WHITE PAPER

Advanced Architectures and Technologies for the Development of Wearable Devices

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One of the exciting new markets expected to see the biggest growth over the next few years is that of wearable devices. According to market research firm IHS, the worldwide market for wearable technology saw revenues of $8.5 billion in 2012 based on shipments of 96 million devices. The firm predicts future increases to $30 billion and 210 million by 2018. Today it is a largely embryonic market that has undergone significant evolution over the past two years. However, the development of advanced technologies to meet the low-power and small-form-factor requirements, which are absolutely critical in wearables, will enable it to become a significant mainstream market that addresses many new use cases and applications in fitness and infotainment, as well as medical, healthcare, industrial and enterprise applications.

ARM is the world leader in developing advanced technologies for mobile and wearable devices, providing an extensive range of processor, GPU (Graphics Processing Unit) and other SoC (System-on-Chip) Intellectual Property (IP). Based on this IP, SoCs from ARM partners have already encouraged hardware developers to adopt wearable device platforms based on ARM that can immediately address this huge base of consumers. In conjunction with world-leading semiconductor partners, ARM is therefore well positioned to apply its expertise in low-power mobile technologies and play a leading role in the creation and development of wearable products. Leading consumer brands and new emerging companies alike can build upon these assets to meet the evolving requirements of the market and innovate at all end-product price points. These technologies also enable the largest community of software developers to create a range of software apps available for mobile markets, running under an Android™ Operating System (OS) and other popular mobile OS's.

Applications

Given that most products are unlikely to be self-contained, stand-alone devices, connectivity is a key requirement for wearables. The diversity of wearable devices means that many will employ 3G or 4G connectivity alongside Wi-Fi which will be used for high-speed local connectivity. The drive for low power, however, will lead to many devices being designed for the “appcessories” (application accessories). These devices will connect via Bluetooth™ LE (Low Energy) or BT (Bluetooth) Smart to a smartphone or tablet to employ its user interface or display, or to process and send data to the Internet and the cloud, thus linking to services and attaining a place in the Internet of Things (IoT). Owing to its low power consumption demands, the short-range Bluetooth LE technology is expected to continue to be a major wireless interface for wearables, as despite not offering the very high data rates of Wi-Fi, it still delivers a very useful 1Mbit per second.

Developers will need to clearly target the intended users of their product, and at the right price point. Major use cases will include health tracking and performance monitoring in fitness sports, from relatively low-cost wrist-worn devices such as fitness activity trackers that cost less than $100, to high-end products costing many hundreds of dollars that are aimed at more extreme outdoor activities such as skiing, climbing or base jumping, and integrating head-up displays, global positioning technologies, video recording and communications. Wearable devices are also used in conjunction with social networking apps, allowing users to communicate data and information to their connected community. The ability to aggregate data relevant to the user and serve it at the right location with the right context means that there is a possibility for the right applications to extend such wearable devices to the workplace with the aim of monitoring and increasing productivity.

Challenges

Wearable technology is being enabled by low-power microcontrollers or application processors, low-power wireless chips and sensors, such as MEMS (Micro-Electro-Mechanical Systems) based motion devices and other environmental sensors. Next-generation devices will see these devices further miniaturized in highly integrated solutions with ever-smaller batteries to deliver increased functionality in ever-smaller form factors. In addition, high-end products will offer increasingly advanced displays and graphics capabilities.

Along with the size and weight of the product as a whole, power consumption will be a critical factor. While it is perhaps acceptable to charge equipment on a daily basis in a business environment, consumer devices that require such frequent charging could well find themselves at the back of a drawer. To provide some context, a typical smartphone –considered by most of us as an essential close-at-hand item – may require a daily charge of around 3000mAh; whereas a high-end wearable product should demand only a 300mAh weekly charge. This is a massive 70x reduction in power, and the importance of creating designs that are based on ultra-low-power technologies should not be underestimated.

The relative speed in which the market has developed is a challenge in itself, as there is constant evolution at this early stage. Today, developers are building wearable solutions based on advanced and highly integrated sensors and a wide selection of off-the-shelf ARM Cortex® CPU-based microcontrollers and mobile-targeted SoCs. This is in conjunction with ARM's robust and extensive software development ecosystem that has been built up over many years for mobile and consumer applications among others. But as the market evolves and volumes grow, the future of wearables will be in the development of low-power custom-designed or application-specific SoCs that deliver the right combination of performance, power consumption and price for deployment in specific markets. Once an initial design is deployed, developers can continue with it, customize it further, or employ a newer and more advanced SoC. So, there are many new opportunities being created for new highly integrated, high-performance and low-power SoCs that will eventually enable whole new rafts of products at many different levels of functionality.

