Summary

This guide is intended for OEM design engineers who might be considering the implementation of a new ‘Bluetooth Smart’ device, based on the new Bluetooth Low-Energy (LE) technology contained in the latest Bluetooth 4.x specification.

It describes the main elements of the Bluetooth 4.x specification, and outlines the way that Bluetooth LE devices communicate with a master device. It also explains how Bluetooth LE relates to the established Classic Bluetooth technology.

It then discusses the types of functions and applications that are suitable for Bluetooth LE technology.

OEM design engineers with no experience of Bluetooth LE will want to know the best way to implement a design: with a chipset, or with a module? The guide highlights the challenges involved in realising a Bluetooth LE product that is based on a chipset.

It then shows how most of the difficulties are eliminated when the designer uses a properly specified and designed module.

This introduction to Bluetooth LE is intended to help the designer discover whether Bluetooth LE is suitable for their application, and whether a module- or chipset-based architecture is most appropriate.

For detailed help with circuit or software development and with the supply chain and production, readers should contact their local branch of Acal BFi, which can provide access to RF, system-design and logistics specialists. Acal BFi can also supply in volume all component types required to produce a finished Bluetooth LE product.
Terminology

Various terms are used to refer to Bluetooth technology. It is important to be clear about these terms, in order to avoid confusion.

Bluetooth Low Energy (Bluetooth LE), the subject of this guide, is a set of technologies developed by the Bluetooth Special Interest Group (SIG, an industry consortium). Use of Bluetooth LE technologies enables manufacturers to implement devices which consume very little power and which are compatible with other Bluetooth devices.

Bluetooth 4.x (originally Bluetooth 4.0, and updated thereafter) is a Bluetooth SIG specification which defines the operation of both master and slave devices. A device may implement Bluetooth 4.x in single mode (as a Bluetooth LE device) or in dual mode (as a Bluetooth LE and Classic Bluetooth device).

**Bluetooth Smart** is the consumer-facing designation for products using Bluetooth LE technologies. A device using the Bluetooth LE technologies as defined in the Bluetooth 4.x specification, and independently certified as conforming to the specification, may carry the official Bluetooth Smart logo, and be described as a Bluetooth Smart product in marketing material.

**Bluetooth Smart Ready** is the consumer-facing designation for products which conform to the Bluetooth 4.x specification in dual mode, and which may operate as either a Bluetooth Smart or Classic Bluetooth device. Most new smartphones, tablets and laptop computers will carry the Bluetooth Smart Ready logo.

Any Bluetooth Smart device will interoperate with any Bluetooth Smart Ready device.

Many manufacturers which implement Bluetooth Low Energy (Bluetooth LE) technology will certify their product and brand it with the Bluetooth Smart logo. But for some, there will be no benefit to incurring the expense of certifying their product’s conformance to the Bluetooth specification, and their product will not be authorised to carry the Bluetooth Smart logo.

Therefore, to avoid confusion, this guide refers throughout to the low-power version of Bluetooth defined in the Bluetooth 4.x specification as Bluetooth LE.
The engineering world has fallen in love with the concept of the ‘Internet of Things’ (IoT). But the industry is not yet clear about the way in which billions of devices are going to connect to the internet.

The introduction of Bluetooth LE appears to move the world one big step closer to universal internet connectivity. Manufacturers of hundreds of types of devices – sensors, monitors, actuators, switches, lamps, even shoes – for the first time have a realistic means to get data from their device to a master device, and then to the internet.

So what makes Bluetooth LE such an attractive technology for IoT devices, and other short-range wireless products?

The answer is its combination of attributes:

- **simplicity** – the radio is based on the familiar Classic Bluetooth radio, and its simple mode of operation can be managed by a small and simple protocol stack
- **extreme low power consumption** – potentially years of operation on a single primary coin cell (depending on the application and the cell). The radio also draws a low peak current, which also suits operation on a small battery.
- **robust wireless connectivity** – designers can target a line-of-sight range of as much as 100m. A frequency-hopping scheme makes a Bluetooth LE radio highly resistant to interference at its 2.4GHz licence-free band.
- **real-time operation** – a connection between a node and a master device can be made, data transferred and the connection shut down in just 3ms
- **compatibility with billions of host devices** – Bluetooth is by far the best known personal area networking technology in the world, and is backed by all the main manufacturers of consumer devices.
- **ready supply of components from many manufacturers** – Bluetooth LE is an industry-standard technology, so the radio may be supplied by multiple manufacturers. Competition will keep component prices low. While system OEMs using a proprietary radio technology are tied to a single source, users of Bluetooth LE can pick from a large number of reputable suppliers.

