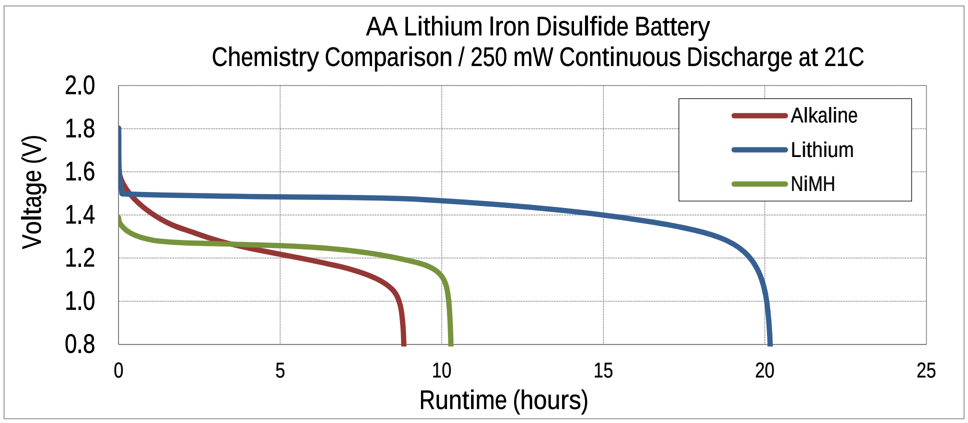
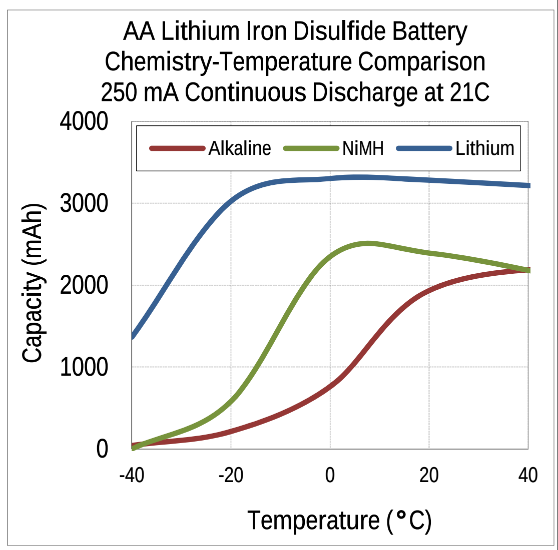
energy (Wh/kg), especially in heavier drain applications where the operating voltage differences are the greatest.

The flatter discharge curve allows for consistent performance throughout the life of the battery. The performance advantages of lithium over alkaline increases dramatically as drain rates increase due to the jellyroll construction and better high rate efficiency. The following chart (Fig. 6) shows the relative constant power performance of an AA size battery for the lithium, alkaline and NiMH chemistries.



(Fig. 6) Relative Constant Power Performance of an AA Size Battery (different chemistries)

Lithium iron disulfide batteries are suitable for use across a broad temperature range. While at elevated temperatures, all chemistries show minimal change in performance versus ambient. At low temperatures, the lithium battery offers more performance than alkaline or NiMH chemistries. The following graph (Fig. 7) shows the impact of temperature on AA size lithium, alkaline and NiMH under a 250 mA drain rate to a 0.9 volt cutoff.



(Fig. 7) Impact of Temperature on AA Size Lithium, Alkaline and

Additional performance comparisons can be found on the individual datasheets listed on the Technical Information Website. Additional LiFeS_2 advantages are listed in the following table:

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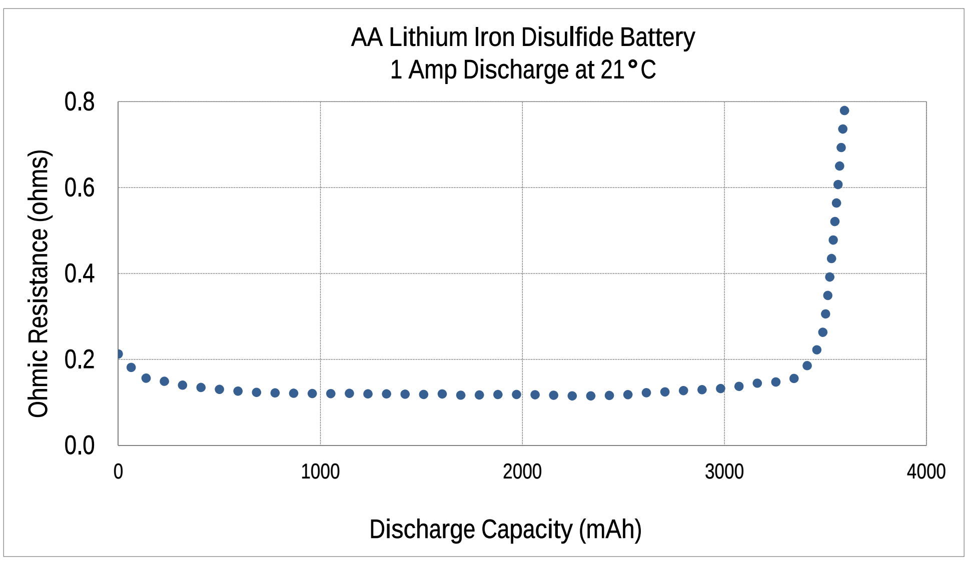
Characteristics	Lithium	Alkaline	NiMH
Cold Temp Performance	Superior	Good	Superior
Weight	33% < Alkaline	33% > Lithium	33% > Alkaline
Shelf Life	20+ Years	5 to 10 Years	3 to 5 Years
Leakage Resistance	Superior	Good	Good
Discharge Curve	Flat	Sloping	Flat
High Rate Capability	Superior	Good	Superior

Internal Resistance:

Another method used to estimate true IR uses a current interrupt technique (CIT), whereby the rapid change in battery voltage during discharge is periodically and briefly interrupted to estimate the battery IR. This has the advantage of measuring the battery IR under realistic drain rates and also enables one to measure the change in battery IR during discharge. The following graph (Fig. 9) shows that there is very little change in battery IR during discharge and in fact it actually improves slightly.



(Fig. 9) True IR of a typical AA size lithium iron disulfide battery during a 1 amp discharge.

True IR is not adversely affected by temperature (almost no change between -20 and 40°C), discharge current, depth of discharge, battery age or storage at elevated temperatures.

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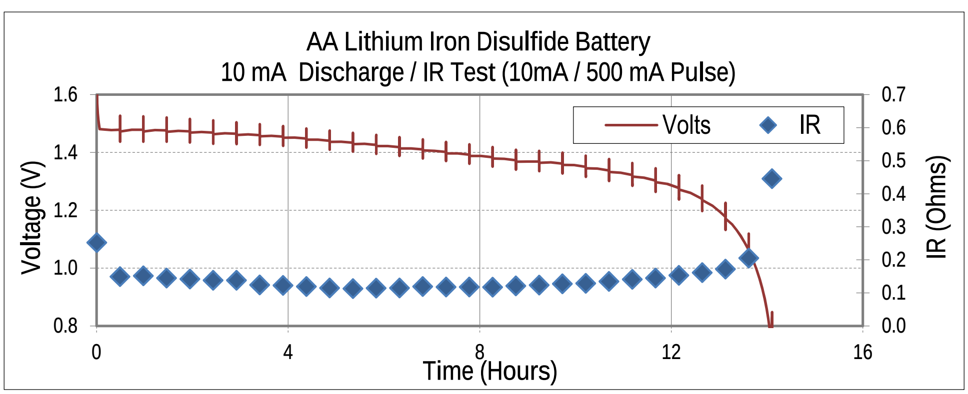
The resistance to current flow that a battery exhibits can depend on the current drain being applied and especially on the time scale of the measurement. The methods described above measure battery IR over a very short time scale. In actual device applications, various polarization effects occurring over longer times will reduce the battery's operating voltage and appear as resistance contributors. From a design engineers' point of view, a more important metric of the battery's performance may be the *effective* IR which is the impedance during actual usage.

Typically, effective IR is greater than the true IR. However, since the effective IR depends on the load and timescale, any measurement that relies upon the OCV of the battery prior to a test should not be used. A commonly used method whereby the resistance is calculated as shown below must not be used with AA size lithium iron disulfide batteries as the values are much higher than the real values. This is due to the initial OCV of AA size lithium iron disulfide batteries being higher than the OCV of the chemistry that actually controls the battery's discharge performance.

Effective IR = (OCV - CCV) / Current Applied (not valid for lithium iron disulfide batteries) Effective IR can be calculated by using a double current pulse CCV measurement whereby the system first applies a low current drain pulse to reduce the OCV and then applies a heavier pulse. The effective IR at the higher drain rate can then be calculated by the voltage difference between the two pulses. The timing of the pulses should reflect the timescale of interest to the application. For example, apply a 10 mA pulse for 50 ms followed by a 500 mA pulse for 100 ms (Fig. 10). Values of effective battery IR measured using this regime are about 100 mΩ.



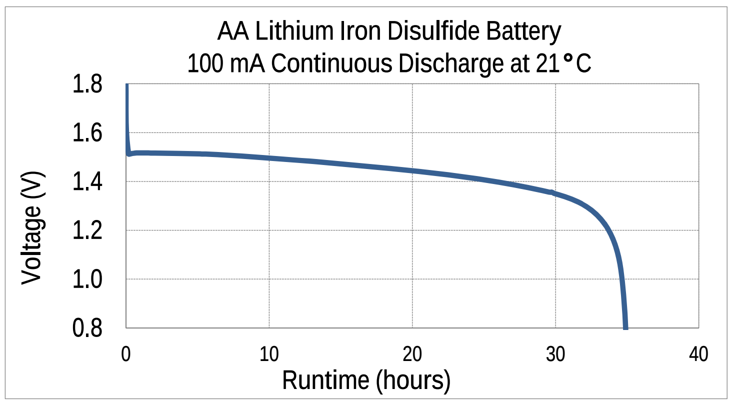
(Fig. 10) IR of a typical AA size lithium iron disulfide battery during discharge.

Effective IR = $(CCV_1 - CCV_2) / (Current_2 - Current_1)$

Again, caution must be exercised in comparing true IR values to effective IR readings or those obtained using other measurement methods. In particular, impedance measurements at 1 kHz or resistance values based on OCV-CCV differences typically overestimate the IR for lithium iron disulfide batteries. Overall, the lithium iron disulfide battery IR changes very little with age, discharge rate, depth of discharge and temperatures of -20 to 40°C. While impedance at lower frequencies can increase during aging, this has very little effect on the impedance of the battery when it is subsequently placed under load.

Capacity:

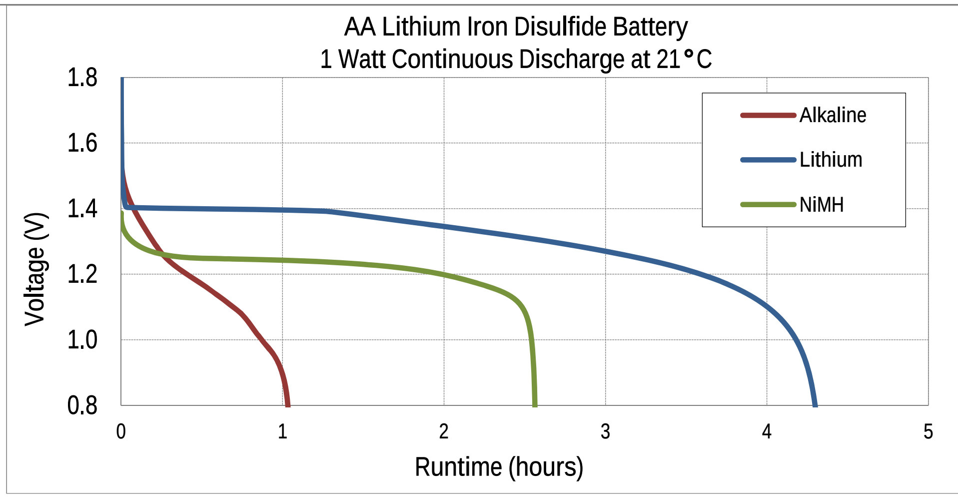
Battery capacity is typically expressed in terms of milli-Amp hours (mAh). This is an indication of how long a battery will provide service at a specific drain rate to a specific cutoff voltage. For example, the following discharge curve (Fig. 11) is for the AA size lithium iron disulfide battery being discharged at 100 mA to a 0.9 volt cutoff.



(Fig. 11) 100 mA Continuous Discharge

The available capacity can then be calculated by multiplying the drain rate (mA) by the hours to the cutoff voltage. For example, this AA battery would have a capacity of (100 mA X 36 hours) 3600 mAh at a 100 mA drain to a 0.9 volt cutoff.

The mAh capacity of lithium iron disulfide batteries will vary with the drain rate and the cutoff voltage. Due to the jellyroll construction and multiple layers of active material, the lithium iron disulfide battery is extremely efficient across multiple drains and is much less sensitive to both the drain rate and voltage cut than alkaline batteries. The flat discharge profile and high operating voltage of lithium iron disulfide allow for longer, consistent run times in high drain / high power devices as shown below (Fig. 12).



(Fig. 12) Chemistry Discharge Curve Characteristics

The application cutoff voltage will also impact the amount of service delivered by the battery. A high cutoff voltage will result in leaving more of the battery's capacity unused. To maximize usage of the available capacity, it is recommended that devices should be designed with a voltage cutoff of 0.8 volts per battery. At this point, a majority of the battery's usable capacity has been removed. However, lithium iron disulfide operates at a higher voltage and is well suited for high cutoff devices. Ideally, to avoid deep discharging batteries, one should not discharge them below 0.5 volts.

In high drain pulse applications, the duty cycle can impact battery efficiency. A very light duty cycle will typically allow the battery more time to recover and extend service compared to a continuous drain. The amount of additional service will depend on the drain rate, and the duty cycle (ON time and OFF time of the pulse). Due to $LiFeS_2$ high rate capability, the effect of intermittent duty cycles is relatively modest compared to other chemical systems. The modest effect of duty cycle on capacity delivered can be seen in the graph (Fig. 13).

