AN14536

Battery-free magnetic security switch with Bluetooth Low Energy connectivity

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Document information

Information	Content
Keywords	magnetic, magnetic security, magnet security switch, Bluetooth Low Energy, Bluetooth Low Energy connectivity
Abstract	This application note discusses the elimination of batteries out of customer products using a magnetic security switch that provides Bluetooth Low Energy connectivity and eliminates batteries in customer designs.

1 Motivation

Like most conveniences in modern life, the batteries usage as an energy source for any electronic device comes with some penalties. Once the battery is depleted, the desired application stops, and the battery must be disposed of and replaced. The penalties then include the loss of coverage during the down time, and all the real dollar, and environmental costs associated with the fabrication, shipping, and disposal of batteries.

There are other compelling reasons to avoid designing in batteries if you can:

- Reduced Maintenance: Without batteries to replace, maintenance costs and efforts are reduced. Depending on the system at hand, maintenance costs (also known as the cost of ownership) can be reduced to zero.
- Environmental Benefits: Eliminating batteries reduces electronic waste and the environmental impact associated with battery production and disposal.
- Cost Savings: Long-term cost savings from not having to purchase and replace batteries.
- Increased Reliability: Battery-free sensors can operate continuously without the risk of battery failure. This reliability is balanced against any new risks associated with the use of some other storage element type, such as a super capacitor.
- Enhanced Deployment Flexibility: These sensors can be placed in hard-to-reach or hazardous locations without worrying about battery access. Hard to reach and hazardous locations are especially true in industrial and commercial settings, where the deployments can be in vaults, embedded in large assemblies, a roof, or a high ceiling mount.
- Sustainability: Once deployed, lifetime battery-free systems present no further burden to the environment.
- Smaller Size: Without the need for a battery compartment, sensing modules can be more compact and lightweight.
- Longer Lifespan: Battery-free sensors have a longer operational lifespan since they are not limited by battery life. They are essentially “forever” deployments.
- Improved Safety: Reduces the risk of battery-related hazards, such as chemical leaks, corrosion, or fire (typical of rechargeable battery systems).
- Uninterrupted Operation: Continuous power supply through energy harvesting ensures uninterrupted operation.

The above arguments for eliminating the battery in your next design are compelling for the owner/operator. These arguments represent the *carrot*. On the *stick* side of the argument, there are new and impending regulatory mandates that effectively coerce the exclusion of batteries in many applications. For example, the European Union has introduced a new Batteries Regulations (EU) 2023/1542, which is now being gradually introduced starting in 2024. This regulation mandates that by 2027, portable batteries in electronic devices are to be removable and replaceable by consumers. The regulation also sets targets for recycling efficiency, material recovery, and the use of recycled content in batteries. In other words, electronic devices that use batteries continue to increase but the batteries must be replaced and the batteries in use are sure to become more expensive as content and recyclability directives are complied with.

There are a lot of good reasons to eliminate a battery from your next design.

2 Alternate energy sources

If a battery is not used, where can power come from for the next generation of electronic device designs? A few of the more common options include:

- Light Energy: Light energy is captured using photovoltaic cells, solar panels, or photodiodes. A few photovoltaic cell manufacturers create cells that are optimized for wavelengths of light common to indoor lighting scenarios.
- Thermal Energy: Thermal energy is harnessed from temperature differentials using thermoelectric generators or pyroelectric materials. In most settings, the interior temperature of a room is kept within a narrow range,

while the external world temperature can swing wildly in comparison. Taking advantage of significant transient temperature gradients that arise during the normal operation of, for example, cooking, HVAC, and water heating systems is also possible.

