The Amazon Echo Dot:

A "Smart Speaker" Teardown

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For

ECEN 5053: Developing the Industrial Internet of Things

On

Friday, March 30, 2018

INTRODUCTION

"When wireless is perfectly applied the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole. We shall be able to communicate with one another instantly, irrespective of distance." – Nikola Tesla [1]

"Any sufficiently advanced technology is indistinguishable from magic." – Arthur C. Clarke [1]

The importance and the growing influence of technology and most importantly, the Internet of Things (IOT), are being largely emphasized and re-iterated in our everyday lives in the form of various devices. The concept of "Smart Home" – an automated home filled with connected products and intelligent technology that simplifies everyday activities – is making lives easier, more convenient and comfortable. [2] Home automation looks to be the wave of the future, with endless possibilities for smart home IoT devices. According to BI Intelligence (Business Insider's premium research service), the number of smart home devices is expected to grow from 83 million in 2015 to 193 million in 2020. In addition to providing greater convenience, these devices help reduce costs and conserve energy. Amazon's range of smart devices is arguably the first and most recognizable name in the smart home devices space. The Echo, Echo Dot and the Tap are devices that function as a central hub for other smart home gadgets, with Alexa (their voice-activated assistant) providing the amount of convenience that few other products can match. [3]

THE AMAZON ECHO DOT

The Echo Dot is Amazon's latest brainchild – a smaller, more affordable, more portable solution to home automation. It is a hands-free, voice-controlled device with a small built-in speaker. It connects to the popular Alexa Voice Service to play music, make calls, send and receive messages, provide information, news, sports scores, weather etc., instantly. It has dimensions 32mm*84mm*84mm, weighs little more than 160 grams and has a speaker of size 0.6 in. [4] Priced at about 50 USD, it is highly affordable and consists of majority of features of its older sister – the Echo. Ever since its launch in March 2016, it has gotten rave reviews claiming it to be "a tiny box with a big brain that keeps getting smarter". [5] The Echo Dot has been the best-selling Alexa Device since its debut and has been the most popular item on Amazon's Prime Day sale. It is also said to be "a tiny little hockey puck that's winning by a mile" in the virtual assistant race. [6] Such is the popularity of the Amazon Echo Dot. The features that make it so are its compactness, the ability to connect to any audio system, its far-field voice recognition capability and constantly evolving functionality. [5] Amazon launched the 2nd generation Echo Dot in October 2016, more compact than the 1st generation and available in two colors – black and white. The device thus fulfills the niche of the higher-end smart home devices, and continues to be a highly rated and reviewed, successful product from Amazon. [4]

HISTORY & PREDECESSORS

Home automation and the concept and reality of a smart or intelligent home go back to long before the term Internet of Things was even coined. Standards and protocols used in building, home automation and lighting and room control context such as KNX, C-BUS or DALI bus technologies and wireless EnOcean have been in existence for over a decade. In the 1970s, the X10 home automation communication protocol was launched and enabled remote control of devices such as

[1] 23 Perceptive Tech Quotes About Information Technology
[2] The Future Of The Smart Home: Smart Homes & IoT: A Century In The Making
[3] How IoT & smart home automation will change the way we live
[4] The Amazon Echo Dot
[5] Amazon Echo Dot review
[6] FORGET THE ECHO. THE DOT IS THE MOST IMPORTANT ALEXA DEVICE

lamps. In the 1980s, platforms/protocols such as LonWorks and CEBus were launched. Some of these mentioned standards can be found in an Industry 4.0 context. In the 1990s, connected IoT devices/appliances already existed, albeit in limited ways and not as they look now. [7] The first smart device was the ECHO IV that was launched in the late 1960s. This device could compute shopping lists, control the home's temperature and turn appliances ON and OFF. It was never commercially sold. [8] The Nest smart thermostat launched in 2011 re-triggered the home automation industry after which many competitors such as Microsoft, Amazon and Google made their foray into the smart devices segment.