No other short-range technology comes close to offering these benefits. OEMs do have other choices of short-range RF technology. ZigBee is an industry-standard radio technology for applications in the home, office or factory, and ZigBee devices from different manufacturers are interoperable. Its flexible mesh networking capability is suitable for complex network architectures. But the sophisticated ZigBee protocol is complex and power-hungry, and requires a large memory footprint. Wi-Fi is popular with consumers and offers very high data rates over a short range, but its high power consumption makes it unsuitable for battery-powered applications.

Many proprietary radio technologies are marketed by various semiconductor manufacturers. Some offer attractive features, such as ultra-low power consumption, extreme immunity to interference or extended range. But no other technology matches Bluetooth LE’s compatibility with millions of phones, tablets, PCs and other devices.

A Bluetooth LE device spends much of the time in a deep sleep mode, drawing almost no energy e.g using a coin cell battery.
To understand the features of Bluetooth LE, it is helpful to study the operation of Classic Bluetooth. Classic Bluetooth is normally used in ‘always on’ mode: a master device – for instance a Bluetooth music player – constantly advertises its presence. When a slave device – for instance a Bluetooth headset – comes into range, a connection is established. This connection remains open, providing an over-the-air ‘pipe’ which may carry a continuous stream of music from the player to the headset.

Classic Bluetooth is therefore inherently power- and resource-hungry: the radio is normally in active rather than stand-by mode, and a complex protocol and modulation scheme are required to support high real data rates of up to 3Mb/s.

Classic Bluetooth, of course, has become a very popular technology for this kind of application. It is widely understood by consumers, and provides for reliable interoperability between any two certified Bluetooth devices.

Bluetooth LE draws on this familiarity with the Bluetooth brand, and on consumers’ acceptance of the Bluetooth pairing process. But its features are the mirror image of Classic Bluetooth:

- A Bluetooth LE device is intended to be (almost) ‘always off’. The radio transmitter is one of the biggest power consumers in a slave device. But because the technology supports lightning-quick connection and short bursts of tiny packets of data, the radio can remain off for most of the time, with the device in deep sleep mode. This capability to provide ‘pulsed’ data transmissions works best when it is used to transmit snippets of data such as ‘the temperature in the refrigerator has risen above 5°C’ or ‘the room is not occupied.’

- A simple protocol supports the basic functions of advertising, connecting, transmitting data and disconnecting. With a tiny memory footprint, the circuitry required to support Bluetooth LE is small and inexpensive.

In fact, every aspect of the Bluetooth LE specification has been optimised for low power and simplicity.

At the same time, it is easy to co-locate Classic Bluetooth and Bluetooth LE in the same device. The features of Classic Bluetooth and Bluetooth LE are both contained in the Bluetooth 4.1 specification (which supersedes the Bluetooth 4.0 specification). A Bluetooth 4.1 device may support Classic Bluetooth, Bluetooth LE or both. A device which supports both Classic Bluetooth and Bluetooth LE is denoted ‘Bluetooth Smart Ready.’

A Bluetooth LE device cannot connect to a device in Classic Bluetooth mode. It can only connect to devices operating in Bluetooth LE mode.
Cleverly, however, the developers of Bluetooth LE re-used much of the existing Classic Bluetooth’s radio physical layer and some of its protocol. For instance, Bluetooth LE uses the same 2.4GHz ISM frequency band as Classic Bluetooth does, and therefore can share the same antenna. But Bluetooth only uses 3 of its 40 channels with 2MHz spacing for advertising (rather than 32 of 79 channels with 1MHz spacing in Classic Bluetooth), which means that its advertising transmissions are much quicker (1.2ms rather than 22.5ms) than Classic Bluetooth’s. This in turn means the radio can spend much longer in deep sleep mode.

Bluetooth LE uses little energy to advertise to master devices. With 37 channels available for data, it can perform frequency-hopping effectively and transmit data extremely fast.

But because Bluetooth LE uses the same frequency and antenna as Classic Bluetooth, manufacturers of Classic Bluetooth chipsets can add support for Bluetooth LE at almost no cost. This is the reason that all new smartphones, tablets and laptops are now shipped as Bluetooth Smart Ready: there is almost no cost to the manufacturer to add this functionality.

This gives makers of Bluetooth LE devices an enormous installed base of master devices in the field to which their slave devices can be paired.

But which devices, and which applications, will be able to take advantage of this capability?
Re-imagining the personal area network

If an application:

- requires the transmission of state or sensor data in intermittent bursts or pulses (and)
- requires operation on a primary coin cell for a period of months or years (and)
- requires interoperability with other manufacturers’ devices, particularly host devices such as smartphones, tablets or laptops

Bluetooth LE is the best technology available today.