The maximum recommended pulse drain for $LiFeS_2$ is based on the battery's ability to deliver high current over a range of 100 milliseconds to 2 seconds. The "AA" size can deliver up to a 3 Amp pulse. At these rates, it is important to consider heat generation by adjacent batteries and consider the effect on the PTC. This part will change from low to high impedance when activated during abusive conditions that cause a temperature rise. Actual testing is needed to determine the amount of additional service expected in pulse applications since there is no simple equation to accurately calculate the impact of duty cycle on service.

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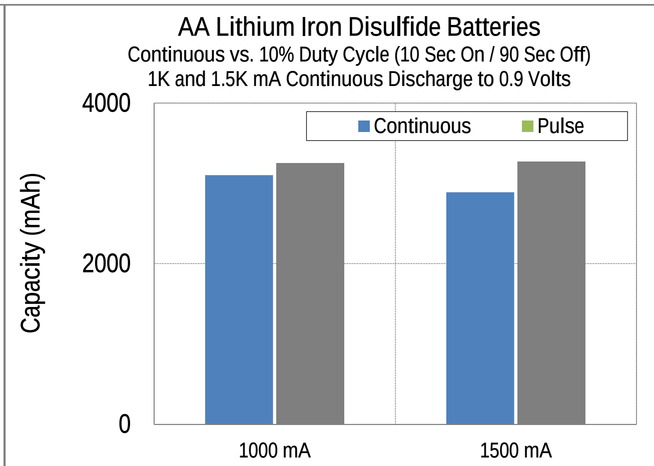
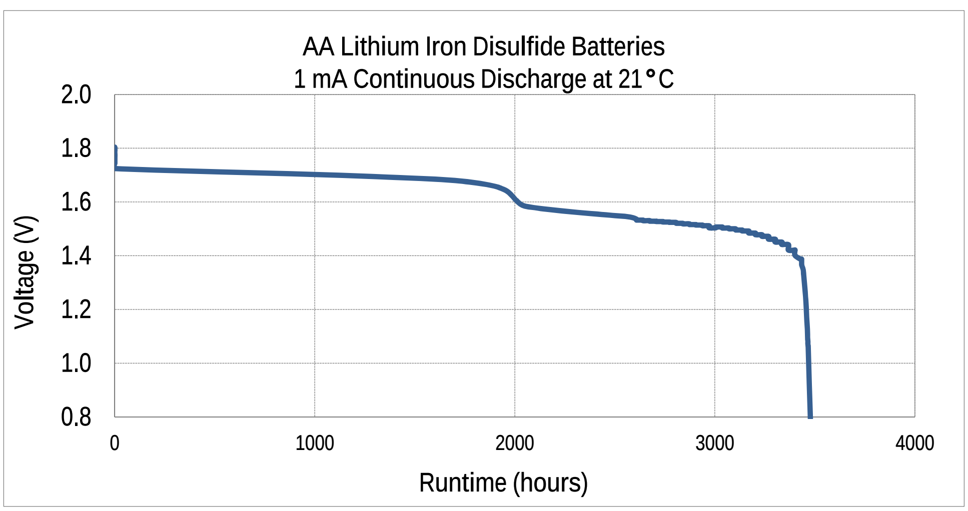


(Fig. 13) Effect of Duty Cycle

In ultra-low drain applications (i.e. currents in micro amps, where the battery is expected to run several months), the discharge curve has a distinct two stage profile. The first step occurs at slightly higher voltage (nominally 1.79V @ 21°C, dictated by thermodynamics) that increases with temperature and is nearly independent of depth of discharge. The second step occurs at a slightly lower voltage (nominally 1.7V @ 21° C) that decreases with temperature and is a function of depth of discharge. At low drain rates, the lithium iron disulfide battery will provide approximately full rated capacity over its lifetime.

The two stage discharge profile can benefit the device manufacturer as a method to implement fuel gauging in low drain applications. The discharge curve below shows the distinct plateaus where voltage, impedance, coulomb counting or combination of these methods could be used to determine depth of discharge needed to calculate remaining battery life. It should be noted that the lithium iron disulfide battery has a steep voltage drop off at the end of life (Fig. 14). Please contact your *Energizer®* sales representative for further information on this subject.



(Fig. 14) Two Stage Discharge

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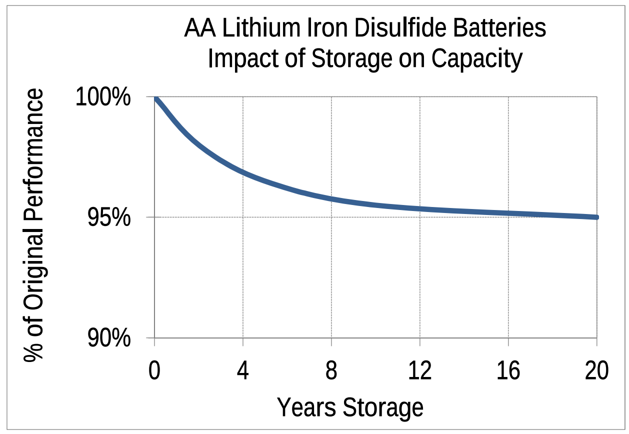
(click to view chapter)

Shelf Life:

Shelf life can be defined as the time at which a battery will deliver approximately 95% of its original capacity (Fig. 15). The lithium iron disulfide battery will retain approximately 95% of its capacity after 20+ years of storage. Because of the very low level of impurities in the materials used and the high degree of seal effectiveness used with lithium batteries, the shelf life after high temperature storage is far better compared to aqueous systems. The recommended storage temperature for lithium batteries is -40°C to 60°C. Exposing lithium batteries to temperatures above 60°C can cause the insulating label to shrink and expose the battery's steel can to potential external short circuits. Cold temperatures will have little impact on shelf life.



(Fig. 15) Impact of Storage

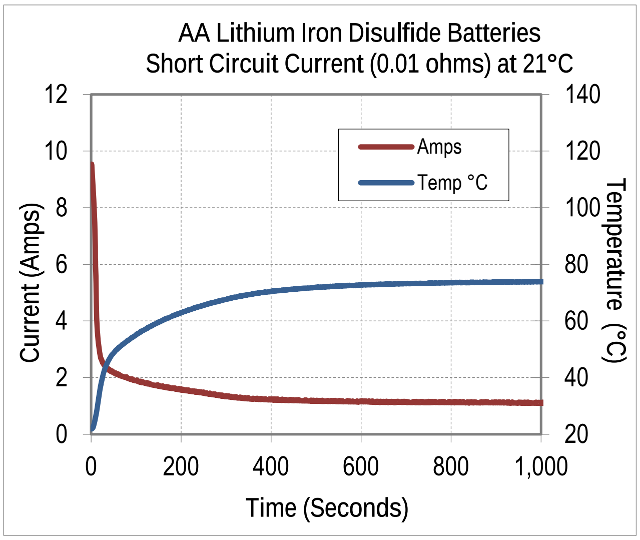
Predicting battery shelf life is done in various ways. Typically, elevated temperature storage is used to accelerate those processes that cause degradation. This method is convenient, but is not always reliable because increasing cell temperature can introduce a new mode of degradation that is not present in batteries stored at lower temperatures. This could yield an underestimate of the true shelf life. Another method for predicting shelf life is microcalorimetry that measures the heat output from batteries and provides an estimate of the chemical changes occurring inside the battery. *Energizer®* has tested $LiFeS_2$ cells using all of these methods.

Testing / Care / Warnings:

The lithium iron disulfide construction incorporates many safety features and extensive quality checks during manufacture on each and every battery. The design includes two safety devices to provide protection against abusive conditions such as short circuit, charging, forced discharge and overheating.

These two safety devices are a resettable thermal switch or PTC (Positive Thermal Coefficient) and a pressure relief vent. The PTC protects against electrical abuse scenarios by limiting the current when the PTC temperature exceeds 85°C. As the battery heats during abuse, the resistance of the PTC rapidly increases and significantly limits the amount of current flowing through the battery, thus allowing the battery to cool. When the PTC cools to below the activation temperature, its resistance returns to a normal level allowing normal battery use. The PTC is extremely effective in safely handling electrical abuse conditions. Here is an example of an "AA" size lithium iron disulfide battery subjected to a direct short showing that the PTC reduces the current within seconds to a safe level (Fig 16).

The PTC can rarely activate during non-abuse conditions, depending on how quickly the battery can dissipate heat generated from discharge. A combination of high discharge rate (which generates more heat) and high ambient temperature can cause the PTC to limit current.



(Fig. 16) Short Circuit Current

In addition, insulation within the battery compartment, proximity to adjacent batteries and neighboring electronic components can generate or retain additional heat. Intermittency, which is common for many applications, can greatly alleviate the internal heating affect.

During use, all batteries generate heat. On light loads the heat dissipates and is not noticeable, but on heavy drains the battery may become noticeably warm to the touch. This is expected and normal and also true of alkaline batteries. Extended exposure to heat may also cause shrinkage of the label. Label shrinkage can occur when the battery is exposed to extreme conditions and is not indicative of battery failure.

The vent mechanism operates at ~150°C and allows a controlled release of pressure thus preventing the battery from exploding in the event of abuse conditions, such as internal short circuits. This venting also limits the current the battery can carry and prevents additional heat generation.

The maximum continuous current drain for the "AA" size is 2.0 amps. Higher drain rates can be used for short periods of time. Because of the number of other variables involved, it is difficult to predict in advance whether lithium iron disulfide batteries can operate under extreme load conditions. In order to determine the highest pulse rate achievable, testing the batteries in the device under worst case conditions is recommended. While the PTC does impose some limitations on high rate applications for which lithium iron disulfide batteries are suitable, it is a critical element in ensuring that the battery is safe and protects the battery, the equipment and the user.
Although the safety mechanisms described above will limit the potential for battery failure due to abuse, there are additional handling considerations for the proper safe use of lithium iron disulfide batteries:

- Avoid potting or encapsulation as this obstructs the pressure relief vent. The vent is required to prevent excessive heat or pressure buildup if the battery is exposed to abusive conditions.
- Avoid charging as lithium iron disulfide batteries are not designed to be recharged.
- Use of pressure contact for batteries is recommended in the device compartment. If welded connections are needed, they should be made to the nickel-plated positive cap and the nickel-plated bottom using a capacitor discharge welder. Solder connections should be avoided because of the intense heat that needs to be applied to the battery.
- Battery labels insulate the battery to reduce the incidence of a potential direct short circuit or inadvertent charging. Battery compartment contacts and welded tab connections must not have sharp edges/burrs that could cut through the battery label especially adjacent to the positive terminal.
- Do not open battery, dispose of in fire, heat above 100°C (212°F), expose contents to water, recharge, install backwards, mix with used or other battery types. These conditions may cause personal injury.
- There is no risk of hydrogen generation with lithium iron disulfide batteries and they can be used safely in water tight applications.

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(click to view chapter)

- Lithium iron disulfide batteries can safely undergo ethylene oxide or gamma radiation sterilization.

For additional information it is imperative to read the section "Design and Safety Considerations" to assure that other safety considerations are not overlooked.

Environmental Compliance and Global Directives:

Current information on environmental compliance, EU Battery Directive, REACH Directive Summary, RoHS-WEEE Directive and Compliance with Industry Standards can be reviewed on the *Energizer*®:

Technical Information Web Site under the "General Information" tab.

Shipping:

Shipping and transportation, including US DOT travelling with lithium battery guidelines, can be reviewed on the *Energizer*® Technical Information Web Site under the "General Information" tab.

There is also information on:

Lithium Battery Transportation for commercial aviation and IATA guidelines.

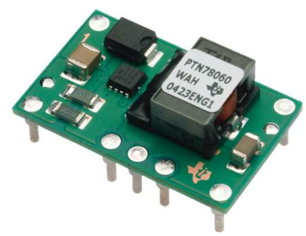
3-A, WIDE-INPUT ADJUSTABLE SWITCHING REGULATOR

FEATURES

- **3-A Output Current**
- **Wide-Input Voltage (7 V to 36 V) / (15 V to 36 V)**
- **Wide-Output Voltage Adjust (2.5 V to 12.6 V) / (11.85 V to 22 V)**
- **High Efficiency (Up to 96%)**
- **On/Off Inhibit**
- **Under-Voltage Lockout**
- **Output Current Limit**
- **Overtemperature Shutdown**
- **Operating Temperature: -40°C to 85°C**
- **Surface Mount Package Available**

APPLICATIONS

- **General-Purpose, Industrial Controls, HVAC Systems**
- **Test and Measurement, Medical Instrumentation**
- **AC/DC Adaptors, Vehicles, Marine, and Avionics**

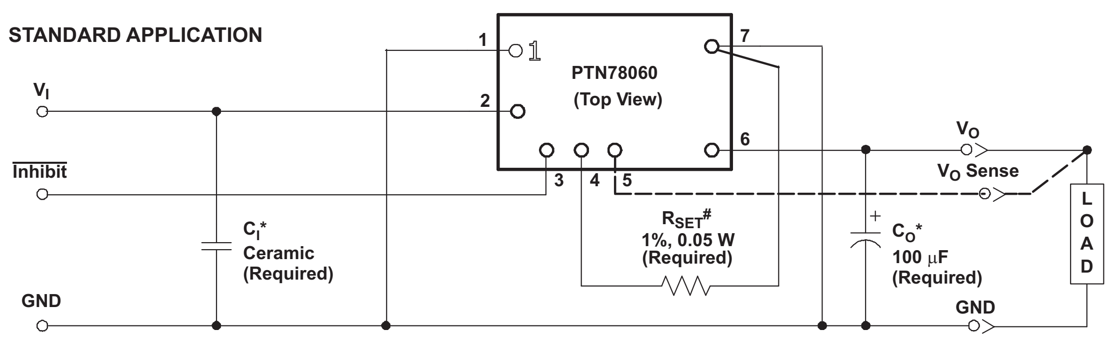


DESCRIPTION

The PTN78060 is a series of high-efficiency, step-down integrated switching regulators (ISR), that represent the third generation in the evolution of the popular (PT)78ST200, 78ST300, (PT)78HT200, and 78HT300 series of products. In new designs, the PTN78060 series may also be considered in place of the PT6200, PT6210, and PT6300 series of single in-line pin (SIP) products. In all cases, the PTN78060 has either similar or improved electrical performance characteristics. The caseless, double-sided package has excellent thermal characteristics, and is compatible with TI's roadmap for RoHS and lead-free compliance.

