**Ultra low power wireless connectivity technology backgrounder**

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**Sections:**
1. The convenience of wireless
2. Use of the 2.4GHz band and avoiding interference
3. Ultra-low power operation
4. Adding a wireless link to portable devices
5. System-on-Chip vs. Single-Chip-Connectivity
6. Beyond the standard

1. The convenience of wireless

If you need two devices to communicate, a wireless link is very convenient. Although wired connections are cheap and reliable, they are prone to wear and damage. And, given the choice, manufacturers would prefer to shy away from adding a connector because it compromises reliability and provides a path for the ingress of moisture and dust to sensitive electronics.

With a wireless connection there are no wires to become tangled and no restraints on where the two devices to be connected are positioned (provided they are within the radio’s operational range, which is typically 10 metres or more for Personal Area Network (PAN) applications).

Moreover, wireless connections allow spontaneity. It’s unlikely, for example, that two users are going to be able to transfer e-business cards from one smart phone to another without wireless technology; it’s impractical to carry the multitude of cables that would be required to ensure your smart phone is going to connect with those from different manufacturers.

Nordic Semiconductor saw the potential for short-range wireless connections over a decade ago. We now predict rapid increases in the applications and growth of wireless technology. Our experience is that consumers don’t like cables and place a lot of value on the added convenience and freedom of wireless products. This is particularly true if the cost of such products is comparable to traditional wired alternatives.

At Nordic we know reliable transmission over the specified range is of the utmost importance when designing a wireless link. We design and manufacture robust wireless links that are as reliable as equivalent wired connections. Our wireless links include features that ensure long battery life, while constantly checking the integrity of the link to offer protection against interference from other radio sources.

Nordic provides RF silicon solutions including:

- Highly integrated RF silicon;
- Sophisticated and flexible development tools;
- Application specific communication software;
- Complete reference designs.

The company’s products feature:

- Class-leading battery lifetimes – Up to years running from regular AA, AAA or coin cell batteries;
• Small size – Ultra compact packaging options that enables miniaturized, ‘wearable’ sensors to be developed;

• Ease-of-use – Works ‘out-of-the-box’ without complex pairing procedures;

• Ease-of-integration – Proven on-chip Nordic Gazell™, ANT™, or Bluetooth® low energy protocols and support for a wide range of application microcontrollers to ease design-in;

• Multi-vendor interoperability – Seamless connectivity to existing ANT+ sensors and hubs, and forthcoming Bluetooth low energy devices;

• Robust wireless connectivity – Excellent co-existence performance with other popular 2.4GHz wireless technologies such as Wi-Fi and Bluetooth;

• Mobile phone connectivity – Seamless connectivity to existing mobile phones with built-in ANT+ support, and forthcoming Bluetooth low energy-enabled handsets;

• Attractive pricing point – Single chip solutions with low cost external Bill-of-Materials (BoM) supporting entry-level product pricing.

Nordic’s product families are aimed at applications in the sports & fitness, gaming, toys, mobile phone peripherals, healthcare, consumer electronics, and industrial & home automation sectors. The nRF24L Series (together with the Nordic Gazell™ protocol stack), for example, is the market leading solution for wireless PC peripherals and is ideal for wireless mice, keyboards, remote controls, trackpads, and presenters.

Nordic chips power the wireless communication of sports watches. (Courtesy: Garmin)

2. Use of the 2.4GHz band and avoiding interference

The unlicensed portions of the electromagnetic (EM) spectrum were originally reserved internationally for non-commercial use for industrial, scientific and medical purposes and are often collectively referred to as the “ISM” band(s). The ISM bands are defined by the ITU-Radiocommunications Bureau (ITU-R) in sections 5.138 and 5.150 of the Radio Regulations.

Some of these bands are: 433.05-434.79MHz (centre frequency 433.92MHz, typically called “433MHz”), 902-928MHz (centre frequency 915MHz, “915MHz”), 2.4-2.5GHz (centre frequency 2.45 GHz, “2.4GHz”) and 5.725-5.875 GHz (centre frequency 5.800GHz, “5.8GHz”). There are many others, including for example a band centred on 868MHz.
It is important to note (in the words of the ITU-R) that: “the use of these frequency bands for ISM applications is subject to special authorisation by the local administration, in agreement with other administrations whose radiocommunication services might be affected”. In other words, some countries may ban the use of certain allocated ISM bands on their territory.

