

Ericsson's Bluetooth modules

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In just over a year, more than 1,600 companies have adopted Bluetooth, making it one of the fastest growing technologies ever. By 2002, it is estimated that more than 100 million mobile phones, computers and other types of electronic equipment will incorporate this technology. Bluetooth, which is a short-range radio communication link developed and introduced by Ericsson, is currently in the process of becoming an accepted world standard.

The authors describe various technical constraints and considerations associated with the development of Ericsson's Bluetooth modules. When these modules are used together with the accompanying OS-independent software stack, customers can focus their R&D resources on developing specific hardware and software for their Bluetooth applications. The authors also discuss the main issues that developers need to consider when designing Bluetooth-enabled equipment.

TRADEMARKS

Bluetooth™ is a trademark owned by Telefonaktiebolaget LM Ericsson, Sweden.

Background

In 1994, Ericsson Mobile Communications launched an initiative to study low-power, low-cost radio interfaces between mobile phones and their accessories. A radio-access solution was sought because it would eliminate the need for cables and overcome line-of-sight restrictions. It was also recognized that a low-cost solution would usher in wireless connectivity for a multitude of new ap-

plications and give rise to a host of associated components and devices.

For more than ten years, Ericsson Micro-electronic has been involved in the research and development of semiconductor and packaging technologies for wireless applications. Capitalizing on this experience, Ericsson's engineers have realized a truly low-cost, high-density solution—Bluetooth.

Industry-wide commitment

Bluetooth was envisioned to be an open, global standard. To achieve a critical mass and to promote a joint worldwide standard, Ericsson approached IBM, Intel, Nokia and Toshiba with its concept. In May 1998, the Bluetooth Special Interest Group (SIG) was announced, and within 18 months more than 1,600 companies had signed the Bluetooth Adopters Agreement. Today, based on massive global interest and support for the technology, analysts are predicting that by 2002 over 100 million mobile phones, computers and other electronic devices will incorporate Bluetooth technology. Bluetooth specifications are issued under the authority of the Bluetooth SIG.

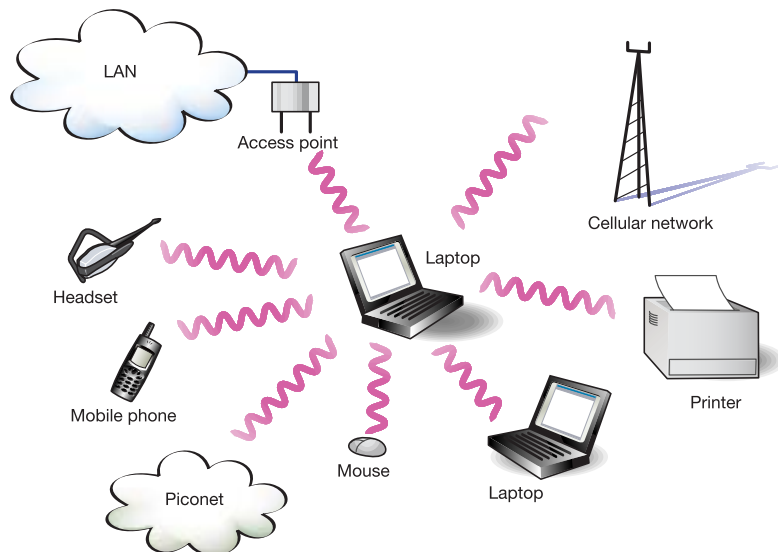
Universally recognized technology

Each Bluetooth unit has a unique identity. Equipment enabled with Bluetooth technology automatically searches the vicinity for other Bluetooth-compliant equipment. On contact, information is exchanged allowing the systems to determine whether or not to establish a connection. At this first encounter, the Bluetooth devices transmit a personal identification number (PIN). After that, no further identification process is necessary. Up to eight devices can operate at the same time in a Bluetooth cell. Moreover, each Bluetooth device can be active in several cells at the same time.

Basic operation

To minimize the risk of disturbance from other radio devices, such as microwave ovens, garage door openers, and so on, a frequency-hop scheme causes the system to switch 1,600 times per second through 80 channels. This means that if one frequency channel is blocked, the disturbance to Bluetooth communications will be limited. It also means that several Bluetooth networks can run concurrently without disturbing one another. First-generation Bluetooth-enabled equipment can exchange information at a rate of 1 Mbit/s at a range of up to

Figure 1
User model with local wireless connectivity. Applications envisioned for the near future.