- Mechanical Energy: Mechanical energy is derived from motion or vibrations using piezoelectric materials or electromagnetic induction. Examples include:
  - A mechanism to capture and convert kinetic energy afforded by an occupied office chair (for example, Z, tilt, swivel, lateral roll).
  - A mechanism to capture the energy of a door movement. For example, a rotary geared generator at hinge pivot, or a linear generator using motion mechanically converted from door movement.
  - In addition to gears/cables, consider also pneumatic and hydraulic motion energy conversion.
  - Conversion of ambient vibrations can be enhanced if the pick-up system is resonance tuned prior to installation (or self-tuned upon installation) to the specific vibration characteristics of the floor, wall, ceiling, pipe, or duct it is mounted to.
  - A slightly pliant flooring system supported by piezo charge generators. As the occupancy load shifts, energy is generated. In a less ambitious form, an energy harvesting “Welcome” mat.
- Radio Frequency (RF) Energy: RF energy is collected from ambient RF signals, such as those from Wi-Fi or cellular networks.
- Wind Energy: Wind energy is realized using small turbines or other wind energy conversion devices. The approach is to convert linear air flow to electrical energy using a turbine or equivalent device. Air flow is used to create a “to and fro” oscillatory motion. For example, a light bendable plate anchored on one end and is placed in an air stream, leveraging the vortex shedding flow. The plate motion is converted to charge (for example, piezo).
- Acoustic Energy: Acoustic energy is captured from sound waves or vibrations.
- Fluid Flow: Fluid flow is energy from fluid movement, such as water or air flow.
- Biochemical Energy: Biochemical energy is extracted from biological processes, such as blood sugar in biofuel cells.
- Inductive Vampire: One potential strategy in the elimination of batteries, the inductive vampire concept; this is not free energy. With this strategy, power is captured using an inductive pick-up of power of extant power wiring.
- Betavoltaics: While not a typical ambient condition that can be harvested, beta voltaic cells convert Beta-minus (β^-) decay into energy, which is the emission of an electron. In this process, a neutron in the nucleus is converted into a proton, an electron (the beta particle), and an antineutrino. This concept is being used to create *forever* batteries.

There are many options to consider.

This reference design strives to keep it simple, low cost and most broadly applicable. The example in this application note harvests indoor light energy using a photovoltaic cell to power the design.

3 Design overview

Section 3 describes the design and operational details of a battery-free, magnetic security switch with Bluetooth Low Energy connectivity.

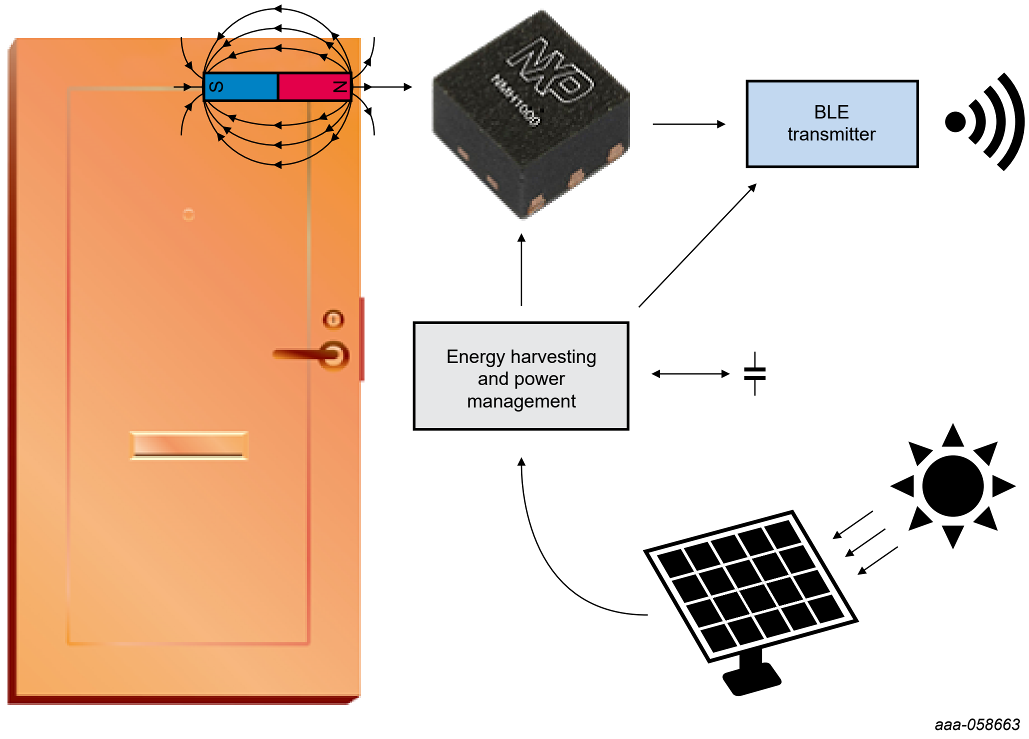

Figure 1. Top-level block diagram

In this example reference design, a window frame/gate/door is fitted with a low-cost magnet. This example uses a door as shown in Figure 1. A security sensor is mounted on the frame of the door, near the magnet to detect when the door is closed.