This creates regional variation. For example, the 433 and 868MHz bands are popular in Europe, 433MHz is common in Japan, while 915MHz is only available for unlicensed use in the US, Australia and Israel. In contrast, the 2.4GHz band is accepted virtually globally. This universal acceptance of 2.4GHz has not escaped manufacturers looking to export their products worldwide, and Nordic is no exception. While the company has manufactured 433 and 915MHz products for many years it now focuses its wireless development efforts on 2.4GHz products.

It’s also no coincidence that IEEE.802.xx international standards such as Wi-Fi®, Bluetooth wireless technology and ZigBee® employ the 2.4GHz band (as well as 868 and 915MHz for regional variants), along with proprietary forms or wireless Ethernet or USB.

As more and more companies produce products that use this portion of the radio spectrum, designers have to deal with the possibility of interference from radio signals from other sources. In fact, regulations governing the ISM parts of the spectrum state “a device must expect interference”.

Some argue that it makes more sense to manufacture products specifically for the relatively radio traffic-free local ISM bands such as 434, 868 and 915MHz. But while these bands do currently experience less radio traffic than 2.4GHz, Nordic predicts that in time they too will be subject to increased usage and designers will be forced to employ the interference management technologies similar to those that have already been developed for the 2.4GHz band.

So, how do we get best performance out of our 2.4GHz products under hostile interference operating conditions? It should be noted that although existing standards such as Wi-Fi, Bluetooth wireless technology and ZigBee include provision for interference management, there is little that can be done beyond what the architects of the standard have provided. In contrast, Nordic Semiconductor’s proprietary products hands control of the protocol to the designer, allowing the introduction of optimised procedures to minimise interference from other sources. Alternatively, Nordic can supply Gazell, an advanced RF protocol that incorporates a sophisticated frequency agility technology.

There are three basic techniques for minimising the impact of interference for devices operating in the 2.4GHz band. These are Time Domain Multiple Access (TDMA), Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS).

TDMA works by subdividing a 1 MHz allocation within the band into a number of timeslots allowing several users to share the same single frequency without danger of clashing. Each transceiver waits for its own timeslot before transmitting, thus avoiding interference. DSSS and FHSS both rely on modulation of the carrier signal. In addition, FHSS allocates a number of channels within the band, the exact width of which depends on the technology (see below).

In simple terms, DSSS transmissions multiply the data being transmitted by a “noise” component. This noise signal is a pseudorandom sequence at a frequency much higher than that of the original 2.4GHz signal, thereby spreading the energy of the original signal across a much wider band. The noise is filtered out at the receiving end to recover the original data, by again multiplying the same pseudorandom sequence by the received signal.

For de-spreading to work correctly, transmit and receive sequences must be synchronised. This requires the receiver to synchronise its sequence with the transmitter’s sequence via some sort of timing search process. DSSS operates at the cost of transmitting excessive data packets, incurring bandwidth usage and current consumption overheads.
Using FHSS, a wireless technology transmits on a clear channel until it experiences interference (resulting in lost packets), whereby it relocates to an alternative clear channel. Alternatively, the transmitter can periodically, pseudo-randomly retune to a different channel to minimise the possibility of encountering interference on a particular channel.

**Bluetooth** wireless technology uses FHSS in conjunction with a technique called Gaussian Frequency Shift Keying (GFSK). GFSK applies Gaussian filtering to the modulated baseband signal before it is applied to the carrier. This results in a “dampened” or gentler frequency swing between the high (“1”) and low (“0”) levels. The result is a narrower and “cleaner” spectrum for the transmitted signal compared with the straightforward approach of FSK (Frequency Shift Keying).

**Bluetooth** wireless technology’s frequency hopping scheme splits the 2.4GHz ISM band into 79 x 1MHz channels (with a 1MHz guard channel at the lower end of the band and a 2MHz guard channel at the higher end). Transmitting and receiving Bluetooth wireless technology devices then hop between the 79 channels 1600 times per second in a pseudo-random pattern. From Bluetooth Version 1.2 on, the technology uses a revised form of frequency hopping dubbed adaptive frequency hopping (AFH). This algorithm allows Bluetooth wireless technology devices to mark channels as good, bad, or unknown. Bad channels in the frequency-hopping pattern are then replaced with good channels via a look-up table.