10 meters. Also, because Bluetooth operates in the global industrial-scientific-medical (ISM) band at frequencies between 2.4 and 2.5 GHz, it has the potential to become a universally recognized standard.¹

Market confidence

Having convinced both the telecommunications industry and the wider electronics industry of the viability of the Bluetooth concept, it has been recognized that products based on Bluetooth technology must be developed, demonstrated and delivered quickly in order to maintain the interest and confidence of these market sectors.

The first goal—to produce actual product demonstrators—has already been achieved. Through enormous efforts of many diverse groups of design and development engineers, Ericsson has been first to successfully demonstrate Bluetooth compliance in real telecommunication products at recent trade shows. With market confidence in the technology established, efforts are now being focused on Bluetooth products and product support for the two major markets—that is, for

- applications within telecommunications; and
- applications within PCs and other electronic equipment.

Bluetooth-enabled products from Ericsson

Within Ericsson, more than twenty separate projects for “Bluetooth-enabled” products are currently under way. These projects, which cover a wide spectrum of applications, are being coordinated through the Ericsson Bluetooth technology council—to ensure that common Bluetooth features and key support activities are properly controlled, and that effective use of resources is maintained. Within these Ericsson products, the Bluetooth function can be integrated into the application to achieve maximum system optimization.

At Mobile Focus and COMDEX/Fall’99, in Las Vegas, USA, Ericsson unveiled the Bluetooth Headset, a practical headset that connects to a mobile phone by a radio link instead of a cable. This is the first hands-free accessory to incorporate Bluetooth technology. The Bluetooth Headset will be available on the market in mid-2000.

The Bluetooth Headset is a lightweight, wireless mobile phone headset with a built-in Bluetooth radio chip that functions as a connector between the headset and a Blue-

BOX A, ABBREVIATIONS

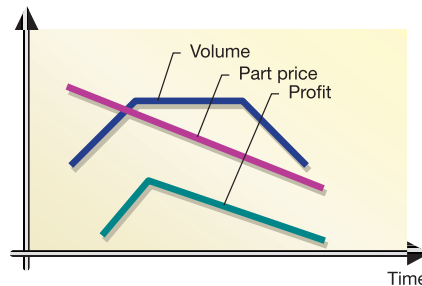
ANSI	American National Standards Institute	LTCC	Low-temperature, co-fired, ceramic
API	Application program interface	OS	Operating system
ASIC	Application specific integrated circuit	PCM	Pulse code modulation
BGA	Ball grid array	PIN	Personal identification number
CMOS	Complementary metal-oxide semiconductor	PSTN	Public switched telephone network
EMC	Electromagnetic compatibility	RF	Radio frequency
ETSI	European Telecommunications Standards Institute	RFCOMM	Serial Port Emulation based on ETSI TS07.10
FCC	Federal Communications Commission	RX	Receiver
HCI	Host Controller Interface	SDP	Service discovery protocol
IC	Integrated circuit	SIG	Special interest group
IrDA	Infrared Data Association	TX	Transmitter
		UART	Universal asynchronous receiver and transmitter
		USB	Universal serial bus
		VCO	Voltage-controlled oscillator

tooth plug on the Ericsson phone. To answer or initiate a call (using a voice-recognition-capable phone, such as the T28, T28 World or R320), the user presses a key on the headset. Because the Bluetooth radio link covers distances of up to 10 meters, the phone can be left in the user’s briefcase, a coat pocket, or even in another room. Weighing a mere 20 grams, the Bluetooth Headset sits comfortably on either ear.



Figure 2
Ericsson’s Bluetooth Headset is the first hands-free accessory to incorporate Bluetooth technology.

Figure 3
A typical product cycle.



Bluetooth products and product support for developers

As already stated, in order for Bluetooth to become accepted, many telecommunications, PC, and other electronic system developers must adopt the technology within their products. In terms of Bluetooth integration, these developers range from the very sophisticated to the complete novice. Accordingly, Ericsson has developed a multi-track strategy that addresses the needs of diverse customers. Ericsson offers a Bluetooth Starter Kit and a complete Bluetooth Developer Kit for Bluetooth evaluation. Finally, to support the software stack, Ericsson has partnered with Symbionics.