The Amazon Echo Dot, as outlined earlier, had a predecessor in the original Echo – Amazon's first smart device. The Echo was lauded as a step along the path to embedded systems that boasted true embedded speech and embedded vision. It introduced Alexa to the world. The Echo, although succeeded by other devices, is still sold today. Available in matt black, the Echo has almost the same size and shape as a cylindrical Pringles container. It is 3.25 inches in diameter and 9 inches tall. It is sold at a price close to 150 USD. [9] Easy to set up, excellent sound quality, expensive, introduction to intelligent automation – the Echo was a luxury to own, until the launch of the more affordable Echo Dot, which had almost all the features of its predecessor.

DEVICE MARKET AND APPLICATION AREA

The smart home devices market is a well-defined, competitive market with many firms selling similar products. With the advent of Industrial IoT and home automation, the popularity for smart home devices grew exponentially. Many SaaS (Software as a Service) based organizations began rolling out their own range of smart home devices, Amazon being one of them. The biggest competitor of Amazon, so far, has been Google, which produces another home automation device – the Google Home. The Apple HomePod is another close competitor, although with a whopping price tag of close to 350 USD, it remains a device for the elite. The Google Home uses Google's own Voice Assistant. The Home is known to be simpler to set up and use, Google Assistant is known to be more efficient at answering questions than Alexa, but the brand value for Alexa and the Echo series is huge and that sets Amazon apart. According to estimates by an online publication, Amazon has sold over 20 million smart home speaker units by October 2017. Three separate reports in 2017 placed Amazon's US market share of smart speakers between 70% and 76%. [10] The Echo Dot shares 32.3% of the total share. [11] Amazon posted a record profit of 1.9 billion USD during the last three months of 2017, which marked its 11th straight quarter of positive net income, the majority of its profits coming from its major growth area – the Alexa voice assistant technology. The profits made may be modest for a company of its size, but Amazon believes in investing in big new initiatives that will allow it to reap meaningful financial results some years down the line and hence runs its core retail machine at break-even. [12]

[7] Smart homes: the smart home in the age of the Internet of Things
[8] The History of Smart Homes
[9] The Amazin' Amazon Echo... Echo... Echo
[10] Amazon Echo's dominance in the smart-speaker market is a lesson on the virtue of being first
[11] Amazon Echo Maintains Large Market Share Lead in U.S. Smart Speaker User Base
[12] Amazon has posted a profit for 11 straight quarters — including a record $1.9 billion during the holidays

The major application area for the Echo Dot is Home automation. Apart from its basic use as a speaker, it serves as an intelligent device and can be connected wirelessly to other devices such as home theatre, smart watches etc., and can provide services such as control of electrical devices. Other application areas include automotive industry (in vehicles), which would allow users to lock, unlock, honk, get status updates on the vehicle using their voice. Alexa is looking to be incorporated in Televisions and Windows 10 computers too. [13] A large number of office managers, assistants and analysts have started using the Echo Dot in their workplace, where they leave the menial tasks to be done by Alexa, leaving them to focus on more valuable and fulfilling work. On the administrative side, the Echo Dot can be used to fetch sales figures, usage metrics or generate reports, book conference rooms, control A/V equipment, assign tasks or set follow-up reminders. The Healthcare sector can also benefit using the Echo Dot, which would provide tracking and logging of information, retrieving information and so on, thereby reducing the amount of work to be done using a pen/paper and improving cleanliness. [14]

THE ECHO DOT – A SOLUTION TO EFFECTIVE AUTOMATION
The Echo Dot, more than solving a problem, focusses on making lives easier through technology and automation. Essentially, in a way, it can be said to solve the problem of "no automation" or "inefficient automation". Where some devices/technologies fail to deliver, the Echo Dot delivers. There is one technology that sets the Echo Dot apart, without which it is just another home speaker. That technology is Alexa – Amazon's Voice Assistant. Moreover, the most wonderful thing about Alexa is how modifiable, customizable and open to further growth it is. Amazon, in a unique manner, introduced the Amazon Developer platform, Alexa Skills Kit and the new Smart Home Skills API, allowing developers to put their skills to work and customize the Echo Dot to perform functions as needed. Developers have been working to make thermostats, smart lights and switches controllable through voice commands issued to the device. Further, smart garage-door openers, security systems, and other smart-home controls are being developed to further extend the usability of the Echo Dot. [5] This is in addition to the usual functions it performs, like connecting to internet music services, making phone calls, controlling lights and temperature, voicing out daily news, getting answers to just about anything, setting alarms and reminders, booking cabs, ordering through Amazon and so on. In addition, Alexa is built in cloud (AWS – Amazon Web Services), which means that it keeps getting smarter. The more the device is used, the more it adapts to our speech patterns, vocabulary and personal preferences. It is always connected and updates are delivered automatically. [4] There is also constant addition of skills, which makes the Echo Dot an ever-evolving smart device.