Operating from a wide-input voltage range, the PTN78060 provides high-efficiency, step-down voltage conversion for loads of up to 3 A. The output voltage can be set to any value over a wide adjustment range using a single external resistor. The PTN78060W may be set to any value within the range, 2.5 V to 12.6 V, and the PTN78060H from 11.85 V to 22 V. The output voltage of the PTN78060W can be as little as 2 V lower than the input, allowing operation down to 7 V, with an output voltage of 5 V. The output voltage of the PTN78060H can be as little as 3 V lower than the input, allowing operation down to 15 V, with an output voltage of 12 V.

The PTN78060 has undervoltage lockout, an integral on/off inhibit, and includes an output current limit and overtemperature protection. It is well suited to a wide variety of general-purpose applications that operate off 12-V, 24-V, or 28-V DC power.



*See the *Application Information* section for capacitor recommendations. The minimum input capacitance is 2.2 µF for PTN78060W, and 14.1 µF (3 x 4.7 µF) for PTN78060H.

#R_{SET} is required to adjust the output voltage. See the *Application Information* section for Values.

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

ORDERING INFORMATION

For the most current package and ordering information, see the Package Option Addendum at the end of this datasheet, or see the TI website at www.ti.com.

ABSOLUTE MAXIMUM RATINGS (1)

over operating free-air temperature range unless otherwise noted
all voltages with respect to GND

				UNIT
T_A	Operating free-air temperature	Over V_I range		–40°C to 85°C
	Wave solder temperature	Surface temperature of module body or pins **(5 seconds)**	Horizontal TH (suffix AH)	260°C
	Solder reflow temperature	Surface temperature of module body or pins	Horizontal SMD (suffix AS)	235°C
			Horizontal SMD (suffix AZ)	260°C
T_{stg}	Storage temperature			–55°C to 125°C
V_I	Input surge voltage, 10 ms maximum			38 V
$V_{(Inhibit)}$	$\overline{\text{Inhibit}}$ (pin 3) input voltage			–0.3 V to 5 V
P_O	Output power		$V_O \geq 15$ V	45 W

(1) Stresses beyond those listed under absolute maximum ratings may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under recommended operating conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

RECOMMENDED OPERATING CONDITIONS

			MIN	MAX	UNIT
V_I	Input voltage	PTN78060W	7	36	V
		PTN78060H	15	36	
T_A	Operating free-air temperature		–40	85	°C

PACKAGE SPECIFICATIONS

PTN78060x (Suffix AH, AS, and AZ)			
Weight			3.9 grams
Flammability	Meets UL 94 V-O		
Mechanical shock	Per Mil-STD-883D, Method 2002.3, 1 ms, 1/2 sine, mounted		500 G (1)
Mechanical vibration	Mil-STD-883D, Method 2007.2, 20-2000 Hz	Horizontal T/H (suffix AH)	20 G (1)
		Horizontal SMD (suffix AS and AZ)	20 G (1)

(1) Qualification limit.

ELECTRICAL CHARACTERISTICS

operating at 25°C free-air temperature, V_I = 20 V, V_O = 5 V, I_O = I_O (max), C_I = 2.2 µF, C_O = 100 µF (unless otherwise noted)

PARAMETER		TEST CONDITIONS	PTN78060W			
			MIN	TYP	MAX	UNIT
I_O	Output current	T_A = 85°C, natural convection airflow	0		3	A
V_I	Input voltage range	Over I_O range	7 (1)		36 (2)	V
V_O	Set-point voltage tolerance	T_A = 25°C			±2% (3)	
	Temperature variation	–40°C to +85°C		±0.5%		
	Line regulation	Over V_I range		±10		mV
	Load regulation	Over I_O range		±10		mV
	Total output voltage variation	Includes set point, line, load –40 < T_A < 85°C			±3% (3)	
V_O (adj)	Output voltage adjust range	V_I < 12 V	2.5		V_I – 2	V
		12 V ≤ V_I ≤ 15.1 V	2.5		V_I – 2.5	
		15.1 V < V_I ≤ 25 V	2.5		12.6	
		V_I > 25 V	0.1 × V_I		12.6	
η	Efficiency	V_I = 24 V, I_O = 3 A				
		R_{SET} = 732 Ω, V_O = 12 V		94%		
		R_{SET} = 21 kΩ, V_O = 5 V		86%		
		R_{SET} = 78.7 kΩ, V_O = 3.3 V		82%		
	Output voltage ripple	20-MHz bandwidth		1% V_O		$V_{(PP)}$
$I_{O (LIM)}$	Current limit threshold	ΔV_O = –50 mV		5.5		A
	Transient response	1-A/µs load step from 50% to 100% $I_O$max				
		Recovery time		100		µs
		V_O over/undershoot		5		%V_O
	Inhibit control (pin 3)	Input high voltage (V_{IH})	1		Open (4)	V
		Input low voltage (V_{IL})	–0.1		0.3	
		Input low current (I_{IL})		0.25		mA
$I_{I(stby)}$	Input standby current	Pin 3 connected to GND		17		mA
F_S	Switching frequency	Over V_I and I_O ranges	440	550	660	kHz
C_I	External input capacitance		2.2 (5)			µF
C_O	External output capacitance	Ceramic or nonceramic	100 (6)			µF
		Ceramic			200	
		Nonceramic			2,000	
		Equivalent series resistance (nonceramic)	10 (7)			mΩ
MTBF	Calculated reliability	Per Telcordia SR-332, 50% stress, T_A = 40°C, ground benign	8.9			10^6 Hr

(1) For output voltages less than 10 V, the minimum input voltage is 7 V or (V_O + 2) V, whichever is greater. For output voltages of 10 V and higher, the minimum input voltage is (V_O + 2.5) V. See the Application Information section for further guidance.
(2) For output voltages less than 3.6 V, the maximum input voltage is 10 × V_O . See the Application Information section for further guidance.
(3) The set-point voltage tolerance is affected by the tolerance and stability of R_{SET}. The stated limit is unconditionally met if R_{SET} has a tolerance of 1% with 100 ppm/°C or better temperature stability.
(4) This control pin has an internal pullup, and if left open-circuit, the module operates when input power is applied. The open-circuit voltage is typically 1.5 V. A small, low-leakage (< 100 nA) MOSFET is recommended for control. An external pull-up resistor should not be used. See the Application Information for further guidance.
(5) An external 2.2-µF ceramic capacitor is required across the input (V_I and GND) for proper operation. Locate the capacitor close to the module.
(6) 100 µF of output capacitance is required for proper operation. See the Application Information section for further guidance.
(7) This is the typical ESR for all the electrolytic (nonceramic) capacitance. Use 17 mΩ as the minimum when using max-ESR values to calculate.

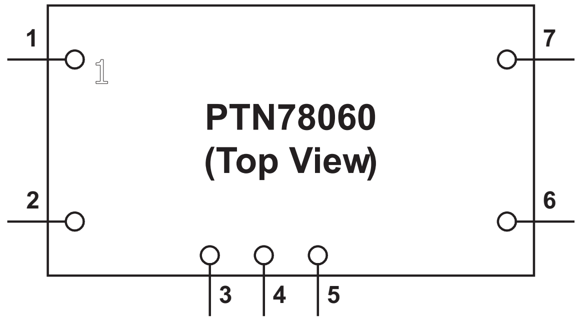
ELECTRICAL CHARACTERISTICS

operating at 25°C free-air temperature, V_I = 24 V, V_O = 12 V, I_O = I_O (max), C_I = 3 × 4.7 µF, C_O = 100 µF (unless otherwise noted)

PARAMETER		TEST CONDITIONS	PTN78060H			
			MIN	TYP	MAX	UNIT
I_O	Output current	T_A = 85°C, natural convection airflow, V_O = 12 V	0		3 (1)	A
		T_A = 85°C, natural convection airflow, V_O = 15 V	0		3 (1)	A
		T_A = 85°C, natural convection airflow, V_O = 22 V	0		2 (1)	A
V_I	Input voltage range	Over I_O range	15 (2)		36	V
V_O	Set-point voltage tolerance	T_A = 25°C			±2% (3)	
	Temperature variation	–40°C to +85°C		±0.5%		
	Line regulation	Over V_I range		±10		mV
	Load regulation	Over I_O range		±10		mV
	Total output voltage variation	Includes set point, line, load –40 < T_A < 85°C			±3% (3)	
V_O (adj)	Output voltage adjust range	V_I < 19 V	11.85		V_I – 3	V
		19 V ≤ V_I ≤ 25 V	11.85		V_I – 4	V
		V_I ≥ 26 V	11.85		22	V
η	Efficiency	V_I = 24 V, R_{SET} = 383 k Ω, V_O = 12 V		93%		
		V_I = 24 V, R_{SET} = 15 kΩ, V_O = 15 V		95%		
		I_O = 2 A, V_I = 32 V, R_{SET} = 95.3 Ω, V_O = 22 V,		96%		
	Output voltage ripple	20-MHz bandwidth		1.2% V_O		$V_{(PP)}$
$I_{O (LIM)}$	Current limit threshold	ΔV_O = –50 mV		5.5		A
	Transient response	1-A/µs load step from 50% to 100% $I_O$max				
		Recovery time		100		µs
		V_O over/undershoot		5		%V_O
	Inhibit control (pin 3)	Input high voltage (V_{IH})	1		Open (4)	V
		Input low voltage (V_{IL})	–0.1		0.3	V
		Input low current (I_{IL})		0.25		mA
$I_{I(stby)}$	Input standby current	Pin 3 connected to GND		17		mA
F_S	Switching frequency	Over V_I and I_O ranges	440	550	660	kHz
C_I	External input capacitance	Ceramic or nonceramic	14.1 (5)			µF
C_O	External output capacitance	Ceramic	0		200	µF
		Nonceramic	100 (6)		2,000	µF
		Equivalent series resistance (nonceramic)	10 (7)			mΩ
MTBF	Calculated reliability	Per Telcordia SR-332, 50% stress, T_A = 40°C, ground benign	8.9			10^6 Hr

(1) The maximum output current is 3 amps or a maximum output power of 45 W, whichever is less. See the Application Information section for further guidance.
(2) For output voltages less than 19 V, the minimum input voltage is 15 V or (V_O + 3) V, whichever is greater. For output voltages of 19 V and higher, the minimum input voltage is (V_O + 4) V. See the Application Information for further guidance.
(3) The set-point voltage tolerance is affected by the tolerance and stability of R_{SET}. The stated limit is unconditionally met if R_{SET} has a tolerance of 1% with 100 ppm/°C or better temperature stability.
(4) This control pin has an internal pullup, and if left open-circuit, the module operates when input power is applied. The open-circuit voltage is typically 1.5 V. A small, low-leakage (< 100 nA) MOSFET is recommended for control. See the Application Information section for further guidance.
(5) Three external 4.7-µF ceramic capacitors are required across the input (V_I and GND) for proper operation. Locate the capacitor close to the module.
(6) 100 µF of output capacitance is required for proper operation. See the Application Information section for further guidance.
(7) This is the typical ESR for all the electrolytic (nonceramic) capacitance. Use 17 mΩ as the minimum when using max-ESR values to calculate.

PIN ASSIGNMENT



TERMINAL FUNCTIONS

TERMINAL		I/O	DESCRIPTION
NAME	NO.		
GND	1, 7		This is the common ground connection for the V_I and V_O power connections. It is also the 0-VDC reference for the *Inhibit* and V_O *Adjust* control inputs.
V_I	2	I	The positive input voltage power node to the module, which is referenced to common GND.
$\overline{\text{Inhibit}}$	3	I	The Inhibit pin is an open-collector/drain active-low input that is referenced to GND. Applying a low-level ground signal to this input disables the module's output and turns off the output voltage. When the Inhibit control is active, the input current drawn by the regulator is significantly reduced. If the Inhibit pin is left open-circuit, the module produces an output whenever a valid input source is applied.
V_O Adjust	4	I	A 1% resistor must be connected between this pin and GND (pin 7) to set the output voltage. If left open-circuit, the output voltage is set to a default value. The temperature stability of the resistor should be 100 ppm/°C (or better). The standard resistor value for a number of common output voltages is provided in the application information.
V_O Sense	5	I	The sense input allows the regulation circuit to compensate for voltage drop between the module and the load. For optimum voltage accuracy, V_O *Sense* should be connected to V_O. If the sense feature is not used, this pin may be left disconnected.
V_O	6	O	The regulated positive power output with respect to the GND node.

TYPICAL CHARACTERISTICS (7-V INPUT)(1)(2)

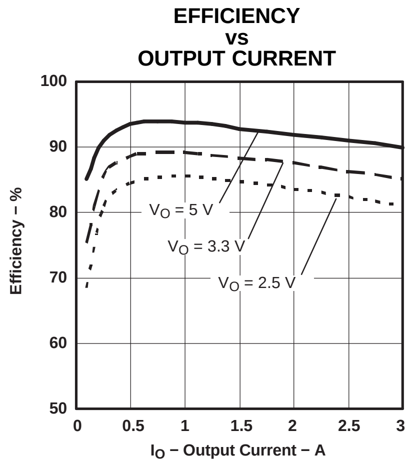


Figure 1.

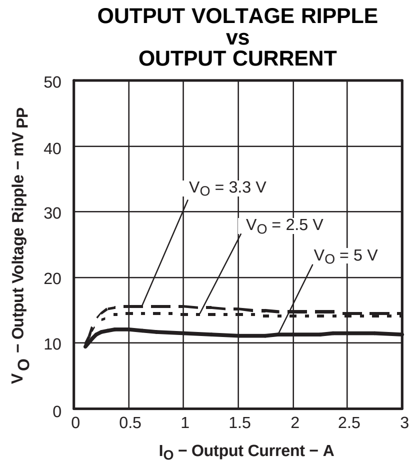


Figure 2.