Bluetooth partitioning

The simplest solution for most developers is to buy a complete Bluetooth module from Ericsson. The module includes radio frequency (RF) and baseband circuits, FLASH memory, and the associated software stack. However, if developers want to integrate the Bluetooth baseband (EBC) themselves, they need only buy a Bluetooth RF module, which is designed to be compliant to the Bluetooth RF interface specification. Before undertaking their own integration, developers should carefully consider time to market, product cycles, and profitability.

Microelectronics for Bluetooth

The Bluetooth module development roadmap is closely associated with the ASIC development roadmap. On first-generation Bluetooth modules, the RF ASIC has been designed on biCMOS technology; the baseband ASIC has been designed on complementary metal-oxide semiconductor

(CMOS) technology. The general trend followed by ASIC silicon technologies is toward processes with smaller geometries and lower supply voltages. Apart from reducing cost per function, this approach also permits greater levels of integration. However, although many future-generation products will benefit from the implementation of single-chip modules, there will continue to be applications in which the optimum level of integration employs a two-chip solution.

Optimum levels of ASIC and module integration

Several factors that could influence decisions concerning the optimum level of integration are:

- circuit compatibility—digital and RF circuits do not mix well;
- functional stability—future products may require baseband ASIC migration to accommodate additional functionality or to take advantage of a less expensive process while the RF interface remains stable; and
- cost—depending on the choice of technology, a multi-chip solution might cost less than a single-chip solution.

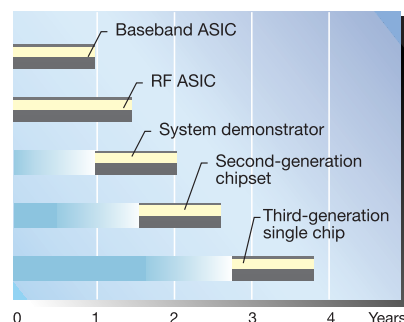
Product cycle and profitability

Sales volumes grow for a short period after a new product has been introduced. This introductory period is followed by a long period during which sales volumes remain stable. Finally, sales volumes decline as market demand decays, or the product is superseded or becomes obsolete (Figure 3).

Initial production volumes do not begin to generate profits until development costs have been recovered. Once this milestone has been passed, profit per unit increases, due to improvements in production and yield. In time, however, profit per unit declines, due to price erosion and increased competition.

The key point to be made is that the end of the product cycle should be thought of as being fixed in time. Consequently, any delay in delivering volumes to the market will result in loss of profit during the most profitable phase of the product cycle. Figure 4 shows typical time scales for the development from scratch of a family of ASIC chipsets. The first-generation product takes approximately two years to develop. Each subsequent generation takes about one year to develop. The ASIC development cycles are on the critical path for product development.

Figure 4
Typical time scale for developing a family of ASIC chipsets from scratch. The first-generation end product takes approximately two years to develop. Each subsequent generation takes about one year to develop.



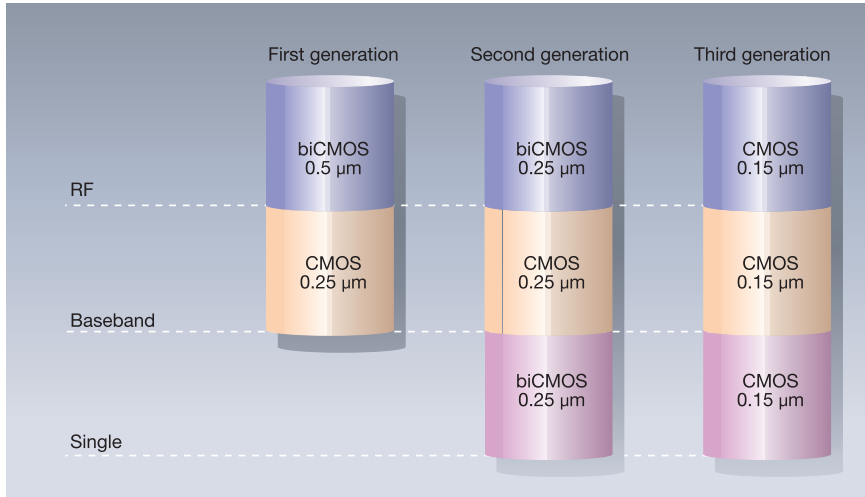


Figure 5
Typical technology roadmap.