Requirements

A critical requirement for any wearable design will be employment of an 'always-on, always-aware' processor to handle the continuous monitoring of sensors such as accelerometers and gyroscopes, global positioning devices, and temperature and pressure sensors. The processor has to manage increasingly complex algorithms and perform 'sensor fusion' by filtering and interpreting data from all these sensors to provide better information for the user. A powerful 32-bit processor core will be required to keep all the processing on-chip, thereby reducing the amount of transmitted data and keeping power consumption to a minimum.

In terms of functionality, a basic device such as an activity tracker will likely feature a simple OS and Bluetooth Smart connectivity to a mobile device, with either no display or a very simple one. On the other hand, a mid-range smartwatch, for example, may use a richer OS, such as a Linux®-based OS, alongside

a color display, graphics, audio and perhaps Bluetooth and Wi-Fi. A high-end smartwatch, meanwhile, running a full OS with a complete app ecosystem such as Android Wear, will require all the capabilities of the mid-range device as well as adding better graphics, global positioning, cellular connectivity, and a camera, potentially with HD video capability.

In terms of architecture, while a product that uses a simple RTOS (real-time OS) such as FreeRTOS or NetBSD, will require SRAM, ROM, Flash, but no Memory Management Unit (MMU) – indicating use of a 32-bit ARM Cortex-M class MCU as the 'always-on' CPU. A wearable product running apps on a rich OS such as Android or Android Wear brings a need for an application processor – a 32-bit ARM Cortex-A processor – plus DRAM, an ARM Mali™ GPU, an MMU, and potentially an ARM Mali Display Processing Unit (DPU) and/or an ARM Mali Video Processing Unit (VPU).

Development

Today there exists a wide portfolio of devices for wearable technology development based on stand-alone microcontrollers that offer built-in connectivity, plus software development support via the extensive ARM and mbed.org ecosystem. There is an extensive range of standalone 32-bit MCUs that are based on the ARM Cortex-M cores and are highly suitable for wearables such as the Kinetis L series of Cortex-M0+ based MCUs – in particular the KL03, which comes in an ultra-small 1.6 x 2.0mm^2 wafer-level chip-scale package (CSP) - and the STMicroelectronics STM32 Cortex-M3 based MCUs, which have seen wide deployment in many wearable products. The market is also seeing the development of very-low-power 'always-on' sensor-processing MCUs that target wearables, such as Cortex-M based MCUs from Ambiq Micro that will become available in 2014/2015. Another important example is the nRF51822 SoC from Nordic Semiconductor, which embeds a 32-bit Cortex-M0 core and a 2.4GHz transceiver that supports the Bluetooth V4.0 (Low-energy) wireless specification. This device is at the core of the nRF51822-mKIT, which is the first mbed development platform specifically aimed at Bluetooth LE applications, and, as mentioned above, is expected to be an important wireless technology for wearables.

There are also a number of Cortex-A based platforms for Android development available. Freescale's Wearable Reference Platform (WaRP), for example, consists of a main board integrating an i.MX 6SoloLite Cortex-A9 based applications processor and a daughtercard, with the Kinetis KL16 Cortex-M0+ based MCU used as a sensor hub and wireless-charging MCU. Another example is the MediaTek MT6572, which is based on a dual-core Cortex-A7 implementation with connectivity options including Wi-Fi, Bluetooth and GPS, plus support for a 960 x 540 display. And a third is the Cubieboard 2 based on a

dual-core Cortex-A7 Allwinner A20 CPU, which also integrates a Mali-400 GPU. And for Linux, there is the Cortex-A5 based Atmel SAMA5D3 Xplained prototyping and evaluation platform and the Freescale Vybrid VF6xx based on a dual-core Cortex-A5 and dual-core Cortex-M4 implementation.