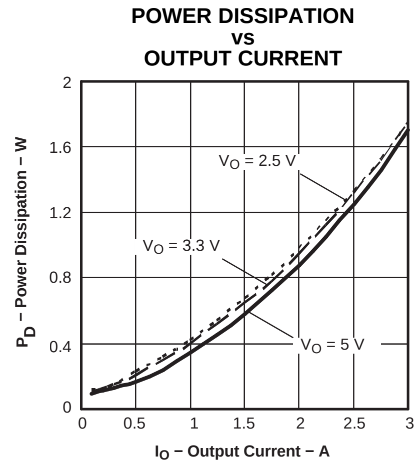


Figure 3.

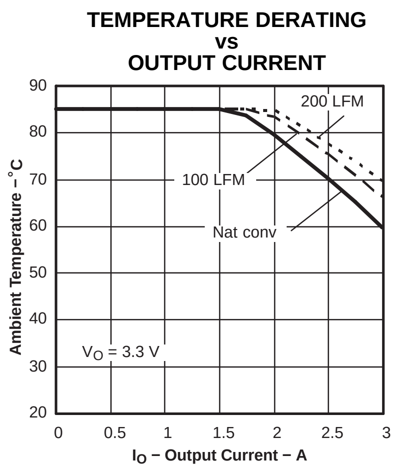


Figure 4.

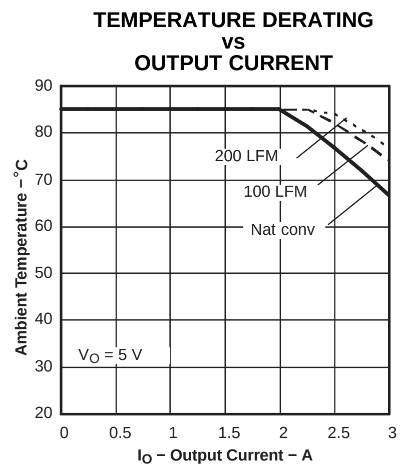


Figure 5.

(1) The electrical characteristic data has been developed from actual products tested at 25° C. This data is considered typical for the converter. Applies to Figure 1, Figure 2, and Figure 3.

(2) The temperature derating curves represent the conditions at which internal components are at or below the manufacturer's maximum operating temperatures. Derating limits apply to modules soldered directly to a 100 mm x 100 mm, double-sided PCB with 2 oz. copper. For surface mount packages, multiple vias (plated through holes) are required to add thermal paths around the power pins. Please refer to the mechanical specification for more information. Applies to Figure 4 and Figure 5.

TYPICAL CHARACTERISTICS (15-V INPUT)[(1)(2)]

EFFICIENCY vs OUTPUT CURRENT

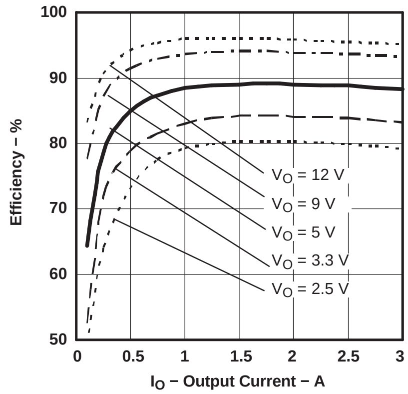


Figure 6.

OUTPUT VOLTAGE RIPPLE vs OUTPUT CURRENT

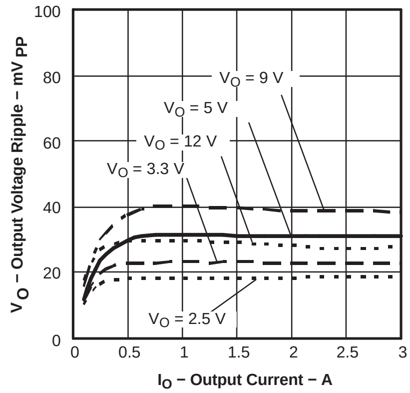


Figure 7.

POWER DISSIPATION vs OUTPUT CURRENT

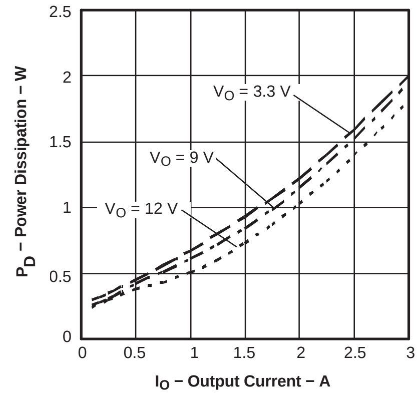


Figure 8.

TEMPERATURE DERATING vs OUTPUT CURRENT

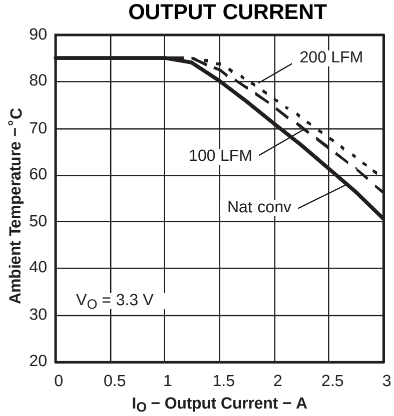


Figure 9.

TEMPERATURE DERATING vs OUTPUT CURRENT

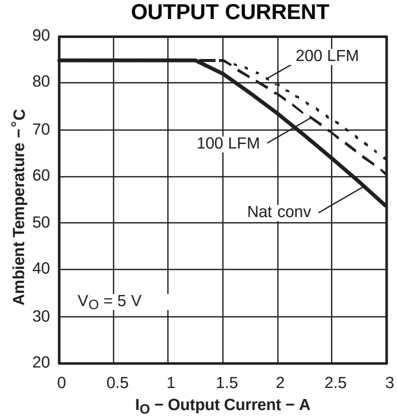


Figure 10.

TEMPERATURE DERATING vs OUTPUT CURRENT

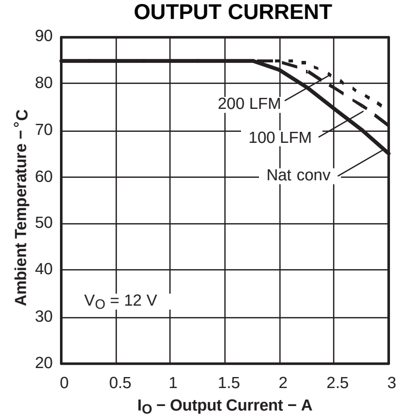


Figure 11.

(1) The electrical characteristic data has been developed from actual products tested at 25° C. This data is considered typical for the converter. Applies to Figure 6, Figure 7, and Figure 8.

(2) The temperature derating curves represent the conditions at which internal components are at or below the manufacturer's maximum operating temperatures. Derating limits apply to modules soldered directly to a 100 mm x 100 mm, double-sided PCB with 2 oz. copper. For surface mount packages, multiple vias (plated through holes) are required to add thermal paths around the power pins. Please refer to the mechanical specification for more information. Applies to Figure 9 through Figure 11.

TYPICAL CHARACTERISTICS (24-V INPUT)(1)(2)

EFFICIENCY vs OUTPUT CURRENT

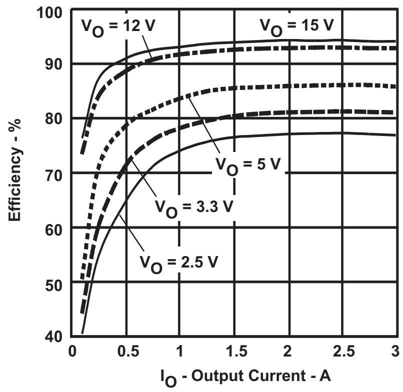


Figure 12.

OUTPUT VOLTAGE RIPPLE vs OUTPUT CURRENT

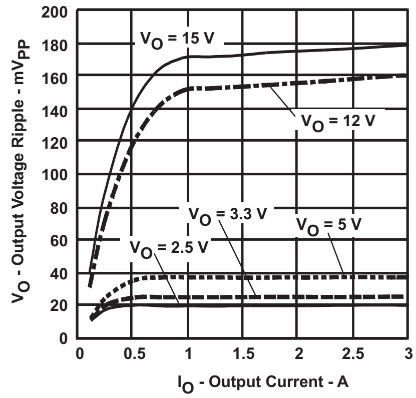


Figure 13.

POWER DISSIPATION vs OUTPUT CURRENT

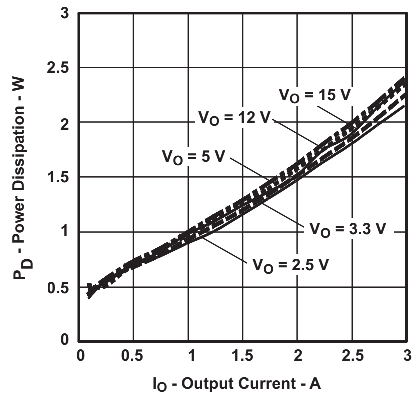


Figure 14.

TEMPERATURE DERATING vs OUTPUT CURRENT

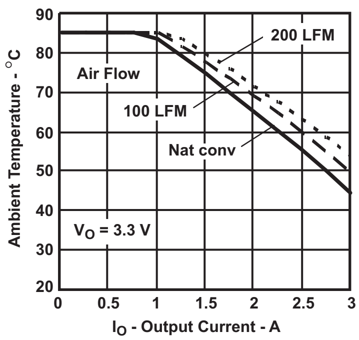


Figure 15.

TEMPERATURE DERATING vs OUTPUT CURRENT

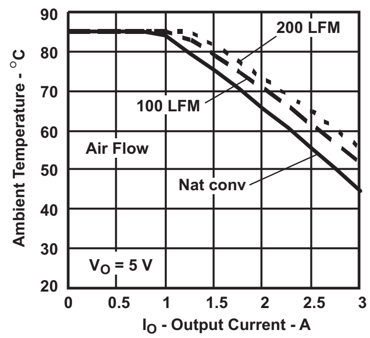


Figure 16.

TEMPERATURE DERATING vs OUTPUT CURRENT

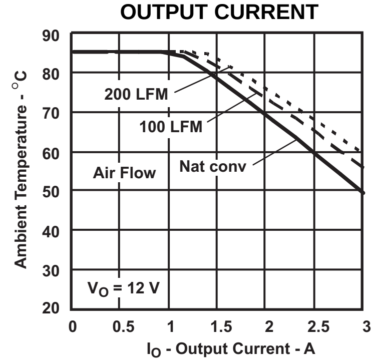


Figure 17.

TEMPERATURE DERATING vs OUTPUT CURRENT

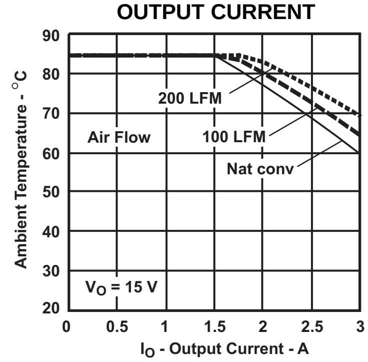


Figure 18.

(1) The electrical characteristic data has been developed from actual products tested at 25° C. This data is considered typical for the converter. Applies to Figure 12, Figure 13, and Figure 14.

(2) The temperature derating curves represent the conditions at which internal components are at or below the manufacturer's maximum operating temperatures. Derating limits apply to modules soldered directly to a 100 mm x 100 mm, double-sided PCB with 2 oz. copper. For surface mount packages, multiple vias (plated through holes) are required to add thermal paths around the power pins. Please refer to the mechanical specification for more information. Applies to Figure 15 through Figure 18.

TYPICAL CHARACTERISTICS (32-V INPUT)(1)(2)

EFFICIENCY
vs
OUTPUT CURRENT

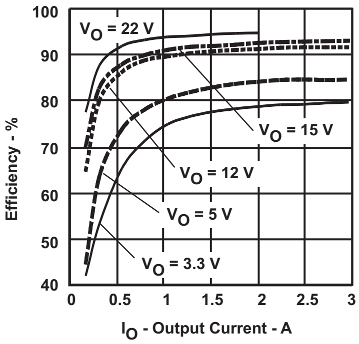


Figure 19.

OUTPUT VOLTAGE RIPPLE
vs
OUTPUT CURRENT

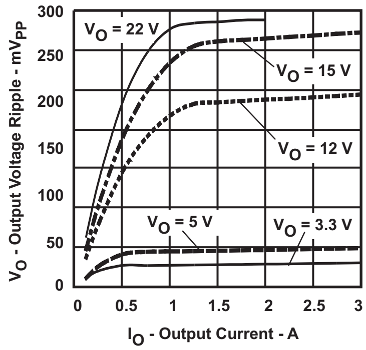


Figure 20.

POWER DISSIPATION
vs
OUTPUT CURRENT

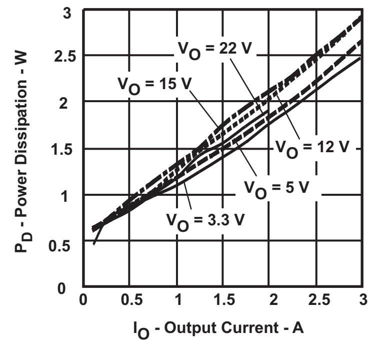


Figure 21.

TEMPERATURE DERATING
vs
OUTPUT CURRENT

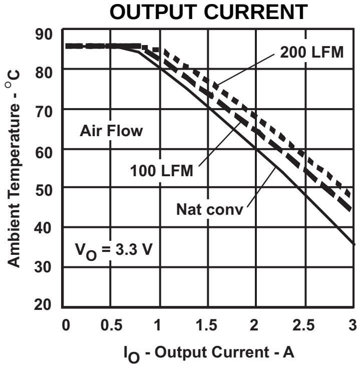


Figure 22.