ASIC technology and chipset roadmaps

Figure 5 shows the ASIC technology roadmap for Bluetooth ASICs. Where RF chips are concerned, the commercial availability of the manufacturing process determines which ASIC technology is used for each generation. Because digital CMOS technology is nearly always more advanced, each generation of baseband ASICs can generally be designed on smaller geometries. However,

for second-generation products, the baseband ASIC design remains on the 0.25 micrometer technology node, to accommodate the option of merging the baseband ASIC with the RF ASIC on a biCMOS single-chip solution. All third-generation ASICs are based on 0.15 micrometer CMOS technology. In this case, the main reason to maintain a separate RF ASIC is to accommodate developers who only require the RF module.

Figure 6 shows the equivalent chipset roadmap. The third-generation ASICs have

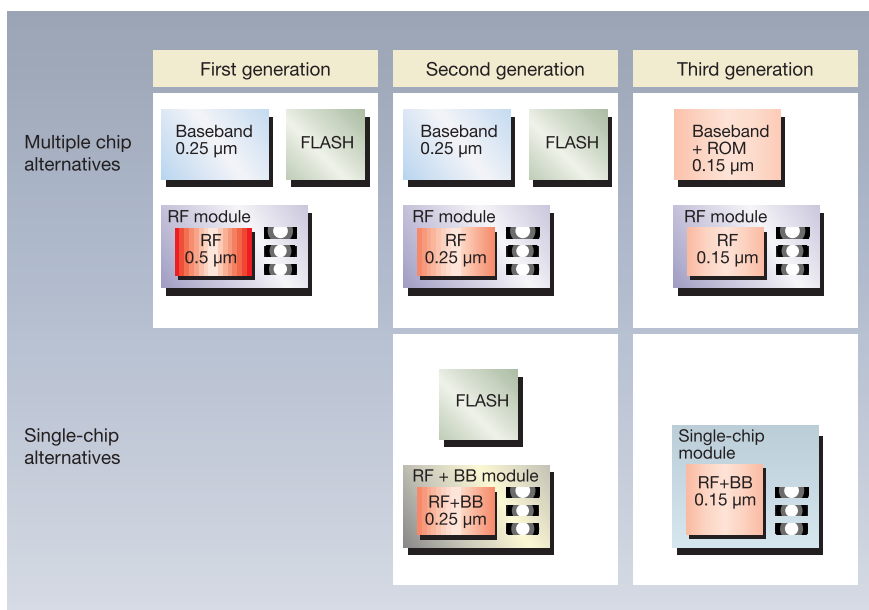
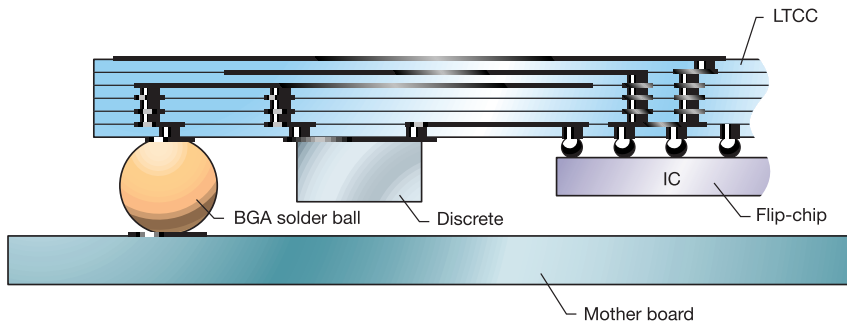


Figure 6
Typical chipset roadmap.

Figure 7
Illustrated profile of the Bluetooth radio module from Ericsson Microelectronics (height: 1.66 mm; width: 10.2 mm; depth: 14.0 mm).



absorbed the external FLASH memory of previous generations. This cannot be done until the product functionality is known to be stable.