The NXP NMH1000 magnetic sensor senses the magnetic field. The NMH1000 has two personalities. As a sensor, it resides on an I^2C bus and provides a quantitative measure of magnetic field strength and also sources an interrupt to a host system whenever field strength measurement crosses the programmed threshold. Alternately, as a *switch*, the NMH1000 stands alone, operating without a host MCU, with field strength thresholds and sample rates set by tying its input pins up or down. The NMH1000 sources an interrupt to the system when those thresholds are crossed. In this reference design, the NMH1000 is used as a switch.

When no magnetic field is detected, the NMH1000 asserts an interrupt signal to the Bluetooth Low Energy transmitter and a preprogrammed Bluetooth Low Energy beacon payload begins to periodically broadcast, alerting the receiver that the door is open.

A photovoltaic cell harvests power for this design, illuminated in this example using typical indoor ambient light levels.

An energy management IC harvests power from the PV cell and stored in a super capacitor. The energy management IC also supplies regulated voltage to the NMH1000 and the Bluetooth Low Energy transmitter.

In this design, this Bluetooth Low Energy enabled magetic security sensor runs forever and requires zero maintenance.

4 Schematic and principles of operation

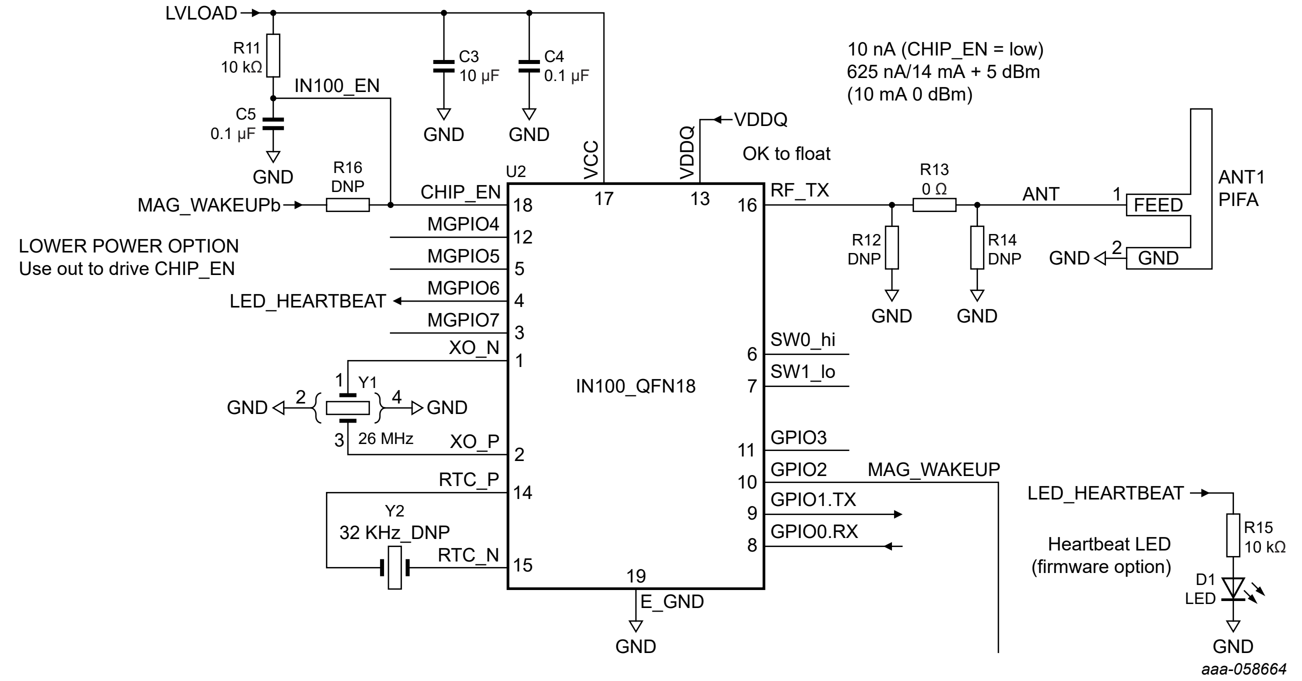

Figure 2. Schematic, Bluetooth Low Energy transmitter

For Bluetooth Low Energy transmission, the IN100 NanoBeacon from InPlay, an NXP partner company, is used. The IN100 Nano is a Bluetooth Low Energy transmit only device. The IN100 behavior is not controlled by a programming language, but rather by programming its sophisticated state machine using an intuitive companion PC-based configuration application.