As shown above, Bluetooth LE provides an industry-standard alternative to ZigBee that is easier to implement, cheaper and uses far less power. This means that designers may find uses for Bluetooth LE as a ZigBee replacement in home-automation and industrial-automation applications. For instance, an array of temperature/moisture sensors could monitor the state of the soil in a greenhouse, providing data that triggers irrigation and ventilation systems.

Bluetooth LE provides an energy-efficient means for personal activity trackers to send intermittent data packets to a Bluetooth Smart Ready phone or tablet.

Bluetooth LE is also expected to dominate the market for sensor connections in personal area networks.

These might include:

- fitness monitors and heart-rate monitors
- medical and patient monitoring equipment, such as blood-glucose monitors and pulse oximeters
- proximity sensors, for instance in access control systems
- smart watches, serving as an auxiliary display for another device
- smart tags, which alert the owner when they are no longer in proximity to a device

In many of these cases, the function of Bluetooth LE is to transmit data to a smartphone host running a dedicated app. In the case of a blood-glucose monitor, for instance, the app will provide a means to display readings and store data. The phone also provides internet and messaging capability, so that readings can be sent to a physician or hospital when appropriate.

It is already possible to see how such applications will benefit from implementing Bluetooth LE, becoming cheaper, simpler and more energy-efficient.

But system designers will also imagine countless other uses for a low-power, wireless connection to smartphones, tablets and computers. When they do, they will need to work out which is the best way to integrate Bluetooth LE capability into their slave device.

Chipset? Or module?
Manufacturers of Bluetooth LE chipsets provide excellent, highly optimised products. The problem for many OEMs is that they are optimised for one thing: low unit cost. This means that they are not optimised for ease of use, simplicity or integration.

Bluetooth LE chipsets are aimed at high-volume products, for which the production runs are counted in the hundreds of thousands or millions of units. The key design constraint for volume OEMs is bill-of-materials (BoM) cost. They can afford to throw design resources at implementing a system design using low-cost discrete components, including RF chipsets.

Any chipset sourced from a reputable supplier will, of course, be functionally sound, and the unit cost will be competitive.

But a Bluetooth LE implementation with a chipset will present considerable challenges to most electronics OEMs. These challenges fall into the following categories:

- RF system design
- protocol software design
- compliance testing and certification

**RF system design**

A Bluetooth LE chipset will include a 2.4GHz transceiver and a baseband controller. This must be integrated into a system design which can reliably communicate over the required range. Key design tasks will therefore include configuring and placing an antenna, routing of connections to and from the RF sub-system, and designing the board layout. This design must take account of sources of interference, and ensure that the radio's sensitivity is not compromised.

This element of the system design calls for deep RF expertise.
**Protocol software design**

A Bluetooth LE device must run a Bluetooth LE protocol stack, typically on the system’s main microcontroller. Chipset manufacturers normally provide a protocol stack ‘reference design’ free to users: this is not a complete, ready-to-use stack; it should be viewed as a starting point for the user’s own stack design.

Again, stack development calls for specialised embedded software development skills.

**Compliance testing and certification**

All new RF products are required to undergo exhaustive tests to verify:

- that their RF emissions are at permitted frequencies and power levels
- that they do not generate interference outside their permitted frequency bands

Testing carried out by independent laboratories is expensive and time-consuming. Design teams are always exposed to the risk of cost and time overruns should a design not pass its compliance tests first time.

Should the OEM want its device to carry the ‘Bluetooth Smart’ logo, it will also need to undergo independent Bluetooth certification, to verify that it complies with the specifications. Again, it is expensive to design for compliance and to undergo a complete set of Bluetooth Smart certification test.

(It is possible to use Bluetooth LE technology without certification by the Bluetooth industry body. This may be appropriate for products which are not intended to be marketed to third parties as Bluetooth Smart devices. All new RF products are required to gain regulatory approvals relating to RF emissions and EMI compliance.)

As described above, there is a huge opportunity for a diverse range of OEMs to profit from new design ideas, including those which use the smartphone as an app host for a wireless sensor, or for IoT devices using the smartphone as a wireless gateway to the internet.

Most such OEMs are not running high production volumes, and do not have extensive design teams which can be dedicated for long periods to RF system design.

A better way for the majority of OEMs, therefore, is to base a Bluetooth LE design on a Bluetooth LE module.
Reducing design cost, time and risk: the Bluetooth LE module

A Bluetooth LE module eliminates all of the problems associated with implementation of a chipset-based design.

No RF system design is required. All the of RF ciruity, including the antenna, is encapsulated within the module. Integrating the module within a device design is simple, since it only needs a power supply and a UART interface to the microcontroller. There is only RF design constraint: since the module contains the Bluetooth LE antenna, it must not be shielded, so the device’s case should be made of plastic rather than metal.