Packaging

Recent developments in flip-chip and module technologies can greatly benefit the control and minimization of circuit parasitics, reduce overall costs, and introduce less stringent requirements regarding the placement of ASIC bonding pads.

RF module design

The radio transceiver function consists of an RF integrated circuit (IC) and some 50 dis-

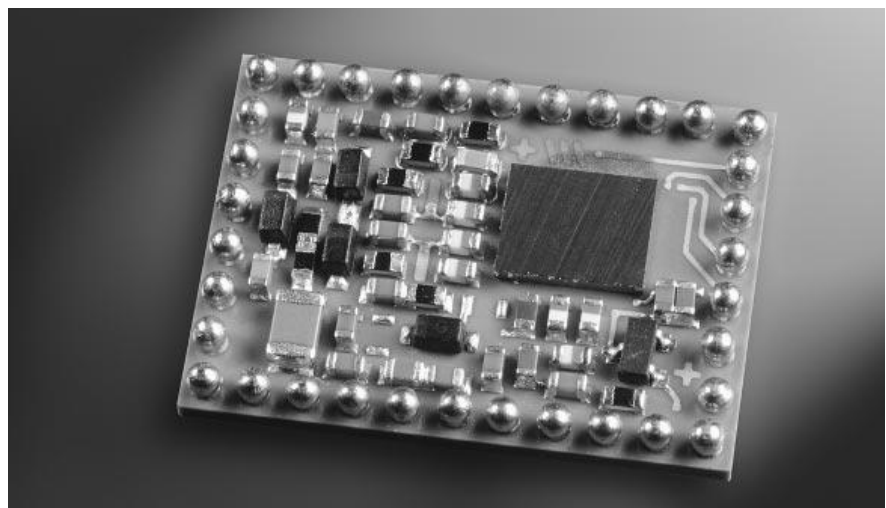
crete components that have been integrated into a single module (Figures 7 and 8).

Important factors that affect the selection of technology and design are:

- small dimensions, including a maximum height of 1.6 mm;
- low cost and ability to manufacture large volumes; and
- a reusable module that can be included in numerous applications.

The decision to package the function as a single-surface mountable device was made very early. The size requirements of the RF IC led developers to choose a flip-chip assembly process. This technology, which has been in use for 25 years, is considered the

Figure 8
Photograph of the Bluetooth radio module.



ultimate assembly and interconnect solution. Until recently, however, it was an exclusive and costly technology that could be handled by only a few companies.

The small size, and requirements for flip-chip compatibility and high-frequency performance and mechanical properties led developers to select low-temperature, co-fired, ceramic (LTCC) substrates. This decision was based on the availability and maturity of the LTCC technology, vendor compatibility, and the promise of denser integration in the future.

The LTCC technique allows engineers to integrate microwave structures for the antenna filter and the receiver (RX) and transmitter (TX) baluns in the substrate. Laser trimming of the critical voltage-controlled oscillator (VCO) tank gives high performance. Dense component packing and the integration of functions in the substrate result in well-balanced utilization of the substrate's top and inner layers.

Simplicity and mainstream technology characterize the design. Because the module is assembled on one side (single-side assembly), all components can be soldered in a single operation (reflow soldering). The ground plane in the substrate and ball grid array (BGA) balls in the periphery of the substrate form electrical shielding.

The Bluetooth module

Ericsson has developed a short-range Bluetooth module that consists of three major functional parts mounted on a printed circuit board. These are a baseband controller, FLASH memory and the RF module. The Bluetooth module, which complies with universal serial bus (USB) and universal asynchronous receiver/transmitter (UART) or pulse code modulation (PCM) interfaces, supports voice and data transmission. Suggested application areas that can be addressed by this module include:

- portable computers;
- handheld devices;
- cameras;
- mobile phone accessories;
- computer peripherals; and
- interfaces to the fixed-line access network.