Architectures

As a leader in low-power technologies for mobile devices, ARM offers a number of Cortex-M and Cortex-A based device architectures for the development of application-specific SoCs that target different segments of the wearables market, from a basic device such as an activity tracker up to a high-end smartwatch. In fact, teardowns of many wearable products available today have already revealed wide use of Cortex-M and Cortex-A class processors. These products include a Pebble smartwatch that integrates an STM32 Cortex-M3 MCU, accelerometer, magnetometer, and Bluetooth connectivity; the Fitbit Flex activity tracker which also integrates an STM32 MCU, plus accelerometer and Bluetooth; while the GoPro HD HERO2 camera uses a Cortex-M4 based Freescale K20 MCU, plus camera SoC (using an ARM11 core). At the higher end of the market is the Omate TrueSmart smartwatch, which offers 2G/3G call/data capabilities, Wi-Fi, Bluetooth, GPS and FM connectivity, and HD-video recording capability. This product implements a Mediatek 6572A application processor SoC, which integrates a dual-core ARM Cortex-A7 CPU and ARM Mali-400 GPU. The Samsung Gear Live and LG 'G' are both Android Wear ARM-based watches, and are powered by a Qualcomm Snapdragon 400 based onthe ARM Cortex-A7 processor.

- **Basic**

An example of a basic wearable device architecture is shown in figure 1: it features on-chip memories (Flash, SRAM, ROM) and is a simple design suitable for an activity/sports band or a very simple watch. Any of the Cortex-M0, Cortex-M0+, Cortex-M3 or Cortex-M4 ultra-low-power processor cores can be used for 'always-on' sensor fusion processing, largely depending on the number of sensors required in the design. In many cases, the Cortex-M3 has already proved to be a highly suitable choice. Running a simple RTOS at an operating frequency of between 20MHz and 150MHz, the design can provide months of battery life.

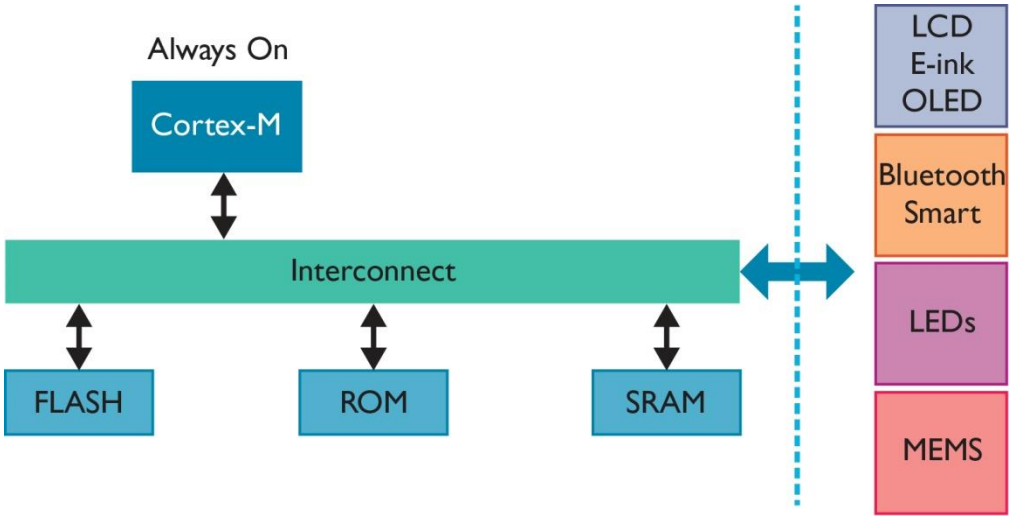

Figure 1 – Basic device architecture

The Cortex-M series has become an industry standard, with more than five billion Cortex-M processors shipped to date and ranges in terms of power consumption from the ultra-low-power Cortex-M0+ up to the top-of the-range, high-performance Cortex-M4 core. This high-end core offers highly efficient signal processing features for digital signal control, as well as offering accelerated SIMD (Single Instruction, Multiple Data) operation.

One difference between the Cortex-M processors is instruction set support. The Cortex-M0 and Cortex-M0+ have a small instruction set with only 56 instructions designed for high code density. The richer instruction set of the Cortex-M3 and Cortex-M4 is better suited to more complex data processing, offering hardware divide, bit field processing and MAC support, for example. The Cortex-M4 also offers an optional single-precision Floating Point Unit (FPU). The performance benchmarks for the Cortex-M3 and Cortex-M4 can easily rival a low-frequency-clocked Cortex-A series processor such as the Cortex-A5. Tables 1 and 2 respectively show data on die area and power consumption, and Dhrystone and CoreMark® performance benchmarks for the Cortex-M series. Static power is less than 0.7µW/MHz for the Cortex-M3 and Cortex-M4. To further reduce power consumption, the Cortex-M processors also feature two architecture-defined sleep modes. Sleep mode stops the processor clock, whereas the deep sleep mode stops the system clock and also switches off the PLL and Flash memory.