A module will be supplied with a complete Bluetooth LE protocol stack, which runs on the module’s own microcontroller.

Configuring the stack and the module’s operation is also simple: AT commands familiar to any modem user control all the module’s functions.

Use of a module also eliminates all of the design risk associated with compliance and certification. The module is supplied ‘pre-certified’: as a stand-alone device in its own right, it already has all applicable approvals globally.

Provided the OEM designer follows the module manufacturer’s guidelines in relation to input power, layout and enclosure, the complete end product, with the module embedded in it, is guaranteed to pass all required compliance and certification tests.

OEMs which choose to use a Bluetooth LE module therefore benefit from reduced cost, time and risk:

- while the unit cost of a module is higher than the BoM cost of an equivalent chipset-based (discrete) design, total costs will be lower for OEMs producing in low or medium volumes. This is due to savings in design costs (staff costs and equipment costs), and savings in compliance and certification test costs.

- an OEM can get to market and to revenue far quicker with a module-based design than with a chipset-based design. Design resources which might have been tied up with a generic RF design can instead be dedicated to optimising the core application.

- RF design and protocol stack development are costly and difficult, which means that OEMs are always exposed to the risk of project delays and costly re-working and de-bugging of failing prototypes. By contrast, a module is guaranteed to work properly under all specified conditions.

- in addition, production and assembly is simpler and cheaper when using a module. Only one SKU must be stocked, rather than multiple discrete parts. And a module is supplied pre-trimmed; it can be assembled on to the end product’s board with no additional processes. By contrast, a chipset-based Bluetooth LE design normally requires expensive end-of-line trimming.

These benefits are not only available to OEMs which use a Bluetooth LE module in volume production. OEMs which intend using a chipset-based design in volume production may also choose to base prototypes and early production runs on a module, in order to get to market as fast as possible, while developing a cost-reduced discrete design for a subsequent high-volume production run.

A pre-certified Bluetooth LE module eases the certification process, allowing the host product to carry the Bluetooth Smart logo
New Bluetooth LE designs: support throughout the design/production cycle from Acal BFi

The majority of OEMs will benefit from use of a pre-certified Bluetooth LE module, such as Microchip’s RN4020 (see below). As this guide has explained, it is simple, quick and inexpensive to integrate a Bluetooth LE module into a host device.

For designers implementing their first Bluetooth LE design, however, the detailed operation of the technology will inevitably be unfamiliar. Fortunately, the experts at Acal BFi are available to help.

Customers of Acal BFi, a European distributor of electronics and opto-electronics components and systems, benefit from the knowledge and experience of design support engineers in the specialisms they most need. This includes specialists in RF system design and microcontrollers – key elements of any Bluetooth LE device.

They can help you:

- choose an appropriate module for your application
- map out appropriate functions and specifications for your Bluetooth LE device
- find detailed information about developing Bluetooth LE devices
- follow best practice in RF system design and board layout, and design-for-compliance
- choose and use peripheral components to support your main application

As a components distributor with operations throughout Europe, Acal BFi also offers customers a smooth and effective supply chain, stocking the devices you need – including the RN4020 – for volume production.

OEMs which wish to outsource a complete system or sub-system design can also commission Acal BFi’s system design centre, based in Berlin, Germany, to provide a turnkey design.

For more information about Bluetooth LE and the Microchip RN4020 module, or to discuss your design-support and component requirements, contact your local branch of Acal BFi.

Microchip has a leading position as a manufacturer of short-range RF modules, with products offering Wi-Fi, Classic Bluetooth and other technologies.

Now Microchip has introduced the RN4020, a complete integrated module for Bluetooth LE devices. Housed in an encapsulated 10mm x 17mm x 2mm package, the RN4020 includes a built-in high performance PCB antenna, 2.4GHz Bluetooth LE transceiver, a microcontroller with a complete embedded Bluetooth LE protocol stack and UART interface. It is pre-certified for Bluetooth Smart, and has FCC, CE and ICS approvals.

EVALUATE THE RN4020 WITH A DEDICATED DEVELOPMENT BOARD

The RN4020-PICTail is a development board from Microchip for designers who wish to evaluate the performance of the integrated RN4020 Bluetooth LE module. The board features an RN4020 module with 7dBm of output power, and offers PICTail / PICTail Plus interfaces for easy connection to other Microchip development boards.

It also includes an ultra-low power PIC18F25K50 USB microcontroller on the reverse for stand-alone operation and can be used together with a PICKit serial programmer/debugger interface, to enable designers to get up and running with the board quickly and easily.