Designing a Bluetooth-enabled product

Three important areas need to be considered before designing a complete Bluetooth-enabled product:

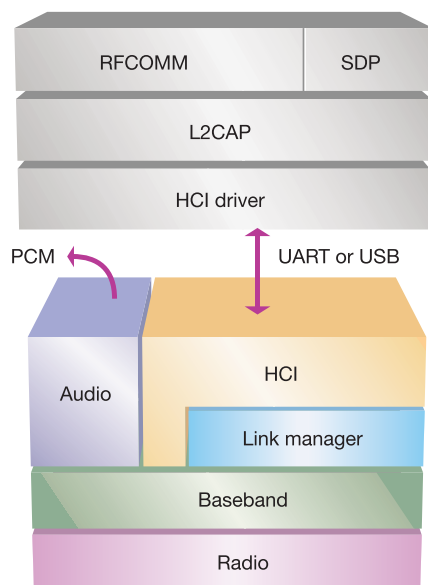


Figure 9
Ericsson's Bluetooth module and OS-independent software stack.

- Bluetooth hardware, firmware and software;
- antenna design and production; and
- application-specific software programming.

Note: in the context below, we assume that Ericsson's Bluetooth module (or an RF module-plus-discrete solution) and the operating system-independent (OS-independent) stack have been used (Figure 9).

The application

Many major applications have already been identified for Bluetooth, most of which presently communicate and transfer data via cable or Infrared Data Association (IRDA) connections (or in some instances via floppy disks). However, Bluetooth has the potential to create completely new areas of applications. When deciding how to implement an application using Bluetooth technology, engineers must first address the Bluetooth profile: all Bluetooth devices must conform to one or more profiles as stipulated by the Bluetooth profile specification

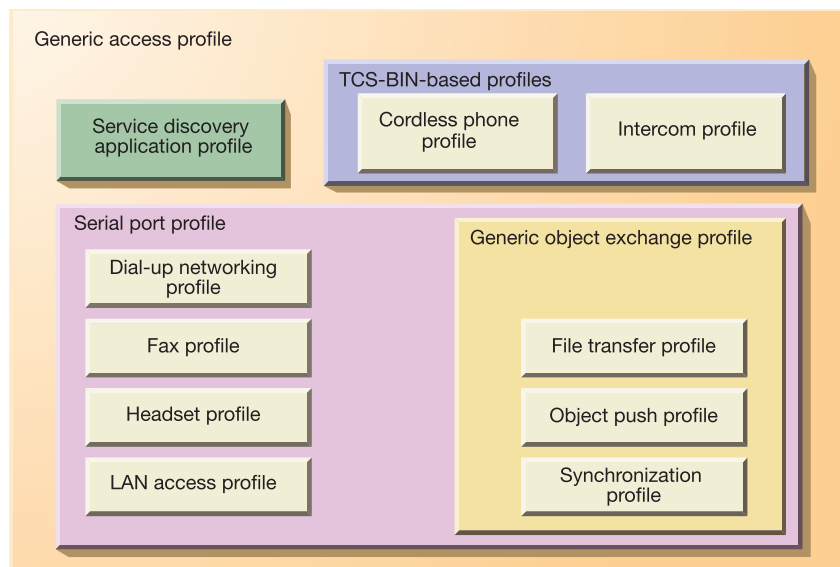


Figure 10
Profiles in Specification 1.0A.

(Figure 10), which defines mandatory and optional messages, procedures, and features. Interoperability is the main reason for defining different profiles for different usage models. New services that do not comply with a standard profile can be implemented, but they must be referred to as non-standard Bluetooth profiles.

Mechanics

The definition or selection of device packages should be started as early as possible during the product development phase. Prime considerations are

- package materials;
- parasitic effects; and
- size.

Ordinarily, between six and twelve months are needed from design to volume production of a new package. Obviously, the mechanics of the product put constraints on the choice of components and antenna implementation.

Bluetooth components

The height and size constraints of the application will influence the decision to use either a discrete or modular solution when implementing the physical hardware with Ericsson Bluetooth components, including

- the Ericsson Bluetooth module; or
- the Bluetooth RF module, plus baseband,

FLASH, and associated components.

Thanks to Ericsson's Bluetooth module and the OS-independent software stack, most of the developer's work on the software and hardware core can be devoted to the application level.

Antennas

Antenna design is affected by the availability or lack of space (physical volume). Developers must thus obtain input from the antenna designers early on in the project. Important parameters are space (volume), package shielding of the product, and production tolerances. When designing the mechanical structure of the product, developers need to have decided whether they will use an omnidirectional or a high-gain antenna—Ericsson can provide information and support.