TEMPERATURE DERATING
vs
OUTPUT CURRENT

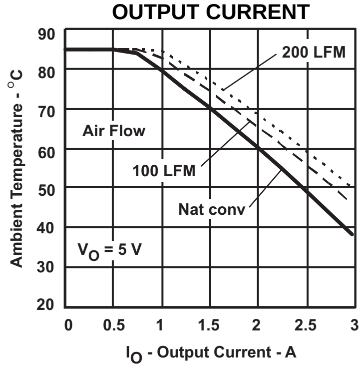


Figure 23.

TEMPERATURE DERATING
vs
OUTPUT CURRENT

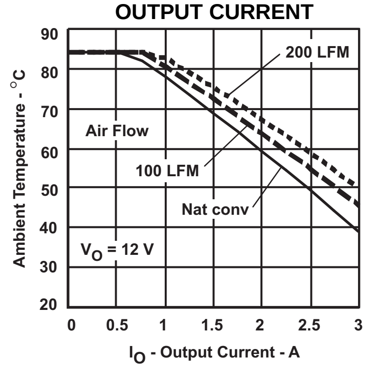


Figure 24.

TEMPERATURE DERATING
vs
OUTPUT CURRENT

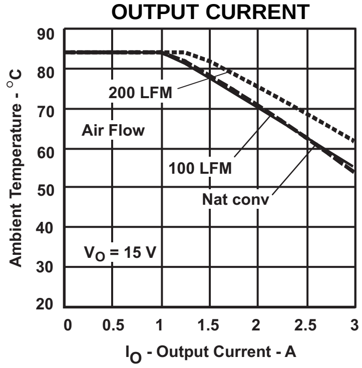


Figure 25.

TEMPERATURE DERATING
vs
OUTPUT CURRENT

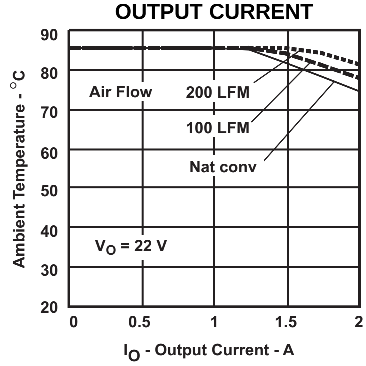


Figure 26.

(1) The electrical characteristic data has been developed from actual products tested at 25° C. This data is considered typical for the converter. Applies to Figure 19, Figure 20, and Figure 21.

(2) The temperature derating curves represent the conditions at which internal components are at or below the manufacturer's maximum operating temperatures. Derating limits apply to modules soldered directly to a 100 mm x 100 mm, double-sided PCB with 2 oz. copper. For surface mount packages, multiple vias (plated through holes) are required to add thermal paths around the power pins. Please refer to the mechanical specification for more information. Applies to Figure 22 through Figure 26.

APPLICATION INFORMATION

Adjusting the Output Voltage of the PTN78060 Wide-Output Adjust Power Modules

General

A resistor must be connected between the V_O *Adjust* control (pin 4) and *GND* (pin 1) to set the output voltage. The adjustment range is from 2.5 V to 12.6 V for PTN78060W. The adjustment range is from 11.85 V to 22 V for PTN78060H. If pin 4 is left open, the output voltage defaults to the lowest value.

Table 2 gives the standard resistor value for a number of common voltages, and with the actual output voltage that the value produces. For other output voltages, the resistor value can either be calculated using Equation 1 and the constants for the applicable product in Table 1. Alternatilvey, R_{SET} can be simply selected from the range of values given in Table 3 and Table 4. Figure 27 shows the placement of the required resistor.

$$R_{SET} = 54.9\ k\Omega \times \frac{1.25\ V}{V_O - V_{min}} - R_P \quad (1)$$

Table 1. R_{SET} Formula Constants

PRODUCT	V_{MIN}	R_P
PTN780x0W	2.5 V	6.49 kΩ
PTN780x0H	11.824 V	6.65 kΩ

Input Voltage Considerations

The PTN78060 is a step-down switching regulator. In order that the output remains in regulation, the input voltage must exceed the output by a minimum differential voltage.

Another consideration is the pulse width modulation (PWM) range of the regulator's internal control circuit. For stable operation, its operating duty cycle should not be lower than some minimum percentage. This defines the maximum advisable ratio between the regulator input and output voltage magnitudes.

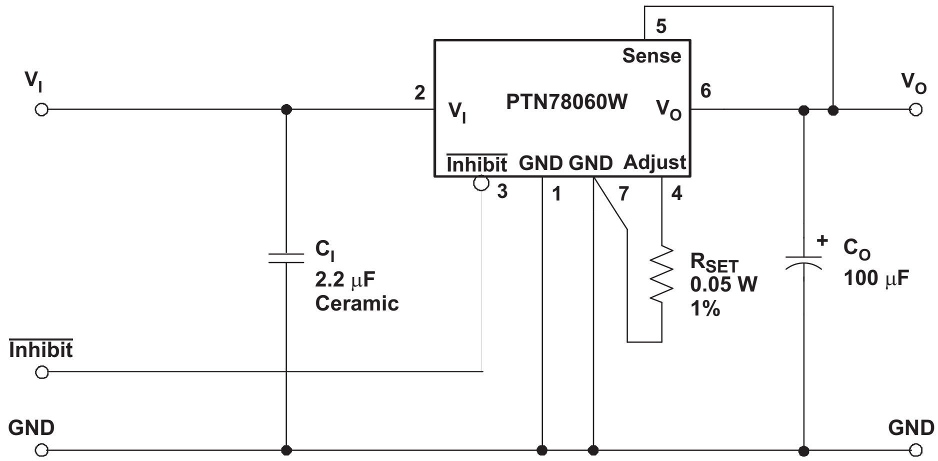
For satisfactory performance, the operating input voltage range of the PTN78060x must adhere to the following requirements.

1. For PTN78060W output voltages lower than 10 V, the minimum input voltage is (V_O+ 2 V) or 7 V, whichever is higher.
2. For PTN78060W output voltages equal to 10 V and higher, the minimum input voltage is (V_O+ 2.5 V).
3. The maximum input voltage for PTN78060W is (10 × V_O) or 36 V, whichever is less.
4. For PTN78060H output voltages lower than 19 V, the minimum input voltage is (V_O + 3 V) or 15 V, whichever is higher.
5. For PTN78060H output voltages equal to 19 V and higher, the minimum input voltage is (V_O+ 4 V) .

As an example, Table 2 gives the operating input voltage range for the common output bus voltages. In addition, the Electrical Characteristics table defines the available output voltage adjust range for various input voltages.

Table 2. Standard Values of R_{set} for Common Output Voltages

PRODUCT	V_O (Required)	R_{SET} (Standard Value)	V_O (Actual)	Operating V_I Range
PTN780x0W	2.5 V	Open	2.5 V	7 V to 25 V
	3.3 V	78.7 kΩ	3.306 V	7 V to 33 V
	5 V	21 kΩ	4.996 V	7 V to 36 V
	12 V	732 Ω	12.002 V	14.5 V to 36 V
PTN780x0H	12 V	383 kΩ	12.000 V	15 V to 36 V
	15 V	15 kΩ	14.994 V	18 V to 36 V
	18 V	4.42 kΩ	18.023 V	21 V to 36 V
	22 V	95.3	21.998 V	26 V to 36 V



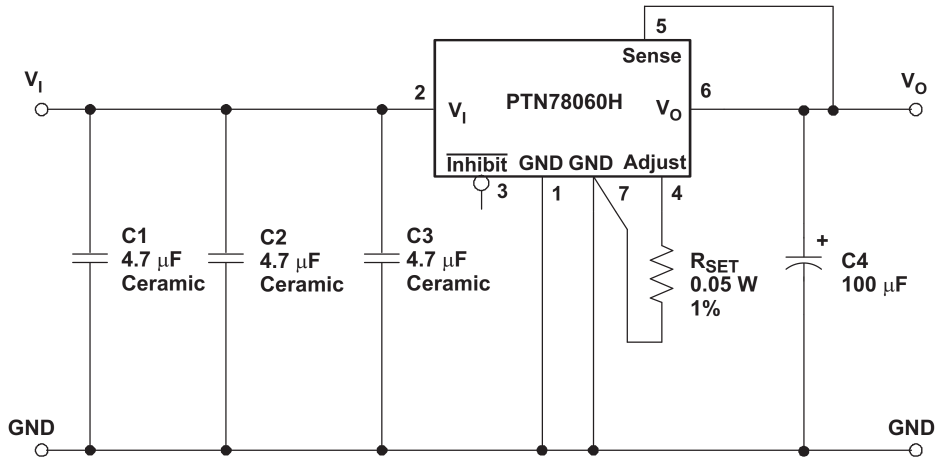
(1) A 0.05-W rated resistor may be used. The tolerance should be 1%, with a temperature stability of 100 ppm/°C (or better). Place the resistor as close to the regulator as possible. Connect the resistor directly between pins 4 and 7 using dedicated PCB traces.

(2) Never connect capacitors from V_O *Adjust* to either *GND* or V_O. Any capacitance added to the V_O *Adjust* pin affects the stability of the regulator.

Figure 27. PTN78060W V_O Adjust Resistor Placement

Table 3. PTN78060W Output Voltage Set-Point Resistor Values

V_O	R_{SET}	V_O	R_{SET}	V_O	R_{SET}	V_O	R_{SET}
2.50 V	Open	3.7 V	50.7 kΩ	6.1 V	12.6 kΩ	9.0 V	4.07 kΩ
2.55 V	1.37 MΩ	3.8 V	46.3 kΩ	6.2 V	12.1 kΩ	9.2 V	3.75 kΩ
2.60 V	680 kΩ	3.9 V	42.5 kΩ	6.3 V	11.6 kΩ	9.4 V	3.46 kΩ
2.65 V	451 kΩ	4.0 V	39.3 kΩ	6.4 V	11.1 kΩ	9.6 V	3.18 kΩ
2.70 V	337 kΩ	4.1 V	36.4 kΩ	6.5 V	10.7 kΩ	9.8 V	2.91 kΩ
2.75 V	268 kΩ	4.2 V	33.9 kΩ	6.6 V	10.2 kΩ	10.0 V	2.66 kΩ
2.80 V	222 kΩ	4.3 V	31.6 kΩ	6.7 V	9.85 kΩ	10.2 V	2.42 kΩ
2.85 V	190 kΩ	4.4 V	29.6 kΩ	6.8 V	9.47 kΩ	10.4 V	2.20 kΩ
2.90 V	165 kΩ	4.5 V	27.8 kΩ	6.9 V	9.11 kΩ	10.6 V	1.98 kΩ
2.95 V	146 kΩ	4.6 V	26.2 kΩ	7.0 V	8.76 kΩ	10.8 V	1.78 kΩ
3.00 V	131 kΩ	4.7 V	24.7 kΩ	7.1 V	8.43 kΩ	11.0 V	1.58 kΩ
3.05 V	118 kΩ	4.8 V	23.3 kΩ	7.2 V	8.11 kΩ	11.2 V	1.40 kΩ
3.10 V	108 kΩ	4.9 V	22.1 kΩ	7.3 V	7.81 kΩ	11.4 V	1.22 kΩ
3.15 V	99.1 kΩ	5.0 V	21.0 kΩ	7.4 V	7.52 kΩ	11.6 V	1.05 kΩ
3.20 V	91.5 kΩ	5.1 V	19.9 kΩ	7.5 V	7.24 kΩ	11.8 V	889 Ω
3.25 V	85.0 kΩ	5.2 V	18.9 kΩ	7.6 V	6.97 kΩ	12.0 V	734 Ω
3.30 V	79.3 kΩ	5.3 V	18.0 kΩ	7.7 V	6.71 kΩ	12.2 V	585 Ω
3.35 V	74.2 kΩ	5.4 V	17.2 kΩ	7.8 V	6.46 kΩ	12.4 V	442 Ω
3.40 V	69.8 kΩ	5.5 V	16.4 kΩ	7.9 V	6.22 kΩ	12.6 V	305 Ω
3.45 V	65.7 kΩ	5.6 V	15.6 kΩ	8.0 V	5.99 kΩ		
3.50 V	62.1 kΩ	5.7 V	15.0 kΩ	8.2 V	5.55 kΩ		
3.55 V	58.9 kΩ	5.8 V	14.3 kΩ	8.4 V	5.14 kΩ		
3.60 V	55.9 kΩ	5.9 V	13.7 kΩ	8.6 V	4.76 kΩ		
3.65 V	53.2 kΩ	6.0 V	13.1 kΩ	8.8 V	4.40 kΩ		



(1) A 0.05-W rated resistor may be used. The tolerance should be 1%, with a temperature stability of 100 ppm/° C (or better). Place the resistor as close to the regulator as possible. Connect the resistor directly between pins 4 and 7 using dedicated PCB traces.

(2) Never connect capacitors from V_O *Adjust* to either *GND* or V_O. Any capacitance added to the V_O *Adjust* pin affects the stability of the regulator.

