

A Genealogy of Standards: Thirty Years of Advancing Connectivity

by Michelle Tham and Michael Bergman

Abstract

Smartphones are not just based in mobile wireless standards; they are based in a rich legacy of additional standards in computing and communications going back decades. Consider some of the things we can do with a smartphone—surf the Internet, take pictures and upload them to a computer, or connect to a DTV screen to play a movie. Such capabilities are only possible because of standardization. **This paper explores a historical trail of standards, highlighting the significance of inheritance in standards development and its usage in advancing ubiquitous connectivity among consumer electronics devices—from the I2C standard leading up to the USB and HDMI standards.** As stated by Mohamed Ismail from EDN Network, by defining protocols and operating characteristics, “Standards have impacted all aspects of technology: device package sizes, pin outs, data and communication interfaces, software drivers, connectors, ESD ratings, environmental compliance, test fixtures.”¹ The more detailed a specification, the better equipped are developers for defining products, such as smartphones, that serve the marketplace. If there is any doubt about the value of defined standards, consider the fact that regardless of brand, all Android smartphones are charged from and compatible with micro-USB cables.

Introduction

Smartphones are an amazing success story. According to a Pew Research Center report, *U.S. Smartphone Use in 2015*, sixty-four percent of the population carries a smartphone, up from thirty-five percent in the spring of 2011.² The smartphone’s success stems from its ability to do so much more than its predecessor, the “dumb” or “feature” phone. The smartphone takes advantage of a world of standards to become one of the most useful and ubiquitous devices ever.

I2C: The Architect

Even the simple act of charging an Android phone calls up a chain of standards beyond just the cable type. This story goes back to 1982, when Philips Semiconductors needed an easy and simple way to connect a CPU to peripheral chips in a TV set. Traditionally, peripheral chips in embedded systems are connected to the microcontrol unit (MCU) using parallel address and data bus.³ This approach required numerous copper lines on the PCB’s to route the address and data lines, as well as a number of address decoders and glue logic to connect everything. In mass production products of that time, such as televisions, VCRs, and audio equipment, such a requirement was not acceptable.⁴ In these appliances, every component that could be reduced meant increased profitability for the manufacturer and increased affordability for the end-user. Thus, in 1982, Philips Labs in Eindhoven provided a solution to the issue of numerous control lines by creating a 2-wire communication bus called the I2C (Inter-IC) bus, which functions as the communication link between integrated circuits.