Ericsson Bluetooth development tools

The development kits provided by Ericsson greatly simplify the design of application-specific hardware and software. Two separate hardware platforms are available:

- the Ericsson Bluetooth Developer Kit, which contains discrete components and provides access to all hardware interfaces. This kit could be regarded as the standard platform for Bluetooth product development; and
- the Ericsson Bluetooth Starter Kit, which uses the Bluetooth module for implementing Bluetooth functionality.

The following application program interfaces (API) will be available in each kit:

- API on HCI;
- API on RFCOMM; and
- API on SDP.

Most profiles depend on the RFCOMM protocol and the application-specific software that works on top of RFCOMM.

Ericsson Bluetooth hardware and firmware

Three hardware interfaces are used with the Bluetooth module or a discrete equivalent solution:

- UART and PCM voice over the PCM interface;
- USB voice over the USB interface; and
- UART or USB is used for control and data transmission.

A host-controller-interface (HCI) driver for the chosen hardware interface is needed to drive the Bluetooth module, which provides the functionality for receiving HCI commands from, and sending HCI events

to, the host application; for setting up links; and for handling timers. The module also handles the actual transmission of data and voice traffic. The formats of HCI commands, events, data packets, and other Bluetooth protocols have been formalized in *Specification of the Bluetooth System v1.0A*.

OS-independent software

High-layer protocols are implemented in source code. Ericsson will license the portable OS-independent software stack (written in ANSI C code) for mass production of devices using Ericsson Bluetooth products. Thanks to the OS-independent stack, software developers need only work with high application-specific layers. Nonetheless, all implementations of the application software must comply with the profile specification: *Specification of the Bluetooth System Profiles v1.0A*.

Qualification

The Bluetooth SIG has outlined a formal qualification program. To pass this program, all products must adhere to the following Bluetooth-specific criteria (use of the Ericsson Bluetooth module will fulfill the first two criteria):

- radio link;
- protocols (lower layers);
- profiles; and
- end-user information.

The qualification program protects the value of the Bluetooth brand by ensuring product interoperability and radio link quality. Manufacturers whose products pass the qualification program may take advantage of IP licensing and use the Bluetooth brand name.

Type approval

Before a product may be introduced into the market of any given country, it must be "type approved" according to national or regional regulations. Regulations are grouped according to

- spectrum constraints;
- radio and telecommunication requirements;
- electromagnetic compatibility (EMC) and safety;
- connection to the public-switched telephone network (PSTN) and encryption; and
- labeling, test reports and procedures.

Ericsson's Bluetooth module will be pre-certified according to regulations by the Federal Communications Commission (FCC) and the European Telecommunica-

tions Standards Institute (ETSI). Moreover, it contains the procedures for putting the device into all necessary test modes.

Conclusion

Bluetooth—which is a wireless technology standard introduced by Ericsson, IBM, Nokia, Intel and Toshiba in May 1998—uses short-range radio signals to connect two or more (up to a maximum of eight) devices, such as mobile phones, computers, handheld devices, household appliances, automobiles, consumer electronics and office equipment.

The Bluetooth module is a standard component from Ericsson Microelectronics that can easily be designed into a wide range of applications for Bluetooth communication. Thanks to the advanced flip-chip assembly of the integrated circuit, a low-temperature, co-fired ceramic substrate, and ball-grid array assembly to the application PBA, the radio module is relatively small. Ericsson will begin large-volume manufacturing of the module during the first quarter of 2000.

Companies who use Ericsson's Bluetooth module, the OS-independent stack, and other components for designing Bluetooth-enabled devices can focus their R&D resources on developing application-specific hardware and software.

In May, 1999, Ericsson launched the Ericsson Bluetooth Developer Kit, a "toolbox" of equipment that provides developers with a flexible environment for designing Bluetooth applications in less time and at lower cost, and for integrating Bluetooth technology into a wide range of electronic devices.

REFERENCES

- 1 Haartsen, J.: Bluetooth—The universal radio interface for ad hoc, wireless connectivity. *Ericsson Review* Vol. 75 (1998): 3, pp. 110-117.