Figure 28. PTN78060H V_O Adjust Resistor Placement

Table 4. PTN78060H Output Voltage Set-Point Resistor Values

V_O	R_{SET}	V_O	R_{SET}	V_O	R_{SET}
11.85 V	2633 kΩ	13.50 V	34.3 kΩ	17.20 V	6.12 kΩ
11.90 V	896 kΩ	13.65 V	30.9 kΩ	17.40 V	5.66 kΩ
11.95 V	538 kΩ	13.80 V	28.1 kΩ	17.60 V	5.23 kΩ
12.00 V	451 kΩ	13.95 V	25.6 kΩ	17.80 V	4.83 kΩ
12.10 V	242 kΩ	14.10 V	23.5 kΩ	18.00 V	4.46 kΩ
12.15 V	204 kΩ	14.25 V	21.6 kΩ	18.20 V	4.11 kΩ
12.20 V	176 kΩ	14.40 V	19.9 kΩ	18.40 V	3.79 kΩ
12.25 V	154 kΩ	14.55 V	18.5 kΩ	18.60 V	3.48 kΩ
12.30 V	138 kΩ	14.70 V	17.2 kΩ	18.80 V	3.19 kΩ
12.35 V	124 kΩ	14.85 V	16.0 kΩ	19.00 V	2.91 kΩ
12.40 V	113 kΩ	15.00 V	14.9 kΩ	19.20 V	2.65 kΩ
12.45 V	103 kΩ	15.15 V	13.9 kΩ	19.40 V	2.41 kΩ
12.50 V	94.9 kΩ	15.30 V	13.1 kΩ	19.60 V	2.18 kΩ
12.55 V	87.9 kΩ	15.45 V	12.3 kΩ	19.80 V	1.95 kΩ
12.60 V	81.8 kΩ	15.60 V	11.5 kΩ	20.00 V	1.74 kΩ
12.65 V	76.4 kΩ	15.75 V	10.8 kΩ	20.20 V	1.54 kΩ
12.70 V	71.7 kΩ	15.90 V	10.2 kΩ	20.40 V	1.35 kΩ
12.75 V	67.5 kΩ	16.05 V	9.59 kΩ	20.60 V	1.17 kΩ
12.80 V	63.7 kΩ	16.20 V	9.03 kΩ	20.80 V	995 Ω
12.85 V	60.2 kΩ	16.35 V	8.51 kΩ	21.00 V	829 kΩ
12.90 V	57.1 kΩ	16.50 V	8.03 kΩ	21.20 V	669 Ω
12.95 V	54.3 kΩ	16.65 V	7.57 kΩ	21.40 V	516 Ω
13.00 V	51.7 kΩ	16.80 V	7.14 kΩ	21.80 V	229 Ω
13.05 V	49.3 kΩ	17.10 V	6.36 kΩ	22.00 V	94 Ω

CAPACITOR RECOMMENDATIONS for the PTN78060 WIDE-OUTPUT ADJUST POWER MODULES

PTN78060W Input Capacitor

PTN78060W has a minimum requirement for input capacitance of 2.2 µF of ceramic capacitance. The dielectric may have either an X5R or X7R temperature characteristic. Ceramic capacitors should be located within 0.5 inch (1,27 cm) of the regulator's input pins. Electrolytic capacitors can be used at the input, but only in addition to the required ceramic capacitance. The minimum ripple current rating for any nonceramic capacitance must be at least 500 mA rms for $V_O \le 5.5$ V. For $V_O > 5.5$ V, the minimum ripple current rating is 750 mA rms. The ripple current rating of electrolytic capacitors is a major consideration when they are used at the input. This ripple current requirement can be reduced by placing more ceramic capacitors at the input, in addition to the minimum required 2.2 µF.

Tantalum capacitors are not recommended for use at the input bus, as none were found to meet the minimum voltage rating of 2 × (maximum dc voltage + ac ripple). The 2× rating is standard practice for regular tantalum capacitors to ensure reliability. Polymer-tantalum capacitors are more reliable, and are available with a maximum rating of typically 20 V. These can be used with input voltages up to 16 V.

PTN78060H Input Capacitor

PTN78060H has a minimum requirement for input capacitance of 14.1 µF (3 × 4.7 µF) of ceramic capacitance. The dielectric may have either an X5R or X7R temperature characteristic. Ceramic capacitors should be located within 0.5 inch (1,27 cm) of the regulator's inpt pins. Electrolytic capacitors can be used at the input, but only in addition to the required ceramic capacitance. The minimum ripple current rating for any nonceramic capacitance must be at least 400 mA rms. The ripple current rating of electrolytic capacitors is a major consideration when they are used at the input. This ripple current requirement can be reduced by placing more ceramic capacitors at the input, in addition to the minimum required 14.1 µF.

Tantalum capacitors are not recommended for use at the input bus, as none were found to meet the minimum voltage rating of 2 × (maximum dc voltage + ac ripple). The 2× rating is standard practice for regular tantalum capacitors to ensure reliability. Polymer-tantalum capacitors are more reliable, and are available with a maximum rating of typically 20 V. These can be used with input voltages up to 16 V.

Output Capacitor

The minimum capacitance required to ensure stability is a 100-µF capacitor. Either ceramic or electrolytic-type capacitors can be used. The minimum ripple current rating for the nonceramic capacitance must be at least 150 mA rms. The stability of the module and voltage tolerances are compromised if the capacitor is not placed near the output bus pins. A high-quality, computer-grade electrolytic capacitor should be adequate. A ceramic capacitor can be also be located within 0.5 inch (1,27 cm) of the output pin.

For applications with load transients (sudden changes in load current), the regulator response improves with additional capacitance. Additional electrolytic capacitors should be located close to the load circuit. These capacitors provide decoupling over the frequency range, 2 kHz to 150 kHz. Aluminum electrolytic capacitors are suitable for ambient temperatures above 0° C. For operation below 0° C, tantalum or Os-Con type capacitors are recommended. When using one or more nonceramic capacitors, the calculated equivalent ESR should be no lower than 10 mΩ (17 mΩ using the manufacturer's maximum ESR for a single capacitor). A list of capacitors and vendors are identified in Table 5 and Table 6, the recommended capacitor tables.

Ceramic Capacitors

Above 150 kHz, the performance of aluminum electrolytic capacitors becomes less effective. To further reduce the reflected input ripple current, or improve the output transient response, multilayer ceramic capacitors must be added. Ceramic capacitors have low ESR, and their resonant frequency is higher than the bandwidth of the regulator. When placed at the output, their combined ESR is not critical as long as the total value of ceramic capacitance does not exceed 200 µF.

Tantalum Capacitors

Tantalum-type capacitors may be used at the output, and are recommended for applications where the ambient operating temperature can be less than 0°C. The AVX TPS, Sprague 593D/594/595, and Kemet T495/T510/T520 capacitors series are suggested over many other tantalum types due to their rated surge, power dissipation, and ripple current capability. As a caution, many general-purpose tantalum capacitors have considerably higher ESR, reduced power dissipation, and lower ripple current capability. These capacitors are also less reliable as they have lower power dissipation and surge current ratings. Tantalum capacitors that do not have a stated ESR or surge current rating are not recommended for power applications. When specifying Os-Con and polymer tantalum capacitors for the output, the minimum ESR limit is encountered well before the maximum capacitance value is reached.

Capacitor Table

The capacitor tables, Table 5 and Table 6, identify the characteristics of capacitors from a number of vendors with acceptable ESR and ripple current (rms) ratings. The recommended number of capacitors required at both the input and output buses is identified for each capacitor type. This is not an extensive capacitor list. Capacitors from other vendors are available with comparable specifications. Those listed are for guidance. The rms rating and ESR (at 100 kHz) are critical parameters necessary to ensure both optimum regulator performance and long capacitor life.

Designing for Load Transients

The transient response of the dc/dc converter has been characterized using a load transient with a di/dt of 1 A/µs. The typical voltage deviation for this load transient is given in the data sheet specification table using the required value of output capacitance. As the di/dt of a transient is increased, the response of a converter's regulation circuit ultimately depends on its output capacitor decoupling network. This is an inherent limitation of any dc/dc converter once the speed of the transient exceeds its bandwidth capability. If the target application specifies a higher di/dt or lower voltage deviation, the requirement can only be met with additional output capacitor decoupling. In these cases, special attention must be paid to the type, value, and ESR of the capacitors selected.

If the transient performance requirements exceed those specified in the data sheet, the selection of output capacitors becomes more important. Review the minimum ESR in the characteristic data sheet for details on the capacitance maximum.

Table 5. Recommended Input/Output Capacitors (PTN78060W)

CAPACITOR VENDOR/ COMPONENT SERIES	CAPACITOR CHARACTERISTICS					QUANTITY		VENDOR NUMBER
	WORKING VOLTAGE (V)	VALUE (µF)	EQUIVALENT SERIES RESISTANCE (ESR) (Ω)	85° C MAXIMUM RIPPLE CURRENT (I_{RMS}) (mA)	PHYSICAL SIZE (mm)	INPUT BUS	OUTPUT BUS	
Panasonic FC(Radial)	50	180	0.119	850	10 × 16	1	1	EEUFC1H181
FK (SMD)	50	330	0.12	900	12.50 × 13.5	1 (1)	1	EEVFK1H331Q
United Chemi-Con PXA (SMD)	16	180	0.016	4360	8 × 12	1 (1)	≤1	PXA16VC180MF60 (V_O < 14 V)
LXZ	50	120	0.16	620	10 × 12,5	1 (1)	1	LXZ50VB121M10X12LL (V_I < 32 V)
MVY(SMD)	50	100	0.300	500	10 × 10	1	1	MVY50VC101M10X10TP (V_O ≤ 5.5 V)
Nichicon UWG (SMD)	50	100	0.300	500	10 × 10	1	1	UWG1H101MNR1GS
F550 (Tantalum)	10	100	0.055	2000	7,7 × 4,3	N/R (2)	≤ 3 (3)	F551A107MN (V_O ≤ 5 V)
HD	50	120	0.072	979	10 × 12,5	1	1	UHD1H151MHR
Sanyo Os-Con SVP (SMD)	20	100	0.024	2500	8 × 12	1 (1)	≤ 2	20SVP100M (V_I ≤ 16 V)
SP	16	100	0.032	2890	10 × 5	1 (1)	≤ 2	16SP100M (V_I ≤ 14 V)

(1) The voltage rating of the input capacitor must be selected for the desired operating input voltage range of the regulator. To operate the regulator at a higher input voltage, select a capacitor with the next higher voltage rating.
(2) Not recommended (N/R). The voltage rating does not meet the minimum operating limits in most applications.
(3) The maximum voltage rating of the capacitor must be selected for the desired set-point voltage (V_O). To operate at a higher output voltage select a capacitor with a higher voltage rating.

Table 5. Recommended Input/Output Capacitors (PTN78060W) (continued)

CAPACITOR VENDOR/ COMPONENT SERIES	CAPACITOR CHARACTERISTICS					QUANTITY		VENDOR NUMBER
	WORKING VOLTAGE (V)	VALUE (μF)	EQUIVALENT SERIES RESISTANCE (ESR) (Ω)	85° C MAXIMUM RIPPLE CURRENT (I_{RMS}) (mA)	PHYSICAL SIZE (mm)	INPUT BUS	OUTPUT BUS	
AVX Tantalum TPS (SMD)	20	100	0.085	1543	7,3 L × 4,3 W × 4,1 H	N/R (2)	≤ 3	TPSV107M020R0085 (V_O ≤ 10 V)
	20	100	0.200	> 817		N/R (2)	≤ 3	TPSE107M020R0200 (V_O ≤ 10 V)
Murata X5R Ceramic	6.3	100	0.002	>1000	3225	N/R (2)	≤ 2	GRM32ER60J107M (V_O ≤ 5.5 V)
TDK X5R Ceramic	6.3	100	0.002	>1000	3225	N/R (2)	≤ 2	C3225X5R0J107MT (V_O ≤ 5.5 V)
Murata X5R Ceramic	16	47	0.002	>1000	3225	1 (1)	≤ 4	GRM32ER61C476M (V_o ~ V_I ≤ 13.5 V)
Kemet X5R Ceramic	6.3	47	0.002	>1000	3225	N/R (2)	≤ 4	C1210C476K9PAC (V_O ≤ 5.5 V)
TDK X5R Ceramic	6.3	47	0.002	>1000	3225	N/R (2)	≤ 4	C3225X5R0J476MT (V_O ≤ 5.5 V)
Murata X5R Ceramic	6.3	47	0.002	>1000	3225	N/R (2)	≤ 4	GRM42-2X5R476M6.3 (V_O ≤ 5.5 V)
TDK X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 1 (4)	1	C3225X7R1E225KT/MT (V_O ≤ 20 V)
Murata X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 1 (4)	1	GRM32RR71E225K (V_O ≤ 20 V)
Kemet X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 1 (5)	1	C1210C225K3RAC (V_O ≤ 20 V)
AVX X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 1 (5)	1	C12103C225KAT2A (V_O ≤ 20 V)
Kemet X7R Ceramic	50	1.0	0.002	>1000	3225	≥ 2 (6)	1	C1210C105K5RAC
Murata X7R Ceramic	50	4.7	0.002	>1000	3225	≥ 1	1	GRM32ER71H475KA88L
TDK X7R Ceramic	50	2.2	0.002	>1000	3225	≥ 1	1	C3225X7R1H225KT
Murata X7R Ceramic	50	1.0	0.002	>1000	3225	≥ 2 (6)	1	GRM32RR71H105KA01L
TDK X7R Ceramic	50	1.0	0.002	>1000	3225	≥ 2 (6)	1	C3225X7R1H105KT
Kemet Radial Through-hole	50	1.0	0.002	>1000	5,08 × 7,62 × 9,14 H	≥ 2 (6)	1	C330C105K5R5CA
Murata Radial Through-hole	50	2.2	0.004	>1000	10 H × 10 W × 4 D	≥ 1	1	RPER71H2R2KK6F03

(4) The maximum rating of the ceramic capacitor limits the regulator's operating input voltage to 20 V. Select an alternative ceramic component to operate at a higher input voltage.
(5) The maximum rating of the ceramic capacitor limits the regulator's operating input voltage to 20 V. Select an alternative ceramic component to operate at a higher input voltage.
(6) A total capacitance of 2 μF is an acceptable replacement value for a single 2.2-μF ceramic capacitor

Table 6. Recommended Input/Output Capacitors (PTN78060H)