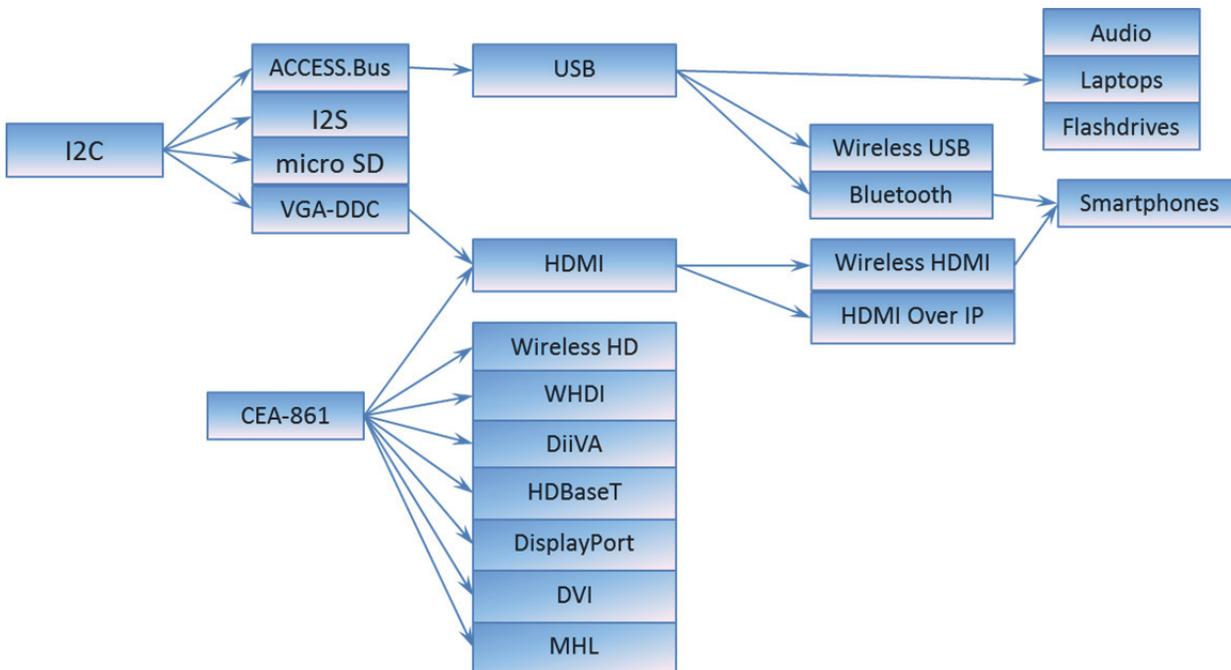


Figure 1. Genealogical Chart: From I2C to USB/HDMI to Smartphones

ACCESS.bus: The Oracle

A few years later, in the early 1990's, I2C was tapped as the solution to a problem with the personal computer. That time frame was marked by a huge increase in laptop sales. However, as manufacturers sought to make laptops thinner, they were limited by the bulky mouse and keyboard connectors used at that time. Digital Equipment Corporation in partnership with Philips took the next step in minimizing and standardizing protocols by developing the ACCESS.bus, which is a peripheral-interconnect computer bus based on I2C. The ACCESS.bus was offered to the computer industry as an open standard. The specifications released by the ACCESS.bus Industry Group stated that, "The motivation behind the ACCESS.bus was to define a single standard that could be used both inside and outside a computer."⁵ The ACCESS.bus allowed a computer host to communicate with the external peripherals as well as with on-board devices. With ACCESS.bus, the system could communicate and control up to 125 devices through a single microcontroller host equipped with an I2C port. This offered a number of advantages to both the end-users as well as the developers of the systems and peripheral devices.

Developers benefited from the efficiency of having to provide only one hardware port to connect to a number of devices. A single communication method for multiple device types logically promoted growth in software and hardware development. Furthermore, as an open standard, the ACCESS.bus had the potential to allow peripheral devices to work with different types of host systems.⁶ For the end-users, by providing an open standard and a common port, the ACCESS.bus design allowed lower cost, ease of implementation, and ease-of-use.

Although the ACCESS.bus design was an enormous stride in unifying peripheral device connectivity, it had a few pitfalls of its own as well. ACCESS.bus wasn't comprehensive enough to meet the needs of the fast-growing PC industry. There was a lack of industry support for the standard because there was a limited amount of devices compatible with the ACCESS.bus. Additionally, the specifications lacked the power and speed industry leaders were looking for. But industry leaders looked at the potential of the concept, and the limitations of the reality of the ACCESS.bus—and the Universal Serial Bus effort was born.

USB: The One (for Peripherals)

The USB effort stemmed from the need to improve the performance of the ACCESS.bus. According to Robert Dezmelyk, the President of LCS/Telegraphics and one of the original team members that worked on both standards, the motivation behind the USB standard was to create "a higher performance bus that would include not only input devices and peripherals such as printers, but also higher bandwidth devices."⁷ Ultimately, the USB device architecture included many design concepts that could be traced to the ACCESS.bus standard. USB's HID (Human Interface Device) class architecture for input devices like mice and keyboards, also borrowed from ACCESS.bus. In many ways, Dezmelyk continued, "the ACCESS.bus effort served as the prototype run for USB."⁸

With more than 6 billion wired USB connections in the world today, the USB standard is considered one of the most successful interfaces in personal computing, consumer electronics, and the mobile industries.⁹ The USB is a personal computer interconnect that can simultaneously support multiple devices using a simple four-wire cable. The motivation behind the USB standard was not only to

improve from ACCESS.bus, but also to increase ease-of-use for the end-user, provide a link for PC-to-telephone interconnects, and increase port availability between various devices.¹⁰ The USB standard increased the ease-of-use for the end-user by allowing the end-user to plug into the system at any time. Specifically, the USB protocol is able to handle the enumeration of the device and the notification to the system that it has arrived, without the end-user having to input additional software or changes in the process. Likewise, because the USB standard was designed to be as flexible as possible in regards to device configurations, it allowed USB devices the option to provide several configurations—increasing the device functions/interfaces.¹¹ For example, while a USB printer only provides printing as an interface, a digital camera provides the interface for direct communication with the camera as well as a mass-storage interface to download photos. Thus, the USB standard became the solution to connectivity for the PC architecture.