In this particular application, the IN100 is postured to reside mostly in a sleep state, rather than in a fully disabled state. In the sleep state, it consumes 625 nA. An asserted MAG_WAKEUP signal (sourced by the NMH1000, in Figure 3) is recognized at GPIO2 and the part wakes up. At part wake-up, its programmed configuration is such that it broadcasts a 31-byte payload once a second to inform any Bluetooth Low Energy receiver in the area: the door is open, the local VCC supply level, and the local on-chip temperature.

An alternate power-saving strategy that is *not* used here: Instead of leaving the IN100 in a sleep state, awakened by assertion of MAG_WAKEUP at the GPIO2 input, MAG_WAKE can be routed to the CHIP_EN input (through R16) to bring the IN100 out of a *disabled* state. (This alternate strategy also requires removal of R11 and C5.) In the “sleep” state, the IN100 draws 625 nA, in its “disabled” state it only draws 10 nA. This alternate enable/disable strategy is the lowest power of the two strategies considered.

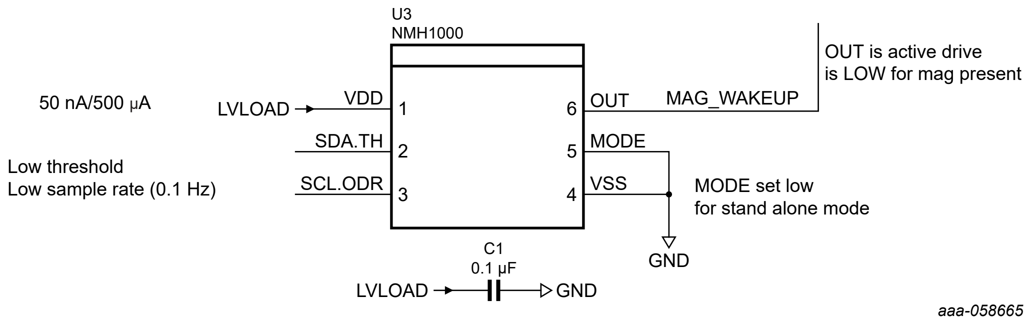

Figure 3. Schematic, NMH1000 magnetic sensor

Figure 3 shows the connection of the NMH1000 magnetic sensor applied as a *switch*. This standalone mode is established by tying the MODE pin low. The OUT push-pull output on the NMH1000 is low when a magnetic field is present and goes high when absent. With MODE set low, I^2C pins are now repurposed to set the sample rate (also known as the Output Data Rate, ODR), and field strength thresholds as shown in Table 1, and Table 2.

Table 1. Setting the Switching Threshold

SDA.TH (Threshold) pin state	Magnetic field detection/switching threshold
Tied Low	Mid, ±160 Gauss
Floating	Low, ±100-Gauss ← this design
Tied High	High, ±230-Gauss

In this particular application, the SDA.TH pin is left floating, which sets the switching threshold to its most sensitive range at ±100 Gauss. Regardless of the range selected, the NMH1000 has about a 20-Gauss hysteresis band.