	90LP (7-track, typical 1.2v, 25C)		40G (9-track, typical 0.9v, 25C)	
	Dynamic power (µW/MHz)	Area mm^2	Dynamic power (µW/MHz)	Area mm^2
Cortex-M0	16	0.04	4	0.01
Cortex-M0+	9.8	0.035	3	0.009
Cortex-M3	32	0.12	7	0.03
Cortex-M4	33	0.17	8	0.04

Table 1 – Cortex-M dynamic power and area

	Dhrystone (official)	Dhrystone (max options)	CoreMark
	DMIPS/MHz	DMIPS/MHz	CoreMark/MHz
Cortex-M0	0.84	1.21	2.33
Cortex-M0+	0.94	1.31	2.42
Cortex-M3	1.25	1.89	3.32
Cortex-M4	1.25	1.95	3.40

Table 2 – Cortex-M Dhrystone and CoreMark performance (CoreMark data courtesy of CoreMark.org)

- **Mid-Range**

An example of a mid-range device architecture is shown in Figure 2 and is suitable for a smartwatch with a rich OS and color display. The architecture implements a Cortex-A5 or Cortex-A7 single-core application processor, which will usually be in sleep mode apart from when the user is interacting with the product. The Cortex-A5 is the smallest Cortex-A series application processor and has a simple eight-stage in-order pipeline, while the Cortex-A7 provides a higher level of performance and functionality.

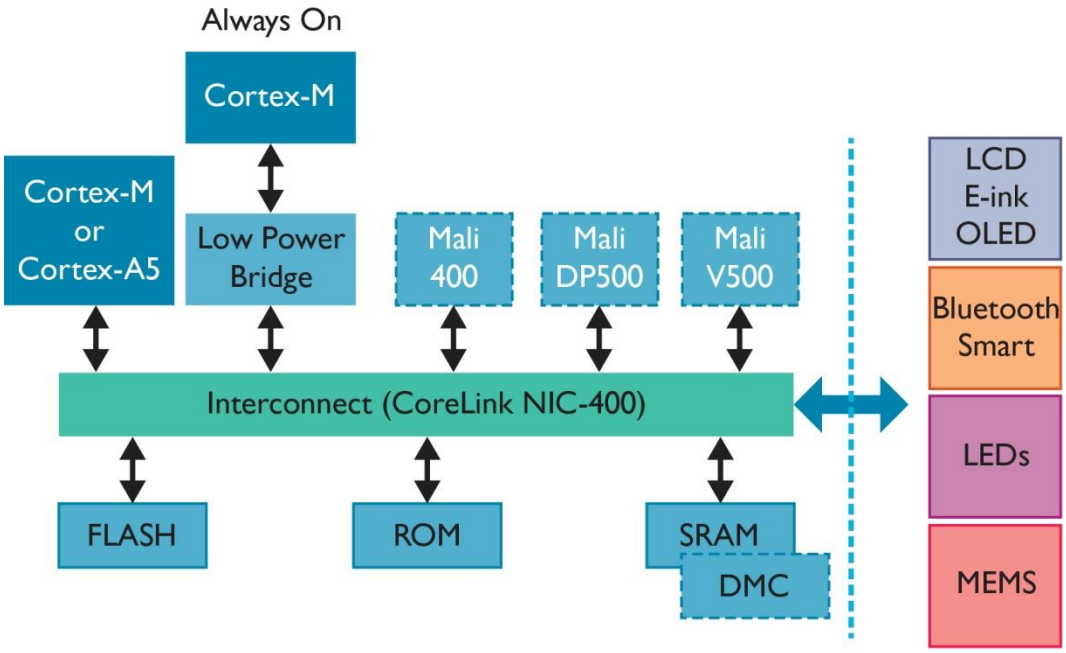

Figure 2 – Mid-range device architecture

The mid-range design typically operates from 250 to 500MHz and will run either an RTOS or a full OS such as Linux. As in the basic device design, the Cortex-M is retained as the 'always-on' sensor-fusion CPU. Based on the OS and the end application, the design may require a Cortex-A5 processor for high level OS support, the memory controller (DMC), Mali-400 GPU, Mali-DP500 DPU and Mali-V500 VPU. The Mali-400 GPU has industry-leading performance density, as it is area optimized for OpenGL® ES 2.0 acceleration and includes a configurable level-2 (L2) cache for efficient bandwidth usage. The success of multiprocessor Mali-400 configurations in smartphones has led to a vast range of apps that are already optimized for Mali-400. As both single and multiprocessor configurations of Mali-400 share binary-compatible drivers, wearables that implement Mali-400 will immediately benefit from this vast range of optimized content.

