TEXAS INSTRUMENTS

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# *BeagleBone Black open-source Linux™ computer unleashes innovation*

Introduction

BeagleBoard.org was founded to give developers, hobbyists and students robust open-source hardware development platforms so they could quickly and cost effectively assemble systems by leveraging the many advantages of the open-source ecosystem. BeagleBoard, BeagleBoard-xM, BeagleBone and now BeagleBone Black provide flexible and expandable open-source platforms for all electronic artists – from those who are just learning to develop to experienced commercial designers.

Unleashing: BeagleBone Black

The next-generation offering from BeagleBoard.org – BeagleBone Black – helps hobbyists, engineers and students alike transform ideas into usable products – for only $45! BeagleBone Black is a ready-to-use, 1-GHz Linux™ computer that offers a truly open hardware and software development platform. Thanks to compatibility with a growing collection of more than 30 "cape" plug-in boards that expand the board's functionality as well as support from a thriving open-source community, open-source development has never been easier or more fun.
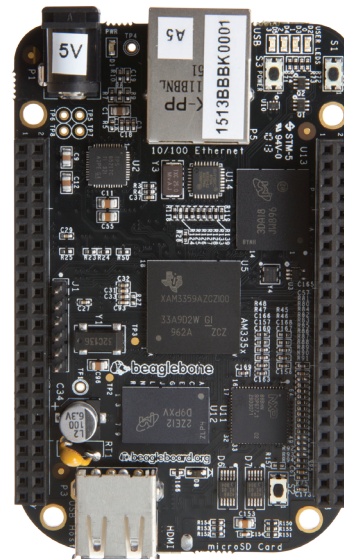
Figure 1. BeagleBone Black, the next-generation offering from BeagleBoard.org, makes innovation easy for everyone from beginner to professional developers.

It's all in the box

For only $45, BeagleBone Black includes all the necessary components in the box to begin developing, providing a lower total cost of ownership than the nearest competitor. With

everything included in the box, developers can start bringing their innovations to life immediately. Compilers, interpreters, integrated development environments, command shells and hundreds of open-source libraries are all just seconds away by USB, over Ethernet or via the included GNOME desktop using the micro-HDMI connection to a TV or monitor.

Faster, more cost-effective

Faster is one thing, but BeagleBone Black not only shatters the speed limits of the prior generation, it does so at a low price of just $45. Based on the Sitara™ AM335x ARM® Cortex™-A8 processor from Texas Instruments Incorporated (TI), BeagleBone Black provides 1-GHz performance – 150 percent higher performance than ARM11™ for more advanced user interfaces and computation power. With all components on the board, including TI's Sitara AM335x processor, commercially available, users can quickly go from prototype to Kickstarter and take their devices to production.

In addition to faster processing speeds, BeagleBone Black adds on-board 8-bit embedded MMC (eMMC) for faster and more cost-effective storage. The board also features 512 megabytes of low-power DDR3L RAM, doubling the size and speed of the volatile memory and ensuring it will execute software faster. With BeagleBone Black, developers can get even more value and more innovation from a smaller investment.