Table 2. Setting the output data rate

SCL.ODR (Output data rate) pin state	Output data rate
Tied Low	Mid, 1 Hz
Floating	Low, 0.1 Hz ← this design
Tied High	High, 10 Hz

The SCL.ODR pin is also left floating, which runs at a low 0.1 Hz sample rate. This scenario results in a net average current draw of about 50 nA for the NMH1000 sensor. Keep in mind, with this low sample rate, recognizing a change in the magnetic field can take several seconds.

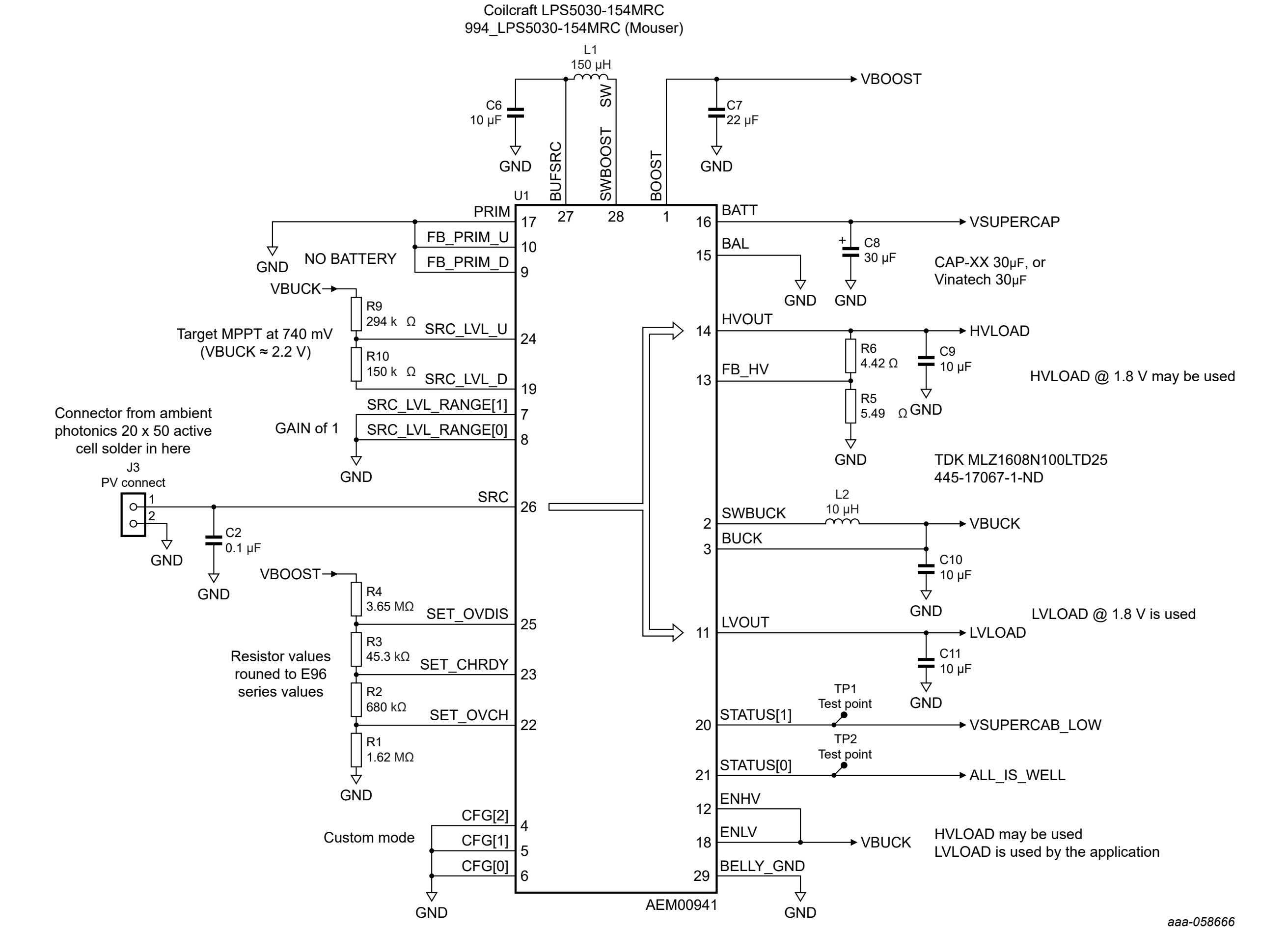

Figure 4. Schematic, energy harvesting IC

Figure 4 shows the application details of the e-Peas AEM00941 energy management IC. The detailed explanation for this portion of the schematic is better left to a deep dive into the e-Peas data sheet. For a high-level description, start with the upper right of the AEM00941 symbol and work clockwise around Figure 4.