- **High-End**

An example of a high-end wearable device architecture is shown in Figure 3 and implements a Cortex-A7 dual-core cluster multiprocessing application processor for scalable performance, and again includes the 'always-on' Cortex-M CPU. An alternative for mid- to high-end designs could also be a dual-core Cortex-A5 implementation. The design also includes the Mali-400 GPU, Mali-DP500 DPU and Mali-V500 VPU

and could meet the needs of a high-end product such as a smartwatch using Android Wear, skiing goggles with an integrated head-up display or perhaps a wearable headset computer system.

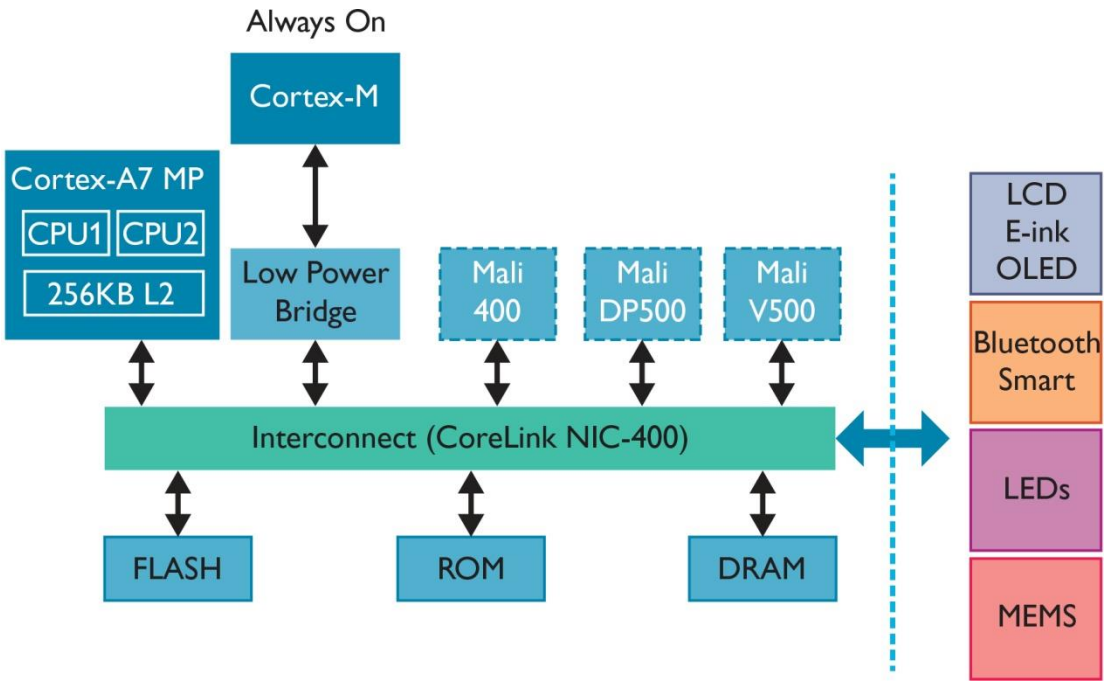

Figure 3 – High-end device architecture

Clocking at between 500 and 800MHz and designed for a rich OS such as Android and Android Wear, the design also offers low active power with low-power modes to reduce standby power, as well as an energy-efficient L2 cache subsystem and low-power DDR memory. In addition, the design enables the use of the ARM NEON™ 128-bit SIMD architecture extension for Cortex-A processors to deliver enhanced multimedia and DSP processing.

Optimization

In both the mid- and high-end wearable designs, a critical element is meeting the power envelope target. Wearables require an even stricter set of design constraints than those employed in the development of a smartphone, for example. It is necessary to optimize the SoC in terms of using smaller data memories, slower clock speeds and choosing the silicon process technology that offers the lowest power consumption.

Smaller memory caches will save on die area and power. In most mobile applications, a 32K L1 cache is common, but halving the size to 16K has a less than 10 percent impact on performance. As well as this, an L2 cache could be reduced if the application requires only a small data set. Fundamentally, cache sizes can be changed depending on the evolution of workloads.