REGULATIONS
All Bluetooth-enabled devices that provide any form of connectivity are subject to FCC regulations in the USA. The Echo Dot falls under Part 15 of the FCC Rules for Class B digital devices (no-license radio services in the USA) [15]. The Federal Code of Regulation (CFR) FCC Part 15 is a common testing standard for most electronic equipment. FCC Part 15 covers the regulations under which an intentional, unintentional or incidental radiator that can be operated without an individual license. [16] FCC Part 15 is said to cover both unintentional radiators as well as intentional radiators. The Echo Dot is a Class B digital device – marketed for use in a residential environment

[13] 8 new places you will find Alexa this year
[14] Three places we'll see Amazon Alexa dominate (besides the home).
[15] LWCA Library Reference Section
[16] Class B digital device part 15 of the FCC rules

notwithstanding use in commercial, business and industrial environments. [16] The Echo Dot is an unintentional radiator – it contains clocks, oscillators or logic circuitry but does not deliberately generate radio frequency emissions. [16] The device, before being brought into the market, is verified to meet the FCC compliance, declared that it meets the appropriate technical standards, and certified based on representations and test data. [16] The operation of the device is subject to two conditions – it must not cause harmful interference, and must accept any interference received, including interference that may cause undesired operation. [17]

The electronics inside of the Echo Dot are tightly regulated in some areas when it comes to their disposal. This is due to the heavy metals and other hazardous materials they contain. It is illegal to dispose of electronics in landfills in cities like Boulder, Colorado. The materials must be taken to specialized recyclers, which separate harmful material from trash and then reuse or dispose them in a different manner than the rest of the non-harmful materials. [18]

TECHNICAL DETAILS

The Amazon Echo Dot V2.0 is primarily a microcontroller-based device. The model number for this device is RS03QR. Its power requirements are 5V DC, 2A. The connector type is USB Female Micro-B. It supports Alexa, Bluetooth 4.1, light ring volume adjustment and has a 3.5mm audio output and a 7-microphone array. [19] Its size is 32 mm * 84 mm * 84 mm. It weighs 5.7 oz. (163 grams). It has Dual-band Wi-Fi, which supports 802.11 a/b/g/n (2.4 and 5 GHz) networks. It does not support connecting to ad-hoc (or peer-to-peer) Wi-Fi networks. It has Advanced Audio Distribution Profile (A2DP) support for audio streaming from mobile device to Echo Dot or from Echo Dot to a Bluetooth speaker. It supports Audio/Video Remote Control Profile (AVRCP) for voice control of connected mobile devices. Hands-free voice control is not supported for Mac OS X devices, and Bluetooth speakers requiring PIN codes are not supported. The device has a built-in speaker for voice feedback when not connected to external speakers. It also has a 3.5mm stereo audio output for use with external speakers. The device can be accessed and controlled using the Alexa App, which is compatible with Fire OS, Android and iOS devices and accessible via web browser. It comes with a 90-day limited warranty and service. [4] It has a MediaTek CPU (1.5 GHz, with 4 cores) and a 512 MiB Micron RAM. It also has a MediaTek Wi-Fi chip. Additional chips include MediaTek Power Management IC, Low Power Stereo Audio Codec from Texas Instruments, 92db SNR Low-Power Stereo ADC from Texas Instruments and Knowles SiSonic Microphone. [19] It contains two circuit boards – the Motherboard and the Control Board. Many of the components in the Echo Dot are very small and do not contain manufacturer's identification markings. It is built around MediaTek microchips. [20]