CAPACITOR VENDOR/ COMPONENT SERIES	CAPACITOR CHARACTERISTICS					QUANTITY		VENDOR NUMBER
	WORKING VOLTAGE (V)	VALUE (µF)	EQUIVALENT SERIES RESISTANCE (ESR) (Ω)	85° C MAXIMUM RIPPLE CURRENT (I_{RMS}) (mA)	PHYSICAL SIZE (mm)	INPUT BUS	OUTPUT BUS	
Panasonic FC(Radial)	50	100	0.162	615	10 × 12.5	1	≥1	EEUFC1H101
FK (SMD)	50	150	0.18	670	10 × 10,2	1 (1)	≥1	EEVFK1H151P
United Chemi-Con PXA (SMD)	16	180	0.016	4360	8 × 12	N/R (2)	≤1	PXA16VC180MF60 (V_O < 14 V)
LXZ	50	120	0.160	620	10 × 12,5	1 (1)	≥1	LXZ50VB121M10X12LL
MVY(SMD)	50	100	0.300	500	10 × 10	1	≥1	MVY50VC101M10X10TP
Nichicon UWG (SMD)	50	100	0.300	500	10 × 10	1	≥1	UWG1H101MNR1GS
HD	50	120	0.072	979	10 × 12,5	1	≥1	UHD1H151MHR
Sanyo Os-Con SVP (SMD)	20	100	0.024	2500	8 × 12	1 (1)	≤ 2	20SVP100M (V_I ~V_O ≤ 16 V)
SP	20	120	0.024	3110	8 × 10,5	1 (1)	≤ 2	20SP120M (V_I~V_O ≤ 16 V)
TDK X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 6 (3)	1	C3225X7R1E225KT/MT (V_I~V_O ≤ 20 V)
Murata X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 6 (3)	1	GRM32RR71E225K (V_I~V_O ≤ 20 V)
Kemet X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 6 (3)	1	C1210C225K3RAC (V_I~V_O ≤ 20 V)
AVX X7R Ceramic	25	2.2	0.002	>1000	3225	≥ 6 (3)	1	C12103C225KAT2A (V_I~V_O ≤ 20 V)
Murata X7R Ceramic	50	4.7	0.002	>1000	3225	≥ 3	1	GRM32ER71H475KA88L
TDK X7R Ceramic	50	3.3	0.002	>1000	3225	≥ 4 (4)	1	CKG45NX7R1H335M
Murata Radial Through-hole	50	3.3	0.003	>1000	12,5 H × 12,5 W × 4	≥ 4 (5)	1	RPER71H3R3KK6F03
Kemet Radial Through-hole	50	4.7	0.003	>1000	5,08 × 7,62 × 9,14	≥ 3	1	C350C475K5R5CA

(1) The voltage rating of the input capacitor must be selected for the desired operating input voltage range of the regulator. To operate the regulator at a higher input voltage, select a capacitor with the next higher voltage rating.
(2) Not recommended (N/R). The voltage rating does not meet the minimum operating limits in most applications.
(3) The maximum rating of the ceramic capacitor limits the regulator's operating input voltage to 20 V. Select an alternative ceramic component to operate at a higher input voltage.
(4) A total capacitance of 13.2 F is an acceptable replacement value for 3 × 4.7 F ceramic capacitors
(5) A total capacitance of 2 µF is an acceptable replacement value for a single 2.2-µF ceramic capacitor

Power-Up Characteristics

When configured per the standard application, the PTN78060 power module produces a regulated output voltage following the application of a valid input source voltage. During power up, internal soft-start circuitry slows the rate that the output voltage rises, thereby limiting the amount of in-rush current that can be drawn from the input source. The soft-start circuitry introduces a short time delay (typically 5 ms – 10 ms) into the power-up characteristic. This is from the point that a valid input source is recognized. Figure 29 shows the power-up waveforms when operating from a 12-V input and with the output voltage adjusted to 5 V. The waveforms were measured with a 2.8-A resistive load.

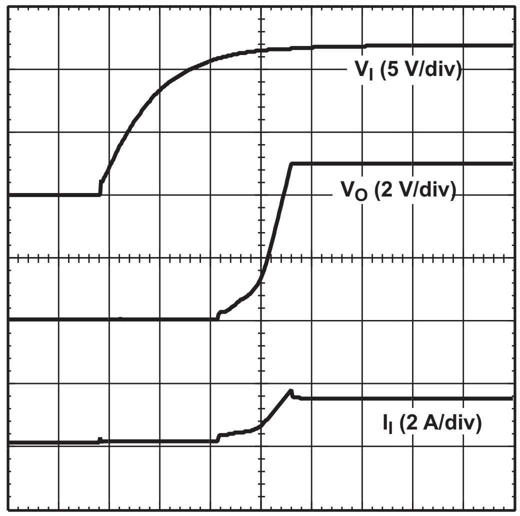


Figure 29. Power-Up Waveforms

Undervoltage Lockout

The undervoltage lockout (UVLO) circuit prevents the module from attempting to power up until the input voltage is above the UVLO threshold. This is to prevent the modulte from drawing excessive current from the input source at power up. Below the UVLO threshold, the module is held off.

Current Limit Protection

The module is protected against load faults with a continuous current limit characteristic. Under a load-fault condition, the output current increases to the current limit threshold. Attempting to draw current that exceeds the current limit threshold causes the module to progressively reduce its output voltage. Current is continuously supplied to the fault until the fault is removed. Once it is removed, the output voltage promptly recovers. When limiting output current, the regulator experiences higher power dissipation, which increases its temperature. If the temperature increase is excessive, the module overtemperature protection begins to periodically turn the output voltage off.

Overtemperature Protection

A thermal shutdown mechanism protects the module's internal circuitry against excessively high temperatures. A rise in temperature may be the result of a drop in airflow, a high ambient temperature, or a sustained current limit condition. If the internal temperature rises excessively, the module turns itself off, reducing the output voltage to zero. The module excercises a soft-start power up when the sensed temperature has decreased by about 10° C below the trip point.

NOTE:*Overtemperature protection is a last resort mechanism to prevent damage to the module. It should not be relied on as permanent protection against thermal stress. Always operate the module within its temperature derated limits, for the worst-case operating conditions of output current, ambient temperature, and airflow. Operating the module above these limits, albeit below the thermal shutdown temperature, reduces the long-term reliability of the module.*

Output Voltage Sense

An external voltage sense improves the load regulation performance of the module by enabling it to compensate for any IR-voltage drop between the module and the load circuit. This voltage drop is caused by the flow of current through the resistance in the printed-circuit board connections.

To use the output voltage sense feature, simply connect the V_O *Sense* input (pin 5) to V_O, close to the device that draws the most supply current. If an external voltage sense is not desired, the V_O *Sense* input may be left open circuit. An internal resistor (15 Ω or less), connected between this input and V_O, ensures that the output remains in regulation.

With V_O *Sense* connected, the difference between the voltage measure directly between the V_O and *GND*, and that measured from V_O *Sense* to *GND*, represents the amount of IR-voltage drop being compensated by the regulator. This should be limited to a maximum of 0.3 V.

Note:*The external voltage sense is not designed to compensate for the forward drop of nonlinear or frequency-dependent components that may be placed in series with the regulator's output. Examples include OR-ing diodes, filter inductors, ferrite beads, and fuses. When these components are enclosed by the external sense connection, they are effectively placed inside the regulation control loop. This can adversely affect the stability of the module.*

Output On/Off Inhibit

The inhibit feature can be used wherever there is a requirement for the output voltage to be turned off. The power module functions normally when the Inhibit control (pin 3) is left open-circuit, providing a regulated output whenever a valid source voltage is connected to V_I with respect to GND. Figure 30 shows the the circuit used to demonstrate the inhibit function. Note the discrete transistor (Q1). Turning Q1 on applies a low voltage to the *Inhibit* control pin and turns the module off. The output voltage decays as the load circuit discharges the capacitance. The current drawn at the input is reduced to typically 17 mA. If Q1 is then turned off, the module executes a soft-start power up. A regulated output voltage is produced within 20 ms. Figure 31 shows the typical rise in the output voltage, following the turn off of Q1. The turn off of Q1 corresponds to the fall in the waveform, Q1 Vgs. The waveforms were measured with a 2.8-A resistive load.

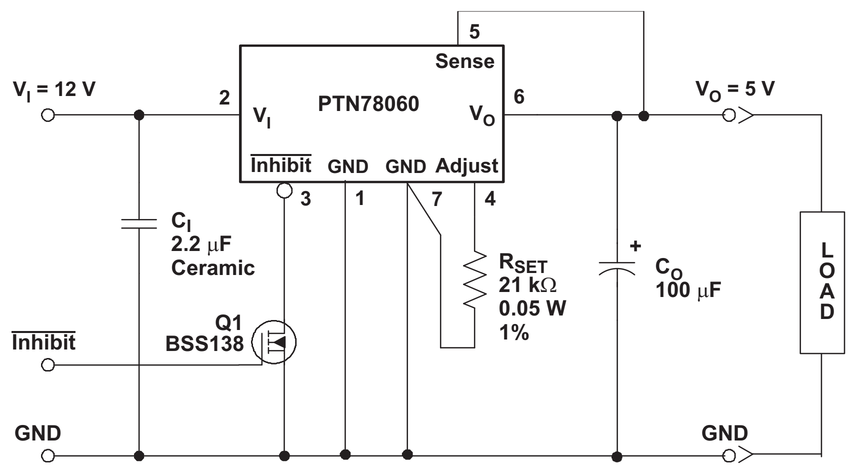


Figure 30. On/Off Inhibit Control Circuit

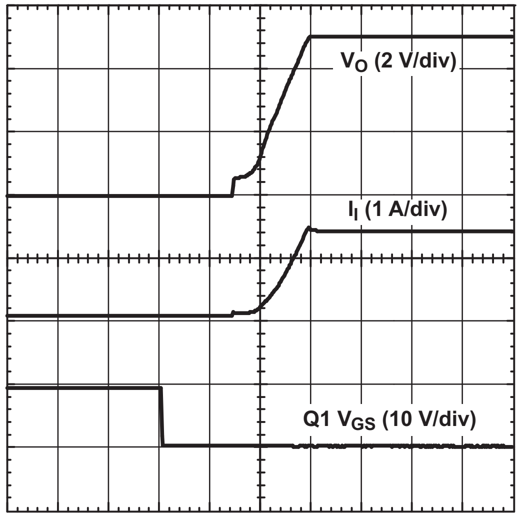


Figure 31. Power-Up Response From Inhibit Control

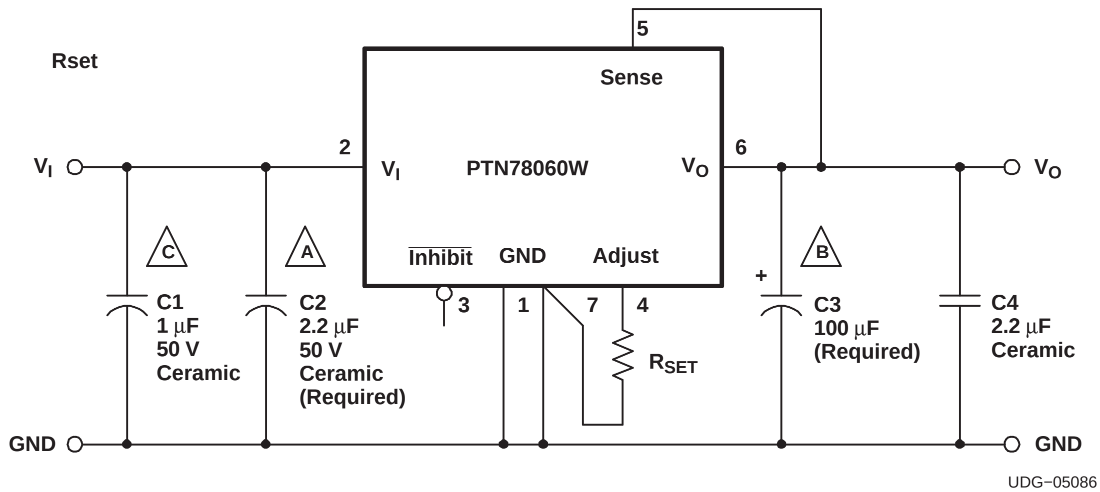
Optional Input/Output Filters

Power modules include internal input and output ceramic capacitors in all of their designs. However, some applications require much lower levels of either input reflected or output ripple/noise. This application describes various filters and design techniques found to be successful in reducing both input and output ripple/noise.

Input/Output Capacitors

The easiest way to reduce output ripple and noise is to add one or more 1-µF ceramic capacitors, such as C4 shown in Figure 32. Ceramic capacitors should be placed close to the output power terminals. A single 2.2-µF capacitor reduces the output ripple/noise by 10% to 30% for modules with a rated output current of less than 3 A. (Note: C3 is recommended to improve the regulators transient response, and does not reduce output ripple and noise.)

Switching regulators draw current from the input line in pulses at their operating frequency. The amount of reflected (input) ripple/noise generated is directly proportional to the equivalent source impedance of the power source including the impedance of any input lines. The addition of C1, minimum 2.2-µF ceramic capacitor, near the input power pins, reduces reflected conducted ripple/noise by up to 20%.



A. See specifications for required value and type. For PTN78060H, C_{C2} = 3 × 4.7 µF.

B. See Application Information section for suggested value and type.

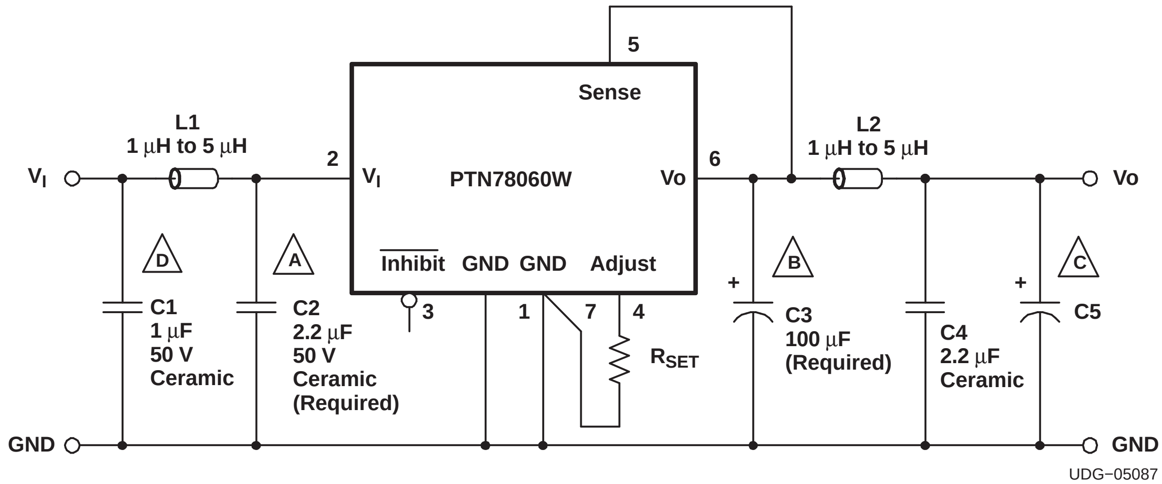
C. For PTN78060H, C_{C1} ≥ 4.7 µF.