Selection of the right silicon process technology is also important. Figure 4 shows the power/performance/area for a single-core Cortex-A7.

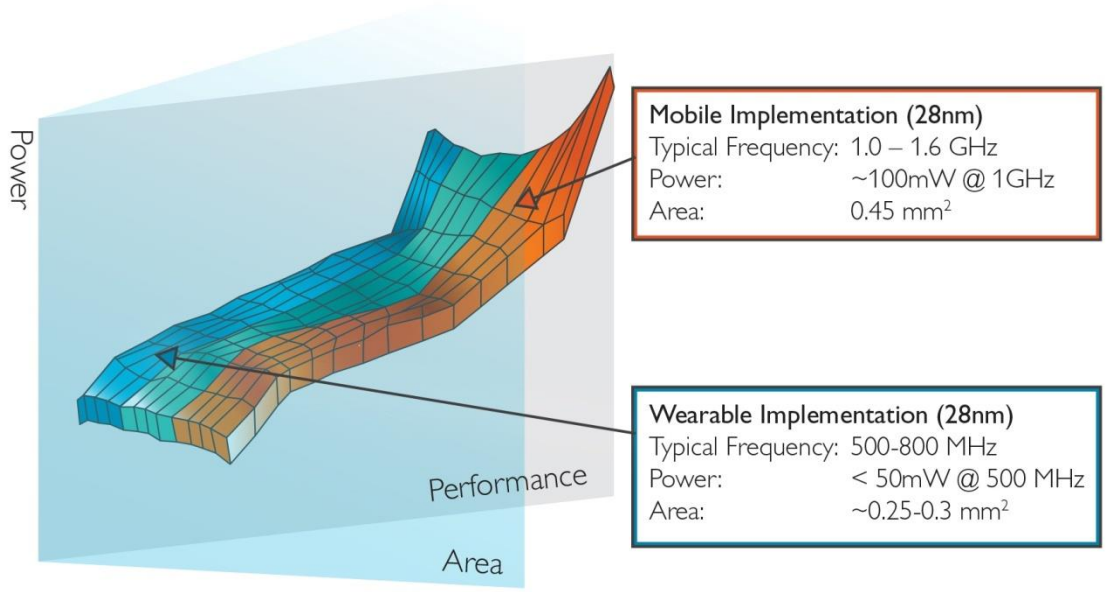

Figure 4 – Process options for wearable versus mobile implementations

A low-power process implementation is critical for wearable devices. A high-performance process targeting mobile applications that clocks up to 1.6GHz with power consumption at 100mW at 1GHz and has a die area of 0.45mm^2 will not suffice for wearables. In addition to this, another important optimization is selecting the right standard cell library to meet performance and power targets.

Fundamentally, it is about making the design trade-offs between performance and power consumption. The extensive range of ARM IP and technologies presents designers with a multitude of options and enables them to select the right performance/power/price point for their SoC.

Conclusions

The market for wearable products is here now – and it is both fast growing and quickly evolving. ARM and its partners have already established a leadership position and a platform of enabling technology for the future development of wearable products. Available for fast deployment is a wide portfolio of solutions based on ARM processors that offer high performance and low power consumption, in conjunction with extensive support via the ARM software ecosystem at all device architecture levels. The vast majority of wearable devices available today have already used this recipe for success, as demonstrated by the market-leading smartwatches such as Omate, Pebble, LG 'G' and Samsung Gear Live among many others. And as the market grows ARM partner semiconductor vendors will deliver application processors and SoCs that are further optimized for wearable device development within the same software ecosystem, in addition to enabling access to a vast portfolio of mobile apps running under Android and other popular OS's.

As the leader in advanced, power-efficient technologies for mobile and wearable devices, ARM has a complete range of embedded low-power processors from the ultra-low-power and tiny Cortex-M series to the highly efficient Cortex-A application processors, as well as a wide range of complementary IP such as the Mali GPUs. In addition, there is a choice for developers to optimize designs further with smaller cache memories, slower clock speeds and low-power technology process options to meet the strict low-power envelopes necessary to deliver high-performance and power-efficient wearable technologies.
With ARM's multitude of cutting-edge, high-performance and power-efficient processor designs, our extensive range of partners are already leading the wearables revolution, designing the most innovative and functional devices for all categories of wearable connected devices, and for the many diverse markets and applications. As the market continues to grow, ARM and its partners are once again achieving extraordinary results, and spearheading the evolution of a new generation of mobile technology.

ENDS