DESIGN CONSIDERATIONS

Amazon's smart home range of products have huge competition in the market, with companies such as Apple, Microsoft and Google. The design, thus, is made to stand out from the competitors. The Echo Dot is an improvement on the original Echo in terms of size, cost, ease of use and portability. Although it compromises on the speaker quality, it is offset by the external speaker support that it offers. The second generation Echo Dot has a more powerful processor. When there is more than one Echo Dot device in the same house/room, Amazon's voice assistant Alexa will use Echo Spatial Perception (ESP) to respond to the user from the nearest device.[21] The Echo Dot

[17] https://d3nevzfk7ii3be.cloudfront.net/igi/kqLes4ELrLqKvwkN.huge
[18] Boulder County Electronic & Computer Waste
[19] Amazon Echo Dot (RS03QR)
[20] Teardown Tuesday: Amazon Echo Dot v2
[21] How Amazon Echo Works

is compact, has nicely rounded edges and has better looks than its competitors like the Google Home. It has glowing LEDs (RGB) to indicate status of the device and a light ring volume adjustment, which enrich its look and usability. The Amazon Developer platform and the Alexa Skills Kit allow continuous updates to be made to the system and new features to be incorporated by third-party developers. The 2.4 GHz and 5 GHz bands are used – these are frequencies used by many modern systems, including Bluetooth and Wi-Fi. Although it results in a band that is packed with interference, the range offers advantages such as more devices per area and better range in modern construction. [22]

WORKING

The Echo Dot has almost all features of its parent – the Echo, and works very similar to it, albeit with a few improvements and new features. It is a Bluetooth speaker that plays music and other audio or connects to other speakers and sound systems. It does so much more than that, though. It has voice-recognition capabilities and is one step closer to the voice-controlled computers of science fiction that have been making appearances in television and movies. The basic functions of the gadget include playing music, telling daily weather forecast, making to-do lists, setting up reminders, dim lights, turn appliances on or off, read daily news and so on. By design, the user interacts with the device in a hands-free manner, which makes it extremely convenient to use. The device connects to the Internet via a home/office Wi-Fi network. It listens and responds to a "magic word" – Alexa, which can also be customized on the app. Once it hears and recognizes the word, it gathers voice commands that follows and sends them to a natural voice recognition service in the cloud called Alexa Voice Service, which interprets them and sends back the appropriate response. The device has an array of microphones that can pick up voices from across the room, even over music and other environmental noise. [21]

The Hardware part of the Echo Dot is quite intricate, with many small components providing various functionalities. A microphone ON/OFF button and an action button at the top of the device exist opposite each other, as are the Volume Up (+) and Down (-) buttons that exist opposite each other. These provide control options for the device. A ring around the circular top consists of LEDs with RGB configurations, which light up appropriately (Red during configuration, Green after successful set up and Blue during listening process). Turning/Rotating the ring enables adjusting of speaker volume. The main control, though, is in the 7-microphone array built into the top, which uses beamforming technology and noise cancellation to hear the user, record it and send it to the cloud for processing work. An LED that gives the status of the device's Wi-Fi connection exists near the base just above the power cord. The Echo Dot comes with a 21-Watt power adapter, which is its only power source. [21] This means that it cannot be carried around to places without plug-point connectivity. The device incorporates a small speaker (Knowles SiSonic) attached to a steel plate, the whole entity protected by a rubber pad/anti-slip mat which ensures that the device does not move or slip while it is being operated. The steel plate has screws (T8 Torx screws) threaded from bottom to top of the device. The speaker connects to the Dot by way of couple of pairs of spring contacts. The device contains two circuit boards – the motherboard and the control board, each housing various components. A thin ribbon cable ties all the layers (rubber pad, steel plate, two boards) together. The motherboard, with its ports, lie at one end while the control board with volume controls and microphone array lie on the other end. The single rubber cable threads its way through the intervening layers to connect the two boards. [23] The motherboard consists of chips on