**Bluetooth** low energy (a hallmark feature of the latest version of Bluetooth v4.0) uses a similar scheme to conventional Bluetooth technology, but employs only 37 channels and a Gaussian Minimum Shift Keying (GMSK) scheme to save power.

In its 2.4GHz variant, ZigBee uses 16 channels at 5 MHz spacing; each channel occupies 3MHz, giving a 2MHz gap between pairs of channels. ZigBee then uses a simple DSSS scheme for data transmission.

Each of the 2.4GHz wireless technologies has made design tradeoffs to mitigate the effects of interference. However, designers that aren’t constrained by the standard protocols are free to develop their own collision avoidance scheme so long as it complies with the relevant country’s regulations. For this reason, Nordic Semiconductor’s transceivers are available without protocols to allow designers to develop their own RF protocol optimised depending on the bandwidth and power consumption constraints of their application.

Alternatively, Nordic has developed Gazell, an RF protocol designed for efficiency, low power consumption and minimum latency. Gazell incorporates frequency agility technology; this employs a simplified frequency hopping scheme where the transmitting and receiving pair establish communication on a particular frequency and then only hop to a different frequency should interference be experienced. The channel on which the interference was experienced is marked and not reused during that particular communication cycle.

Devices such as Nordic’s nRF24AP2 - used in very low duty cycle applications such as sports-based heart rate monitoring and wireless transmission to a watch-based recorder – employ a proprietary form of TDMA developed by Nordic’s design partner ANT. The nRF24AP2’s TDMA-like collision avoidance approach relies on each transceiver transmitting in a clear timeslot. If there are a number of discrete systems working side-by-side – such as a row of rowing machines all lined up next to each other in a gym – then by “listening” for drifting transmission sources on its frequency the wireless node can determine if there is approaching interference and adapt its transmissions accordingly.
highly specialised powered wireless device is therefore typically measured in days, or weeks at most. (Note: There are some transfer of stored digital images typically used for short burst of intense activity and when frequent battery charging is not too inconvenient. Bluetooth typically finds use for wirelessly connecting a mobile phone to a headset or the transfer of stored digital images from a camera to a Bluetooth-enabled printer. Battery life in a Bluetooth-powered wireless device is therefore typically measured in days, or weeks at most. (Note: There are some highly specialised Bluetooth applications that can run on lower capacity primary batteries.)
Because ULP RF transceivers draw on such modest power reserves they are not capable of high duty cycle applications and therefore don’t generally compete directly with Wi-Fi and Bluetooth wireless technology. (However, note that there is some overlap and a ULP RF transceiver can be a better choice than these alternatives for some applications even if larger (AAA or AA) batteries are used as the power source.)

However, Nordic’s ULP RF transceivers can run from coin cell batteries (such as a CR2032 or CR2025) for periods of months or even years (depending on the application duty cycle). These coin cell batteries are compact and inexpensive, but have limited energy capacity, typically in the range of 90 to 240mAh (compared to, for example, an AA cell which has 10 to 12x that capacity) - assuming a nominal average current drain of just 200µA.

![Coin cell battery](image)

The CR2032 coin cell is a common battery choice for ultra-low power wireless sensors

A 240mAh CR2032 coin cell can sustain a maximum nominal current (or discharge rate) of just 27µA if it’s to last for at least a year (220mAh/(24hr x 365days)). A silicon radio featuring peak currents of tens of milliamps can transmit or receive for no more than about 0.25 percent of the time – quickly reverting to a sleep mode, drawing just nanoamps - if the average current is to be kept to just a few tens of microamps.

In practice the situation is even more complicated, because the peak currents typical of some so-called ultra-low power transceivers can compromise the nominal battery capacity detailed in the data sheet. This effect is referred to as battery (capacity) degradation and happens because the internal resistance of the battery increases as its energy is drained. The higher the internal resistance, the higher the risk that the battery will be unable to supply the minimum voltage required by the RF circuit during peak current transients (due to Ohms’ Law) even though it may still retain significant capacity.