Connected pup

High-speed peripheral interfaces like USB, Ethernet and HDMI on the credit-card-size BeagleBone Black mean that practically any peripheral device can be connected to these fast, portable, low-power computers. Enhanced user interfaces to connect with devices such as a keyboard, a mouse and an HD LCD display are a snap to deploy.
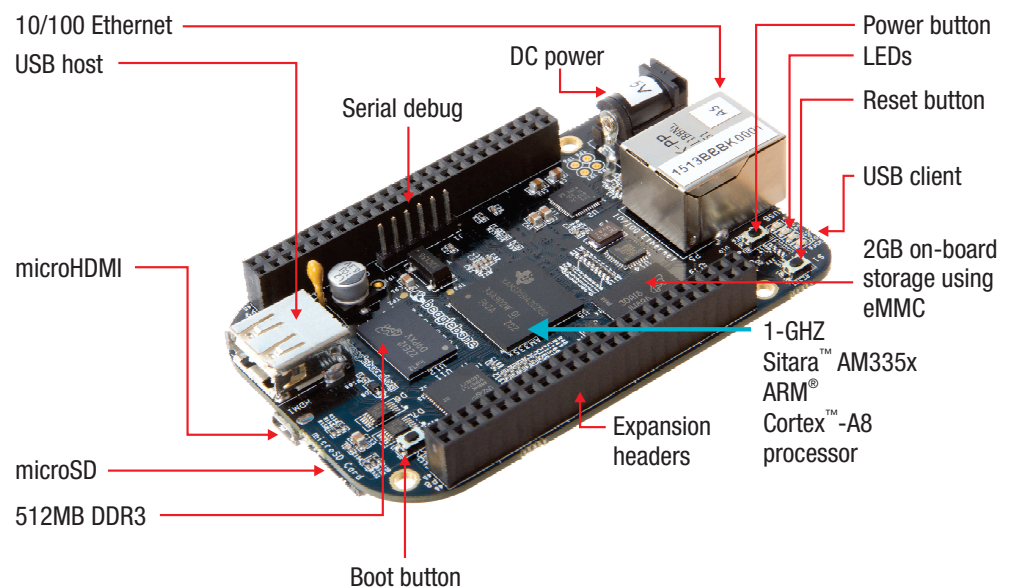

Figure 2. BeagleBone Black offers high performance and various connectivity options.

Besides the many commercially available off-the-shelf peripheral devices that are compatible with the interfaces on BeagleBone Black, a variety of plug-in boards – called "capes" – can be deployed almost immediately by simply plugging one or more capes into one of the board's expansion headers. As many as four capes can be stacked on top of each other for even greater capabilities. Prototype systems with 3D printers, a DMX lighting controller, a Geiger counter, a telerobotic submarine, LCD touch screens and other functionality can be up and running without spending significant time and energy integrating these peripheral devices. These capes have given us projects that are just plain fun, like a mustache camera, LED lights and sounds, tiny computers with sensors that fit into the palm of a hand or real-life superhero costumes. Of course, there are the more serious commercial projects too, such as 3D printers, underwater autonomous robots, drone aircraft, weather stations, intelligent digital signage, home automation and much more. More than 30 capes are available today, with more to come in the future, to enable an even broader range of innovation projects.

Open-source software and hardware

To accelerate development and jumpstart innovation immediately, BeagleBone Black comes pre-loaded with a Linux operating system and Cloud9 IDE – an online development environment for Node.js-based Javascript applications as well as HTML, CSS, PHP, Java, Ruby and 23 other languages – on an eMMC. This also frees up the board's microSD slot for additional storage. The Linux software has been optimized, enabling even new users of embedded Linux to develop creative solutions. With an ecosystem that includes free access to documentation, example code and recent Linux kernel support for other distributions like Ubuntu, Android™ and Fedora, experienced developers are able to bring up functional system prototypes faster and deliver new, innovative products to market sooner. Support is available from TI, Linaro, and the Ubuntu and Yocto Project™ communities. Because of the kernel and driver flexibility inherent in BeagleBone Black, new hardware and drivers can be integrated rapidly and seamlessly.

Community in action: "Cape" plug-in boards

The concept of plug-in capes for BeagleBones was born out of eagerness. Makers, developers and entrepreneurs alike don't want to wait for an extended period of time while prototypes are being assembled and built. When a creative idea or concept knocks, they want to try it out right away and move on to the real innovative portion of development. More than 30 capes covering a wide range of functionality are currently compatible with BeagleBone Black to satisfy the eager nature of creative engineers. Details on a few are described below.

Figure 3. Cape plug-in boards easily expand the capabilities of BeagleBone Black.

BeBoPr 3D Printer Cape

The BeBoPr 3D Printer Cape provides all the necessary I/O to control a Mendel/Reprap 3D-printer. The cape contains three analog inputs optimized for thermistors, six digital inputs for limit switches, and more. All the "hard" real-time control runs on a dedicated coprocessor that is part of TI's Sitara AM3359 ARM Cortex-A8 processor on BeagleBone Black. The "soft" real-time control runs on the ARM processor under Linux.
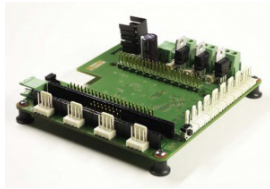
Figure 4. BeBoPr 3D Printer Cape.