Additionally, the USB standard was able to define the concept of a “device class” based on concepts in ACCESS.bus.¹² In short, devices that have similar reporting characteristics are grouped together into a “device class.” This approach eliminated the need for a unique software driver for each type of computer peripheral device, and instead, only required a single “class” driver for each device class. For instance, the USB’s “HID Class” is one such group—with capabilities to describe themselves further to the class driver, i.e. what types of data the device can send and precisely how it reports data.⁹ In particular, a USB HID class device would meet the requirements of the USB core and HID Class specifications. These specifications would define the protocol, while the commands and data would be passed between the USB host adapter and the device. Consequently, the concept of a “device class” defined by the USB standard enabled future devices to be developed without the burden or need to modify the host software.

As innovation continued to pave the road in connectivity, USB 1.0 was quickly replaced by USB 1.1. Version 1.1 took over the industry, but was shortly superseded by USB 2.0. Simultaneously, smaller connectors were required for smaller devices, so the USB Implementers Forum also introduced the mini-USB connector in 2000—which was then replaced by the micro-USB connector in 2007.¹³ The micro-USB connector addressed the need for smaller components while meeting all the requirements for electrical performance within the USB 2.0 specification.¹⁴ You probably have at least one gadget with a micro-USB connector; it is now the industry standard for all smartphones other than Apple, and has been adopted as the power connector for cameras, MP3 players, and other small devices.

Evidently, from I2C to ACCESS.bus to USB 1.0/1.1/2.0 to power connectors on a variety of modern gadgets, standards development organizations have built a bridge of compatibility. By establishing the USB standard in peripheral devices, developers are given more freedom to focus on designing devices with value-added capabilities—without worrying about compatibility. For instance, whether a mouse is a wireless mouse or a gaming mouse, both utilize the USB standard to communicate with the computer host. For end-users, it has been easier than ever before to power and connect devices interchangeably.

HDMI: The One (for Display)

Comparable to the USB standard’s success in the mass market, the ubiquitous connectivity HDMI (High-Definition Multimedia Interface) standard shows up in many consumer electronics devices. According to Manmeet Walia from Synopsys, “with 18 Gbps bandwidth and performance, simplicity, and reliability as its key advantages, HDMI is the standard multimedia interface for digital [display] devices and continues to grow its install base.”¹⁵ In fact, beyond display devices, some smartphones support micro-HDMI for connecting your smartphone to a flat panel television, to play out a stored movie on the big screen. This starts—again—with I2C. In 1987, IBM launched the VGA display. As time went on, the need to signal parameters to the display grew until, in 1994, the DDC2 (Display Data Channel) standard was created by the Video Electronics Standards Association (VESA)—offering bi-directional communication between the display device and the computer graphic host.¹⁶ When VESA defined the DDC2 standard, VESA implemented different modes of communication: DDC2B, DDC2Bi, DDC2B+, and DDC2AB. Using I2C as the base protocol, the suite of DDC2 standards enabled the display device to communicate its display modes to the adapter, which then allowed the computer graphic host to adjust parameters on the display device, such as brightness and contrast. Furthermore, to encourage compatibility, the DDC2AB mode implemented the ACCESS.bus interface—also I2C-based—so that monitor manufacturers or end-users who still support ACCESS.bus peripherals, such as a mouse or keyboard, are able to directly connect their devices to a display device as well.¹⁷ Thus, the DDC2 standard effectively established the concept of a “plug and play” experience for computer displays.