Nordic’s ULP wireless technology reduces power consumption by keeping peak currents low and minimising the time the radio has to spend transmitting or receiving. (Nordic’s ULP Systems-on-Chip (SoCs), for example, feature peak transmit and receive currents of around 13mA.) By ensuring the transceiver can locate the target receiver rapidly, maximising the packet payload (i.e. ensuring it carries a lot of useful data), increasing bandwidth (so that a lot of packets can be sent per unit time), reducing peak current and facilitating a graceful and rapid disconnection, a Nordic 2.4GHz transceiver minimises its time in a relatively high power transmission mode and extends battery life.

In contrast, Bluetooth wireless technology’s relatively inefficient protocol (because the packet structure includes comprehensive access codes and headers to ensure interoperability, reducing the amount of actual information each packet can carry) and connection strategy demands longer transmission times. This is because Bluetooth wireless technology was designed to allow users to connect several devices from different manufacturers into a piconet. In such a piconet (which can comprise up to 8 devices) each device is assigned a 48-bit identity number. The first device identified (usually within 2 seconds) becomes the master, and sets the 1600 frequencies to be used each second across the 2.4GHz band. All other devices in the piconet “lock” or synchronise to this sequence. The master transmits in even slots, the slave responds in odd slots. Active slave devices in the piconet are assigned an address, and listen for slots addressed to them.

The system works well in applications like this for which it was designed, but in addition to needing lots of access code and header information it does mean the Bluetooth devices must constantly transmit to avoid re-linking delays by sending a 160-bit packet every 625µs (1600 packets/s, or a net data rate of 256kbps) to
maintain the link, whether it’s transmitting useful data or not. Consequently a Bluetooth chip continues to run at 8mA even in “idle” mode. While Bluetooth wireless technology does allow chips to enter a “sleep” mode to save power, it can take up to 3 seconds for the link to be re-established – which is a level of “unresponsiveness” that many users find frustrating.

(Note that the Bluetooth low energy, a hallmark element of Bluetooth v4.0 is an ultra low power form of the technology. Nordic manufactures chips that operate using the Bluetooth low energy. For more information please see Nordic’s “Bluetooth low energy wireless technology technical backgrounder”.)

ZigBee, designed from the outset for low power operation uses a different connection scheme whereby transceivers wake up at preset intervals to detect communication from “beacons”. This allows the transceivers to spend most of their time in a ULP sleep mode. However, ZigBee features a bandwidth of 250 kbps; compared to Nordic’s chips which have bandwiths up to 2 Mbps, ZigBee has to transmit for eight times as long to send the same amount of useful information, sapping battery capacity.

Nordic’s nRF24LE1 features a bandwidth of 2 Mbps

It doesn’t take much thought to realise that many wireless applications only need point-to-point communications rather than a piconet. Nordic Semiconductor’s transceivers use a different technique because they don’t need to adhere to the Bluetooth wireless technology standard’s requirement to support a piconet (that doesn’t mean they can’t be used to form networks – Nordic’s ANT chips can be networked together in several simple network topologies).

Let’s look at an example of an application of one of our products to illustrate the point. Nordic Semiconductor’s nRF24Z1 audio streamer is designed with a maximum bandwidth of 4 Mbps to transmit native CD-quality sound (i.e. without compression) across a wireless link.

Because this is a dedicated point-to-point application the transmitter and receiver are “paired” because there is no requirement to communicate with another device. When transmitting, the transceiver remains at a given carrier frequency for 2.9ms. During this time interval audio and control information is sent to the receiving end of the link, any lost audio content is retransmitted, and acknowledgement and control information is received from the receiver. The system then hops to a different frequency and repeats the process.

When there is no content to be streamed, the chip can enter various sleep modes. In the “deep sleep” mode the radio is shut down almost completely – aside from a tiny 5-µA current used to retain memory content. In a “lighter” sleep mode the radio is woken at regular intervals to look for a counterpart but the power consumption still remains at only a few milliamps.

When the transmitting end of the link and receiver are turned on the devices are able to locate one another (typically within 10 ms) by means of an on-chip frequency-scanning algorithm. There is no need for a power-sapping synchronisation technique. When waking from sleep, the wakeup time can be set from fractions of a second upwards, with the tradeoff that the lower the idle power consumption, the longer the response time (but nothing like the several second delay it takes Bluetooth wireless technology to re-link). Depending on the
chosen sleep mode, the user will perceive or experience almost instantaneous music whether waking the transceivers from sleep or simply turning them on.