Figure 32. Adding High-Frequency Bypass Capacitors To The Input and Output

π Filters

If a further reduction in ripple/noise level is required for an application, higher order filters must be used. A π (pi) filter, employing a ferrite bead (Fair-Rite part number 2673000701 or equivalent) in series with the input or output terminals of the regulator reduces the ripple/noise by at least 20 db (see Figure 33 and Figure 34). In order for the inductor to be effective ceramic capacitors are also required. (Note: see Capacitor Recommendations for additional information on vendors and component suggestions.)

These inductors plus ceramic capacitors form an excellent filter because of the rejection at the switching frequency (650 kHz - 1 MHz). The placement of this filter is critical. It must be located as close as possible to the input or output pins to be effective. The ferrite bead is small (12,5 mm × 3 mm), easy to use, low cost, and has low dc resistance. Fair-Rite also manufactures a surface-mount bead (part number 2773021447). It is rated to 5 A, and can be used on the output bus. As an alternative, suitably rated 1-µH to 5-µH wound inductors can be used in place of the ferrite inductor bead.



A. See specifications for required value and type. For PTN78060H, C_{C2} = 3 × 4.7 µF.

B. See Application Information section for suggested value and type.

C. Recommended whenever I_O > 2A.

D. For PTN78060H, C_{C1} ≥ 4.7 µF.

Figure 33. Adding π Filters (I_O ≤ 3 A)

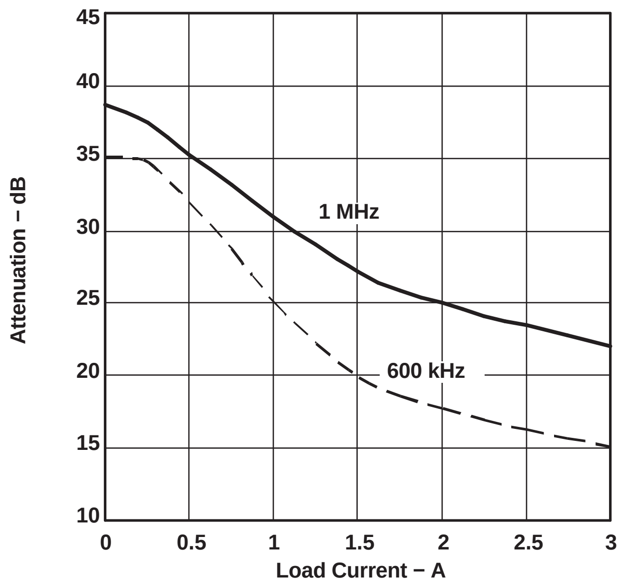


Figure 34. π-Filter Attenuation vs. Load Current

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
PTN78060HAH	ACTIVE	Through-Hole Module	EUW	7	36	RoHS (In Work) & Green (In Work)	SN	N / A for Pkg Type	-40 to 85		Samples
PTN78060HAS	ACTIVE	Surface Mount Module	EUY	7	36	Non-RoHS & Green (In Work)	SNPB	Level-1-235C-UNLIM/ Level-3-260C-168HRS	-40 to 85		Samples
PTN78060HAZ	ACTIVE	Surface Mount Module	EUY	7	36	RoHS (In Work) & Green (In Work)	SNAGCU	Level-3-260C-168 HR	-40 to 85		Samples
PTN78060HAZT	ACTIVE	Surface Mount Module	EUY	7	250	RoHS (In Work) & Green (In Work)	SNAGCU	Level-3-260C-168 HR	-40 to 85		Samples
PTN78060WAD	ACTIVE	Through-Hole Module	EUW	7	36	RoHS (In Work) & Green (In Work)	SN	N / A for Pkg Type	-40 to 85		Samples
PTN78060WAH	ACTIVE	Through-Hole Module	EUW	7	36	RoHS Exempt & Green	SN	N / A for Pkg Type	-40 to 85		Samples
PTN78060WAS	ACTIVE	Surface Mount Module	EUY	7	36	Non-RoHS & Green (In Work)	SNPB	Level-1-235C-UNLIM/ Level-3-260C-168HRS	-40 to 85		Samples
PTN78060WAST	ACTIVE	Surface Mount Module	EUY	7	250	Non-RoHS & Green (In Work)	SNPB	Level-1-235C-UNLIM/ Level-3-260C-168HRS	-40 to 85		Samples
PTN78060WAZ	ACTIVE	Surface Mount Module	EUY	7	36	RoHS (In Work) & Green (In Work)	SNAGCU	Level-3-260C-168 HR	-40 to 85		Samples
PTN78060WAZT	ACTIVE	Surface Mount Module	EUY	7	250	RoHS (In Work) & Green (In Work)	SNAGCU	Level-3-260C-168 HR	-40 to 85		Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

[2] **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

[3] MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

[4] There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

[5] Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

[6] Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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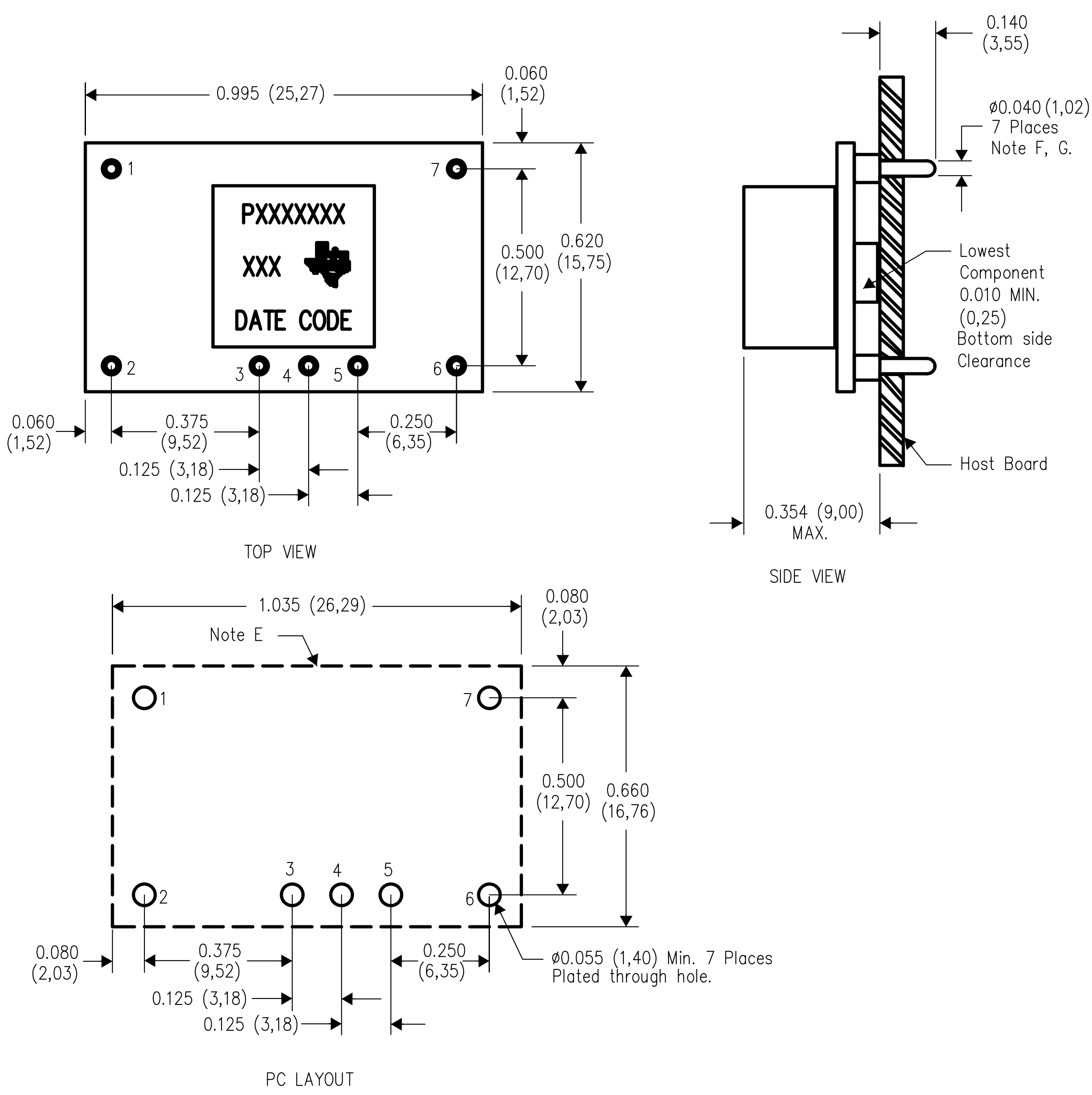
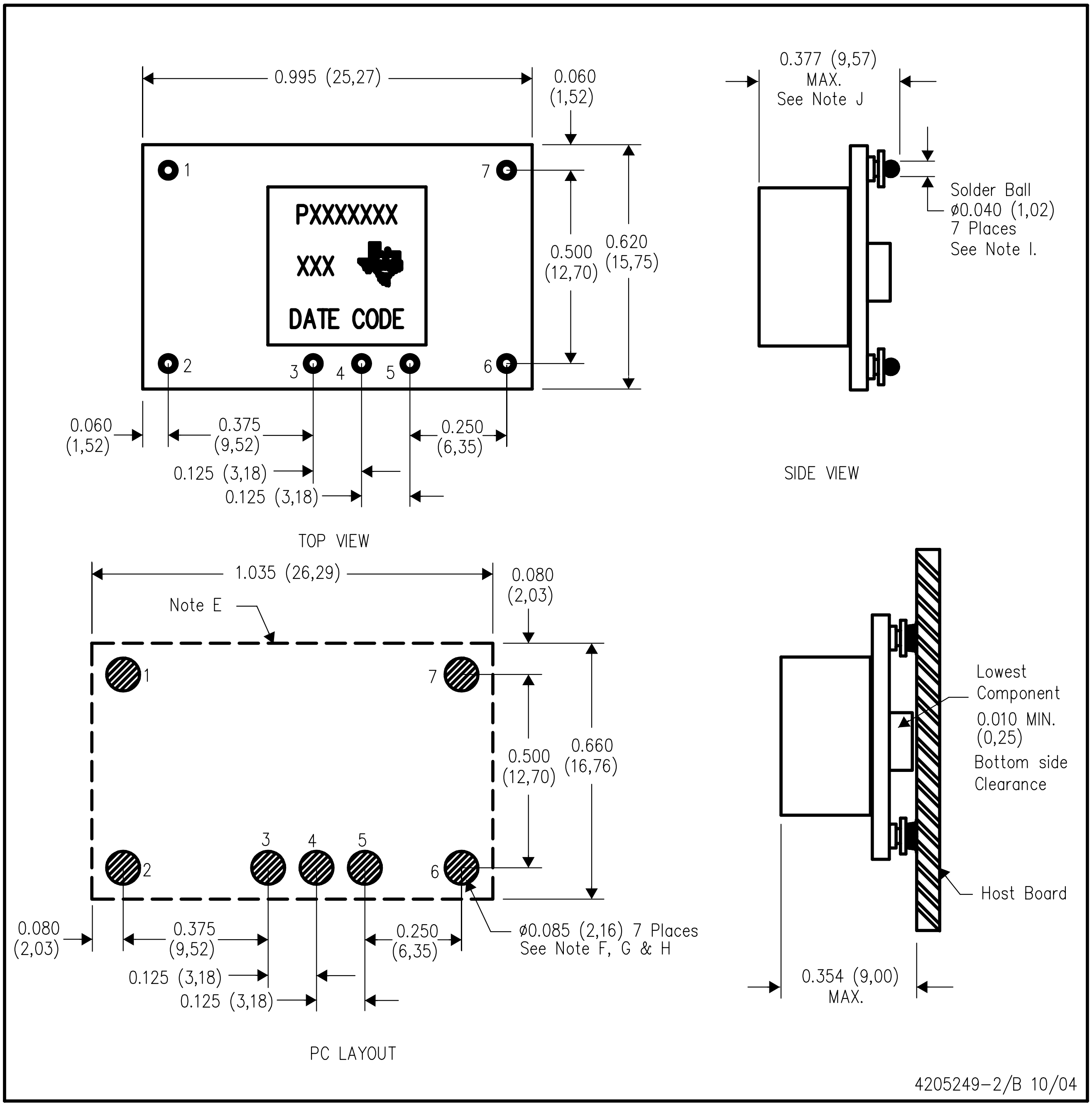
EUW (R–PDSS–T7) DOUBLE SIDED MODULE



4205248–2/B 10/04

NOTES:
- A. All linear dimensions are in inches (mm).
- B. This drawing is subject to change without notice.
- C. 2 place decimals are ±0.030 (±0,76mm).
- D. 3 place decimals are ±0.010 (±0,25mm).
- E. Recommended keep out area for user components
- F. Pins are 0.040" (1,02) diameter with 0.070" (1,78) diameter standoff shoulder.
- G. All pins: Material – Copper Alloy
  Finish – Tin (100%) over Nickel plate

EUY (R–PDSS–B7) DOUBLE SIDED MODULE



NOTES:
- A. All linear dimensions are in inches (mm).
- B. This drawing is subject to change without notice.
- C. 2 place decimals are ±0.030 (±0,76mm).
- D. 3 place decimals are ±0.010 (±0,25mm).
- E. Recommended keep out area for user components.
- F. Power pin connection should utilize two or more vias to the interior power plane of 0.025 (0,63) I.D. per input, ground and output pin (or the electrical equivalent).
- G. Paste screen opening: 0.080 (2,03) to 0.085 (2,16). Paste screen thickness: 0.006 (0,15).
- H. Pad type: Solder mask defined.
- I. All pins: Material – Copper Alloy
  Finish – Tin (100%) over Nickel plate
  Solder Ball – See product data sheet.
- J. Dimension prior to reflow solder.

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