- The BATT pin is connected to a 30 F super capacitor. This capacitor is the energy storage element for this design. Some models of super capacitors include a center terminal to which the BAL pin is connected.
- HVOUT is one of the two regulated outputs of the AEM0041. In this case, the resistor values chosen set the HVLOAD node to 1.8 V but the power source is otherwise *not* used in this design.
- The LC network at SWBUCK/BUCK are the recommended values for voltage regulation.
- LVOUT is the 1.8 V regulated voltage source the balance of this design uses.
- STATUS pins are made available as test points.
- ENHV and ENLV are tied to VBUCK. As VBUCK comes up, the HV and LV output regulators are enabled.
- Pins 4-6, 22, 23, and 25 set the operating mode of the AEM00941. They establish the Over-Discharge, Over-Charge, and Charge-Ready voltages of the particular super capacitors used.
- The SRC input pin is connected to the positive terminal of a photovoltaic cell. In this application, the specialized PV cell technology from Ambient Photonics is showcased. Ambient Photonics creates photovoltaic cells that are especially optimized for wavelengths and light levels common to indoor lighting scenes.
- Pins 7, 8, 19, and 24 set-up the buck regulator.
- Pins 9, 10, and 17, are associated with a primary battery. This design has no battery.
- Pins 1, 27 and 28 set-up the boost regulator.

The AEM00941 supplies a well-regulated continuous 1.8 V supply to the balance of the design, the LVOUT output was used. It uses a 30 F super capacitors as its energy reservoir. Resistors R1-R4 set the charge/ discharge threshold optimized for the particular super capacitors used. Resistors R9 and R10 set the Maximum Power Point Tracking (MPPT) specific to the PV cell used. The MPPT assures an optimal impedance match between the PV Cell and the AEM00941 to assure the most efficient transfer of energy from the PV cell.

The AEM00941 supplies a constant 1.8 V power rail to the balance of the design.

When there is sufficient light energy, the AEM00941 steers the PV Cell current back into the super capacitor.