Camera Cape

A camera cape avoids plugging a camera interface into one of the USB ports and reduces total power consumption. Possible applications include automatic identification and data capture applications such as bar code readers and smart cards; portable consumer applications such as smartphones; industrial tablet computers; and many others.

Weather Cape

The BeagleBone Weather Cape provides temperature, barometric pressure, humidity and ambient light data.

Interacto Robotic or Drone Cape

The Interacto robotic cape was one winner of a BeagleBoard.org-sponsored cape design contest. Interacto provides the basis for robotic or aerial drone development. Included is a triple-axis accelerometer, gyroscope and magnetometer plus a 30 frames-per-second camera with 640 × 480 resolution.

Geiger Cape

The BeagleBone Geiger Cape – the third winner of BeagleBoard.org's cape contest – has multiple Geiger tubes to measure radiation counts from background and test sources. Detecting low-level radiation is critical in certain industries such as security and medical.

BeagleBoard.org yields innovation

BeagleBoard.org's offering of highly flexible and expandable open-source development platforms and a community committed to mutual collaboration can't help but yield a myriad of exciting systems.

One example of the projects being developed is the OpenROV sub-community within the BeagleBoard.org community. OpenROV has focused on robots for underwater exploration and adventure. With the assistance of the original BeagleBone platform, the OpenROV community has developed a low-cost remote control submarine that can map caves or the floor of the ocean in 3D, collect water samples where divers could not reach and other feats yet to be determined by the creativity of the community. The BeagleBone basis for the OpenROV submarine has been supplemented with a common depth sensor often found in scuba diver computers and a high-definition web video camera.
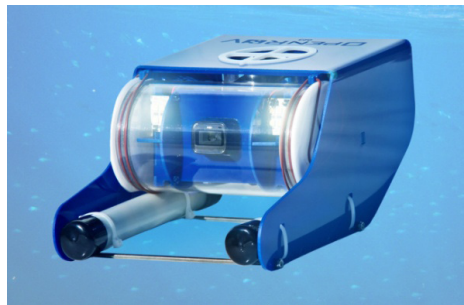
Figure 5. The OpenROV submarine.

Other creative developers in the BeagleBoard.org community have decided that bringing about the Internet of things is just as interesting as deep-sea exploration. Developed on the original BeagleBone, Ninja Blocks (**http://ninjablocks.com/**) feature sensors, actuators and other types of capabilities that can connect, monitor and control the doors, windows or other previously unconnected things around the house. The residence becomes a true Internet of things.

Figure 6. A Ninja Block ready to spring into action.

Another innovative BeagleBone project is the Descriptive Camera, which is a entirely new kind of camera altogether. Instead of outputting a visual image of the subject captured by the camera, it prints a textual description of it.

The above BeagleBone projects have practical uses in our lives. However, others are just for fun. The BeagleStache, for example, is another sort of camera. It captures an image of a person, but the person appears with a handlebar mustache.

Figure 7. BeagleStache demo.

Hilarity typically ensues, of course. Another example is the Blitter Bike, a self-contained interactive light sculpture that's towed by a bicycle. The Blitter Bike has made appearances at festivals around the world.

One innovative BeagleBone Black project is the SpiderBot, which was manufactured with a BeagleBone-based 3D printer. This 3D printer is built using the BeBoPr Cape, which provides all the necessary I/O to control Mendel/Reprap 3D printer mechanics. BeagleBone Black provides the speed to improve the movement routines of the printer, which creates all of the components of the dancing SpiderBot robot. Typically, microcontrollers are used to control 3D printers. However, the high-performance BeagleBone Black running Linux can directly interact with web servers like Thingiverse for sharing designs. With its 3D graphics co-processor, BeagleBone Black can be used to provide dynamic preview perspectives. Further, it can process the designs on-board, with no additional computer needed, and provide all of the low-level real-time controls using the programmable real-time units (PRUs).