4. Adding a wireless link to portable devices

Many designers are wary of adding wireless functionality because they perceive it to be complex. After all, silicon radios feature RF, analogue and digital functions and are complicated products. However, most silicon radio vendors have produced integrated transceivers, software and development kits that make the process somewhat easier. But it’s still not just a case of dropping a chipset onto the PCB though; the designer has to be aware of the issues that will affect the performance of the design.

“Over-designing” costs money and battery power, and adds complexity. For example, most portable wireless links only need to operate over a few metres, so it is unwise to use a chip that can operate at up to tens of metres as that increases cost and power consumption. It also pays to accurately determine the bandwidth requirements – if bandwidth isn’t needed, it shouldn’t be specified.

Designers should also be encouraged to consider the level of support they will get from the supplier. They may need help with testing or antenna positioning, for example. Or if the PCB layout isn’t optimised from an RF perspective, the radio may be more prone to interference. If the customer is buying from a distributor they should make sure they understand silicon radios – there’s much more to it than just selling a chipset. Nordic prides itself on customer technical support. The company employs many field applications engineers who are expert in RF design and its practical application.

Power is a (if not the) major issue in portable design. In a portable (thus battery driven) device the designer will always have work within the constraints of a modest power budget. If the product features a powerful microprocessor and a backlit screen, for instance, then 50-60 percent of the battery power has already been allocated. Yet consumers want cell phones and mp3 players with batteries that last for as long as possible and today that means at least tens of hours on a single charge. To achieve this the radio has to be very efficient.

The designer has to work within the constraints of a modest power budget when designing portable devices. (Courtesy: Suunto)

This is one of the reasons why Bluetooth radios are really only suitable for low-to-medium duty cycle applications. Used in a wireless audio streaming application, for example, a Bluetooth radio will exhaust batteries in just a few hours. ZigBee has addressed this to an extent by limiting the synchronisation requirement but features limited bandwidth and is not really suitable – nor was it every really designed – for consumer devices. (ZigBee’s focus has always been industrial and home automation-type applications.)
contrast, Nordic’s chips have been specifically designed to run at ultra-low power and typically exhibit twice the battery life compared with Bluetooth wireless technology in an identical application, but with the same bandwidth and range. Nordic’s chips also outperform ZigBee on power consumption while offering superior bandwidth and a lower price.

Finally, designers are under a lot of pressure to shrink the electronics to fit the compact profile demanded by consumers of mobile devices. That means that there just isn’t the space to add big transceivers and peripheral components onto an already crowded PCB. While most silicon radio vendors have done a pretty good job of integration, the chips tend to demand some form of supervisory microcontroller and an array of support components. Nordic offers variants with on-board microcontrollers.

Nordic has specialised in meeting the critical challenges for portable equipment designers looking to add a wireless link to their products. The transceivers are integrated and compact, relatively simple to design-in, use an efficient protocol, offer bandwidths of 1, 2 or even 4Mbps, are extremely power frugal and feature adaptive frequency hopping. Devices equipped with Nordic chips can also be networked and our chips are very keenly priced.

5. System-on-Chip vs Single-Chip-Connectivity

ULP wireless has already made inroads into the sports, health, entertainment, computing, remote control, gaming, cell phone accessories, home automation and industrial control sectors, and will spread to many others in the coming years.

These diverse applications do have one thing in common that plays to the strength of ULP wireless technology – they’re based on compact sensors and peripherals with small batteries. These devices send small quantities of data (typically a few bits) infrequently (i.e. once every few seconds to a few times per second at most). Despite this commonality, applications as diverse as a wireless PC peripheral (for example, a wireless mouse), a bike computer and associated performance sensors (such as a speed & distance monitor), an RF remote control and a medical sensor (such as a heart rate monitor) demand very different types of silicon.

In the simplest terms, wireless connectivity requires a radio (the transceiver), a protocol (the software code that controls how the radio communicates) and an application processor (with its own code, that controls the specific application, such as a heart rate monitor). But how these elements are implemented affects the efficiency, size and cost of the wireless system.

A wireless mouse is a relatively simple (but certainly not trivial), high-volume ULP RF application. Wireless mouse manufacturers demand a compact, efficient and inexpensive connectivity solution. In other words, they want their wireless mouse to be sleek, feature long battery life and retail at a price that large numbers of consumers can afford.