5 Layout

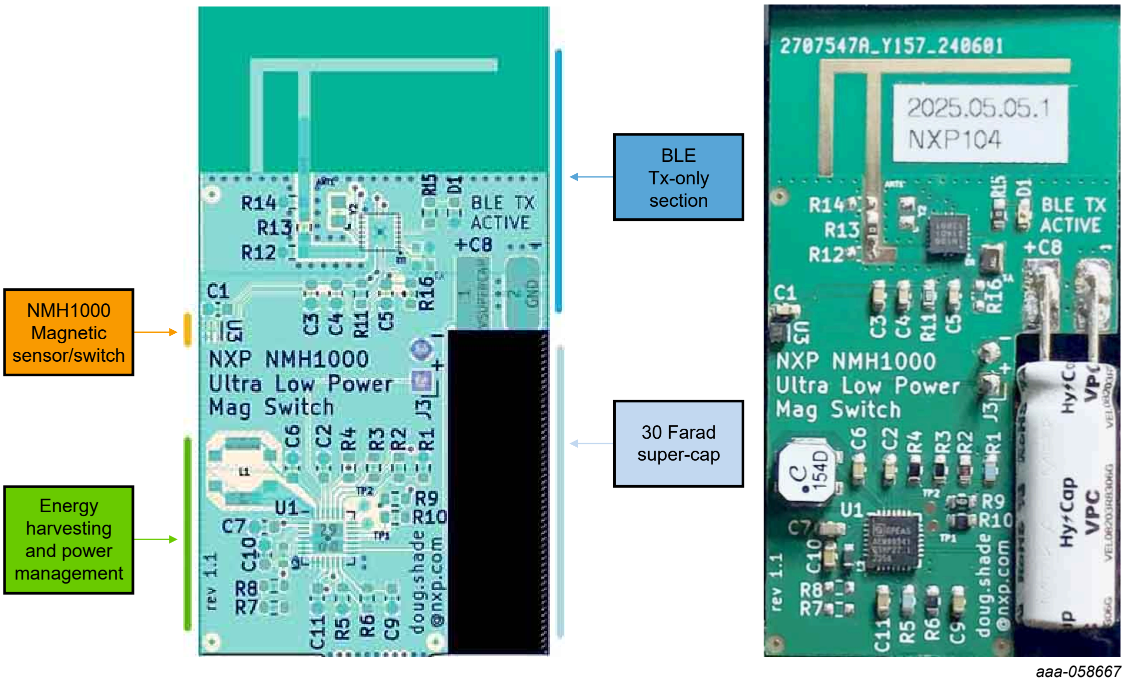

Figure 5. Layout of PCB

The PCB layout is a simple 2-layer construction as shown in Figure 5. Nearly all routing is accomplished on the top copper layer. Both the top and bottom layers are flood-filled with GND copper, the exception being the Printed Inverted F Antenna (PIFA), around and underneath where there is no copper.

6 Payload contents

Support for a non-connectable beacon was introduced in the Bluetooth 4.0 specification, released in 2010. The beaconing support has evolved significantly since then, but at the time a payload of up to 31 bytes was permitted, with the content being defined by the user. For simplicity, the older standard was used to come up with our own payload definitions to convey a “Door Open”, the local “Supply Voltage”, and the local chip “Temperature”. This example is a form of LTV (Length Type Value) encoding. Customer applications obviously have other needs and strategies for payload content.

7 Energy requirements – sample calculations

The following Amp-Second calculations are for a single TX Event:

Table 3. Sample calculations

I^2C bus current:	0.00 µA-Seconds[1]
NMH1000 (active sensing): 500 ms x 580 uA =	290.00 µA-Seconds
LED Current: 7.6 ms x 1.6 V / 300 Ω ≈	40.53 µA-Seconds[2]
IN100 Active: 6.4 ms x 2.2 mA ≈	14.08 µA-Seconds
IN100 +5 dBm TX: 1.2 ms x 13.8 mA ≈	16.56 µA-Seconds
TOTAL	361.17 µA-Seconds

[1] In this application, the I^2C bus is not used. The NMH1000 is applied as a standalone switch. Output data rates and switching thresholds are set with hard wiring.
[2] Including an LED is a bit of a luxury here, can be dropped from the demo, or at least noted in the power calculations.

The following current numbers consist of the baseline or quiescent current draw state:

IN100 Sleep:	0.625 µA[1]
NMH100 Sleep:	0.048 µA
TOTAL	0.673 µA

[1] Recall that in this particular version of the design that the not-transmitting periods of the application we opted to put the IN100 to a 625 nA “sleep” state and reserve the option to instead put it into a 10 nA “disable” state for further power savings.

Assume 50 transmitted events for a 24-hour period. The total charge required for a 24-hour period is found as:

- = 50 TX Events × 361.17 µA-Seconds/TX Event + 0.673 µA × 24 hours
- = 18058 µA-Seconds + 16.15 µA-Hours
- = 5.02 µA-Hours + 16.15 uA-Hours
- = 21.17 µA-Hours

8 Summary

Batteries have been an obvious and convenient solution for powering portable electronics. Globally estimated, nearly *28 billion disposable batteries are disposed of annually*.

With its low 48 nA average operating current, the NMH1000 magnetic sensor adds an insignificant burden to the power budget of portable systems. This reference design demonstrates how the NMH1000 can allow the entire system to reside in low power, sleep, or even lower power disabled states to conserve power to the point where energy harvesting becomes a viable alternative to battery power.

Eliminating the battery from designs is good for our customers, end users and is great for the environment.

9 Appendix A - Illuminance and typical available light levels

Light level or illuminance is the total luminous flux incident on a surface per-unit area. The area, the work plane, is where the most important tasks in the room or space are performed.