The BeagleBone Beer demo helps brew beer by controlling a heat exchanger and water pump to maintain a constant temperature during the fermentation process. During the beer fermentation process, it's necessary to maintain a constant temperature to prevent unwanted flavors from developing. To maintain a constant temperature, a metal coil through which water will run is interested into the beer. The running water is circulated through a heat exchange in order to cool the water as it circulates through the system. Heat is removed from the beer via the coil, and then removed from the coil via the air-to-liquid heat exchanger. The entire system is controlled by BeagleBone Black, which takes the temperate of the beer and controls the heat exchanger and water pump. Data is logged to a MySQL database so that the temperature can be tracked

online. The target temperature and manual overrides can also be controlled online through the webserver installed on BeagleBone Black.

TI has established **www.arowboat.org** for developers of BeagleBoard.org platforms and TI's ARM processors. The site features extensive Android™ resources, including shared source code. With Android, developers can run Android games like Fruit Ninja and Angry birds as well as other Android applications.

Spider Bot, the 3D printer, the BeagleBone beer demo and the Android games are among the first projects to be developed on BeagleBone Black. It remains to be seen the amazing innovations that will be brought to life on this platform.

Community engagement fosters innovation

The key to maximizing the full potential of BeagleBone Black is to tap into the wealth of information available on the BeagleBoard.org community. The motivation behind BeagleBoard.org has always been to empower and encourage innovative development by unleashing the creativity of designers. This concept has proven wildly successful as the community has exploded with creative and intelligent designs. Within the Beagle-Board.org community, developers are able to interact, learn, answer questions, and share ideas to solve their problems quickly and enhance their creativity. With the newest open-source platform – BeagleBone Black – the community is excited to see what new projects are possible.

If the 50,000 hits per month on its web site are any indication, BeagleBoard.org is thriving and has become one of the most active and collaborative groups in the open-source world. In addition, the community has global reach. Regional organizations have grown up in Brazil, Japan and Turkey, with more on the way. Each community fosters the sharing of the latest software developments, while hosting live forums and online chats for easy collaboration. These communities are available to anyone who wants to join and take advantage of a strong support system where interaction with other developers, learning about new trends and the sharing of ideas happen every day.

Since the introduction of BeagleBoard.org to the open-source community in 2008, the support ecosystem, tools and sense of collaboration prevalent in the community have continued to expand. Thousands of members, made up of engineers from Fortune 100 companies, industry leaders, hobbyists and academics, are actively involved in BeagleBoard.org.

Although BeagleBoard.org receives support from TI, by and large it is a self-sustaining community whose hardware development is funded by distributor pre-orders and previous board sales. All BeagleBoard.org platforms – including BeagleBone Black, BeagleBone, BeagleBoard, and BeagleBoard-xM – integrate components that are available through distribution in low quantities so that a resulting design can be assembled and enhanced by practically any manufacturer, from the Kickstarter to a hot commercial product.
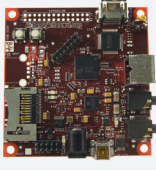
	BeagleBoard	BeagleBoard-xM	BeagleBone	BeagleBone Black
Board				
Quick summary	The original open hardware ARM®-based development board	All features of the original BeagleBoard with extra memory	Low-cost, open-source community platform with plug-in board expansion	Next-generation BeagleBone featuring 1-GHz processor
Memory	256KB L2 cache	512MB DDR2	256MB DDR2	512MB DDR3
Special features	2D/3D graphics acceler-ator, HD video capable, USB powered	1-GHz processing power, four-port hub with 10/100 Ethernet	USB-powered, 10/100 Ethernet, USB JTAG	eMMC, on-board HDMI, USB, Ethernet and HDMI interfaces
Price ($U.S.)	$149	$179	$89	**$45**

Figure 8. The evolution of BeagleBone Black.

Conclusions   The innovative approach that was the foundation of BeagleBoard.org has been both an educational and fun experience for engineers, hobbyists and students. Now, BeagleBone Black takes the next step, unleashing a new level of creativity and breakthrough design by enhancing the possibilities with the next level of perfor-mance. BeagleBone Black removes any impediments to innovation and, because of its greater capabilities, it enables a new range of exciting applications.

For more information on BeagleBone Black, go to **www.beagleboard.org/black**. To learn about the BeagleBoard.org community, go **to www.beagleboard.org**.

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