This best alternative for this application is a System-on-Chip (SoC) comprising radio, a factory-supplied protocol and application processor on a single slice of silicon. The high volumes offset the vendor’s higher non-recurring engineering (NRE) costs of developing a SoC and the maker can tailor the hardware and software performance to perfectly meet the demands of the target application. In addition, the mouse maker does not have to spend development time and effort generating code to run on the external application processor (which typically requires its own development kit).

Nordic, for example, supplies its SoCs to the desktop peripherals market. The devices include 2.4 GHz radios, powerful microcontrollers, Flash memory, application software and RF protocol software. These single chip devices measure just 5 by 5mm - allowing it to fit into even the smallest of wireless mice designs.

SoCs, however, do have some downsides. For example, because the wireless chip manufacturer often doesn’t know the target application to which the chip will be put, the maker is forced to integrate many functions onto the SoC to make sure it can cope with all potential applications. This introduces a trade-off; for while the resulting device is satisfactory, it is not optimised for any single application and carries additional overhead compromising performance (for example, latency or power consumption).
In addition, the high level of integration required for a SoC increases the part’s size and therefore its cost. Finally, there are many applications that already employ a microcontroller or processor to run other functions that could also be used to control the wireless application – and no one wants to pay for an integrated microcontroller on the SoC that they’re not going to use.

Many OEMs prefer to add their own code required to look after the wireless application to the existing microcontroller’s software. In this case, because the target application already features its own application processor, the OEM has typically already invested in development expertise and hardware so there is little additional cost in producing this extra code.

So what’s the alternative to a SoC? To answer that question, the example of a wireless bike computer. Professional and amateur cyclists alike use these handlebar-mounted devices to monitor performance sensors such as heart rate monitors, speed & distance pods, cadence monitors and crank power meters. The bike computer is a sophisticated device that has its own processor that can also be used to supervise the wireless function so there is no need for the wireless chip to integrate an embedded processor.

![Image of a cyclist with a wireless bike computer](image)

*Professional and amateur cyclists alike use Nordic ULP wireless technology to monitor performance (Courtesy: Suunto)*

The devices used by the wireless sensors and bike computers preferred by the professionals come from Nordic’s ANT chip product range. The devices feature a 2.4GHz ULP transceiver, ANT wireless protocol and high-quality microcontroller/processor interface in a single chip. There is no application processor on the chip - saving cost, reducing power consumption and shrinking chip size. In use, the device looks after the wireless connectivity and links seamlessly to the application processor in the bike computer that supervises the wireless application. Nordic refers to this approach as “Single-Chip-Connectivity” as it precisely describes the functionality offered.

(Note that Nordic also offers ANT SoCs that incorporate a powerful microcontroller.)

6. Beyond the standard
Bluetooth wireless technology and ZigBee demonstrate how the electronics community can collaborate to create operating standards that ensure compatibility across global markets. Both are excellent technologies that work well in the defined sectors for which each was originally designed. You only have to attach a Bluetooth headset to your mobile phone to experience this very practical RF technique in action and to appreciate its benefits. But if a manufacturer is making both ends of the link – and particularly if the link operates with a high duty cycle – for example an mp3 player streaming wireless audio to a pair of wireless headphones or a wireless mouse communicating with a PC, transceivers using proprietary technology are an extremely viable alternative worthy of further investigation.

Technology based on standards does have its disadvantages. First, competitors have easy access to the same technology, making it difficult to differentiate the product in a fiercely competitive global market. Second, to employ the standard you have to meet the standard – and that commits the designer to costly non-recurring engineering (NRE) charges in initial design and testing for interoperability. Finally, by their very nature, standards have to be a “one-size-fits-all” solution offering little opportunity for design flexibility. For example, there are limits to how much the power consumption can be reduced and bandwidth boosted in an RF product.

Engineers do select Bluetooth wireless technology because of its high market profile and somewhat hyped reputation. However, for products that demand long battery life, and reliable wireless communications with low duty cycles, proprietary transceivers are an alternative solution. There are scores of applications where these design criteria apply. Examples include wireless games controllers and wireless communication between a heart rate sensor and sports “computer”.

DOCUMENT ENDS

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