Illuminance can be expressed as:

$E = \Phi / A$

Where:

- *E = light intensity, illuminance (lm/m^2, lux)*
- *Φ = luminous flux – the quantity of light emitted by a light source (lumen, lm)*
- *A = area (m^2)*

9.1 Measuring units light level - illuminance

Illuminance is measured in *foot candles (ftcd)* in the Imperial system or *lux* in the metric Si system.

- *one foot candle* = *one lumen* of *light density per square foot*
- *one lux = one lumen per square meter*
- *1 lux = 1 lumen / sq meter = 0.0001 phot = 0.0929 foot candle (ftcd, fcd)*
- *1 phot = 1 lumen / sq centimeter = 10000 lumens / sq meter = 10000 lux*
- *1 foot candle (ftcd, fcd) = 1 lumen / sq ft = 10.752 lux*

9.2 Outdoor light levels

Table 4. Common outdoor light levels at day and night

Condition	Illumination	
	(ftcd)	*(lux)*
Sunlight	10000	107527
Full daylight	1000	10752
Overcast day	100	1075
Dark day	10	107
Twilight	1	10.8
Deep twilight	0.1	1.08
Full moon	0.01	0.108
Quarter moon	0.001	0.0108
Starlight	0.0001	0.0011
Overcast night	0.00001	0.0001

9.3 Indoor light levels

The outdoor light level is approximately *10,000 lux* on a clear day. In a building in an area closest to the windows, the light level can be reduced to approximately *1,000 lux*. In the middle area, it can be as low as *25 lux to 50 lux*. More lighting is often necessary to compensate for low levels.

According to *EN 12464 Light and lighting - Lighting of workplaces - Indoor work places*, the minimum illuminance is 50 lx for walls and 30 lx for ceilings. Earlier it was common with light levels in the range *100 lux to 300 lux* for normal activities. Today the light level is more common in the range *500 lux to 1,000 lux*, depending on activity. For precision and detailed work, the light level may approach *1,500 lux to 2,000 lux*.

Table 5. Recommended light levels for different types of workspaces

Activity	Illuminance *(lx, lumen/m^2)*
Public areas with dark surroundings	20 to 50
Simple orientation for short visits	50 to 100
Areas with traffic and corridors, stairways, escalators, and travelators, lifts, storage spaces	100
Working areas where visual tasks are only occasionally performed	100 to 150
Warehouses, homes, theaters, archives, loading bays	150
Coffee break room, technical facilities, ball-mill areas, pulp plants, waiting rooms	200

Table 5. Recommended light levels for different types of workspaces*...continued*

Activity	Illuminance *(lx, lumen/m^2)*
Easy office work	250
Classrooms	300
Normal office work, PC work, study library, groceries, show rooms, laboratories, check-out areas, kitchens, auditoriums	500
Supermarkets, mechanical workshops, office landscapes	750
Normal drawing work, detailed mechanical workshops, operation theaters	1000
Detailed drawing work, detailed mechanical works, electronic workshops, testing and adjustments	1500 to 2000
Performance of low contrast, small-size visual tasks for prolonged periods of time	2000 to 5000
Performance of prolonged and exacting visual tasks	5000 to 10000
Performance of special visual tasks of low contrast and small size	10000 to 20000

9.4 Calculating illumination

Illumination can be calculated as:

$E = \Phi_l\ C_u\ L_{LF}\ /\ A_l$

Where

- E = *illumination (lux, lumen/m^2)*
- Φ_l = *luminance per lamp (lumen)*
- C_u = *coefficient of utilization*
- L_{LF} = *light loss factor*
- A_l = *area per lamp (m^2)*

9.4.1 Example - Illumination

Ten incandescent lamps of 500 W (10,600 lumens per lamp) are used in an area of *50 m^2*. With $C_u = 0.6$ and $L_{LF} = 0.8$, illumination can be calculated as:

$E = 10\ (10{,}600\ \text{lumens})\ (0.6)\ (0.8)\ /\ (50\ m^2)$

$= \underline{1018}\ \text{lux}$

10 Revision history

Table 6. Revision history

Document ID	Release date	Description
AN14536 v.1.0	29 January 2024	• Initial version

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