As the need for a direct communication channel between a computer host and display device was answered by the DDC2 standard, the need for an interface to deliver high quality audio and video signal over a single cable arose and was answered by the HDMI standard in 2002. The HDMI standard was defined by seven of the largest consumer electronics manufacturers—Hitachi, Matsushita (Panasonic), Philips, Silicon Image, Sony, Thomson, and Toshiba.¹⁸ In addition, the HDMI standard inherited the DDC2 standard and used it for configuration and status information. The DDC2 standard defined the critical two-way communication line within the HDMI standard and provided content protection through the HDCP (High Digital Content Protection) signal.¹⁹ The HDMI standard offered several advantages to the digital video/audio world by being the first to provide uncompressed digital signals for the highest picture and sound quality, PC compatibility, two-way communication for easy system control, automatic display and source matching for resolution, and one cable for video, audio, and control functions for simplicity.²⁰ For developers, a one cable solution to video, audio, and control functions lowered overall BOM cost while simplifying software and driver development efforts for seamless integration.²¹ For end-users, the HDMI standard not only increased ease-of-use by eliminating the need for a maze of cables behind an

entertainment center, but also provided superior, uncompressed digital video and audio quality. Thus, the HDMI standard was able to immediately become globally accepted and industry supported.

CEA-861: Rules of the Road

Meanwhile the HDMI specification defined electrical and mechanical compatibility, the information it carries must also be standardized. A key element of this was defined by the ANSI/CEA-861-F, “A DTV Profile for Uncompressed High Speed Digital Interfaces” standard. This standard identified all the important characteristics of the uncompressed video to be carried. For example, it standardized the protocols and reference information used to identify the video format (e.g., whether it is HDTV, 4K UltraHD, etc.); details of how color information is transported; audio format and more. It also laid out implementations of the Video Electronics Standards Association (VESA) Enhanced Extended Display Identification Data Standard (E-EDID), which was used by televisions and other devices to declare their display capabilities and characteristics to the video source.²² Evidently, many video interface standards can trace such information formats back to CEA-861-F (Figure 1).

We’ve only touched on part of the story of standards that have inspired innovation in connectivity by addressing industry and consumer needs. But literally thousands of standards documents are involved in just this part. Each standard is built upon the fabric of an existing standard. Through looking at the evolution in connectivity, from smartphones to peripheral devices to display interfaces, standards provide the foundation for compatibility to permeate throughout diverse consumer electronics devices. Furthermore, the process of standards development creates a medium for issues such as the reliability in performance, the flexibility in design, and the simplicity in configuration to be addressed. For instance, the development of the I2C standard simplified the method in communication channels while the efforts in designing the ACCESS.bus standard provided the foundation for the USB standard to stem from. Although the HDMI standard’s current success stems from its ability to offer functions prior standards could not support, the HDMI standard could not have done so without tracing portions of its design back to functions defined by previous standards such as the DDC2 standard. The suite of DDC2 standards, in return, relied on protocols defined the I2C and ACCESS.bus standards. As developers continue to design future devices and value-added capabilities, it is crucial to be reminded of how to maximize the potential of future products through the ability of compatibility established by a world of existing standards.

Authors

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² Smith, Aaron, Pew Research Center, “*U.S. Smartphone Use in 2015*” 1 April 2015 <www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015/>.

³ Embedded Systems Academy, “*History of the I2C Bus*” <www.esacademy.com/en/library/technical-articles-and-documents/miscellaneous/i2c-bus/general-introduction/history-of-the-i2c-bus.html>.

⁴ *Ibid.*

⁵ *Ibid.*

⁶ ACCESS.bus Industry Group, “*ACCESS.bus Specifications Version 3.0.*,” September 1995 <http://measure.feld.cvut.cz/groups/micro/soucastky/spec/serial_p/Access_bus_spec_3_0.pdf>.

⁷ R. Dezmelyk, email, 3/2/2015. Mr. Dezmelyk chaired the USB Human Input Device (HID) standards committee during the period in question. <www.pointing.com/index.html>.

⁸ *Ibid.*

⁹ USB Implementers Forum, Inc., “*Wireless USB makes it easy*” <www.usb.org/channel/About_WUSB.pdf>.

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