[22] WHY EVERYTHING WIRELESS IS 2.4 GHZ
[23] Amazon Echo Dot Teardown

one side and ports on the other. It consists of a MediaTek Digital Media Processor – which processes music and other media to be voiced out, Micron 512 MB RAM to house and process data, a Micron 4GB High performance NAND Flash memory used as data buffer or for firmware upgrades, MediaTek dual-band 802.11n Wi-Fi and Bluetooth 4.0 modules to enable Wi-Fi and Bluetooth connectivity, MediaTek Integrated Power Management IC and a Texas Instruments DAC for conversion of digital signals to analog for processing. The top of the motherboard also consists of an audio jack that is mechanically fastened to the circuit board next to the micro-USB port. [20] The top of the control board consists of four tactile switches that control volume, mute microphone and serve as action button. It also consists of a microchip U3 that serves as a light/color sensor. Also located are six equidistant perimeter holes and one central hole to support the 7-microphone array located on the opposite side of the circuit board. [20] The bottom of the control board consists of two variations of surface-mount microphones, 12 RGB LEDs that are used to indicate change of state, 4 Two-channel Texas Instruments ADCs that convert the microphone outputs to digital signals, a microcontroller that connects the switches and the LEDs, and the ribbon cable connector that leads to the mother board. [20]

The real brains behind the device rest in the Cloud, and that is where software plays a huge role. [21] The bulk of the processing work is not taking place on the device, but in the cloud. Alexa is a cloud service – software-based service running on many powerful servers in one or more data centers accessible via the Internet. Alexa parses spoken words, interprets commands and routes them to appropriate web services to get the response. The response is then converted and sent back via audio to the device, and in many cases via text and graphical cards to the Alexa app home screen. The device connects to other devices via Bluetooth and supports audio streaming from smartphones and tablets via A2DP and AVRCP. [21] The device can be set up and accessed via the Alexa App, as well as via an optional remote control. The glue that ties all components and functions of the device together is the software. Automatic Speech Recognition (ASR) is the Echo Dot's signature feature. It is enabled by software algorithms that provide language modeling and natural language understanding capabilities that make the platform unique, and help offset the rigors of reverberant speech. It consists of cloud-based deep neural networks (DNNs) capable of performing roughly 1 billion arithmetic operations per second in support of ASR algorithms, beamforming and noise cancellation techniques. Innovations in sensor technology can help remove some of the overhead associated with massive DNNs to eliminate background noise and improve directional acquisition for speaker isolation. The optical sensor technology converts vibrations from a speaker's cheek, larynx and other facial areas into an audio signal, which is then fused with inputs from traditional acoustic microphones to generate noise-free audio signals that can be used to enable applications such as access control and voice authentication. [24] Alexa's voice-recognition algorithms improve with use, learning speech patterns and word usage. It is interactive in nature, with feedback helping Alexa to hear and speak better. Updates download to the device automatically and many of the device's features reside in the cloud, enabling Amazon and third party developers to add to them anytime. [21]

The constraints with using the Echo Dot are the necessity of electrical connectivity and Internet connectivity. Without Internet, the device would feature only as a speaker; without electrical connectivity, the device cannot be powered on at all.

[24] Deconstructing Alexa – Software and sensors of the Amazon Echo and beyond

SECURITY CONCERNS

As with any device/technology, there are downsides to the Echo Dot too. A major issue with the Echo Dot is security. The device tends to perk up and listen "too much"/even when we do not want it to. The response, then, to what is sure to be a misunderstood question will come as a surprise especially when we are out of visual range/did not realize we were being listened to. Alexa's Far-field communication capability – which allows the device to hear users even when they are all the way across the room, is also a security concern. People consider the device as an invader of privacy/spy. [5] The notion of a device "listening" to us continuously is disturbing to many. In addition, the device answering when it was not meant to be asked something is a factor that pulls the rating of the device down. Also, AWS regions experiencing widespread outages and the service to their Alexa-powered device being knocked out as a result for almost a day, means that the device(s) is/are vulnerable to external environmental problems and cannot offer complete predictability/response. Thus, the device can be taken down by a variety of problems, including internet outages, loss of internet access, AWS outages, and loss of Wi-Fi access. In such cases, alerts like broken pipes would not be received, smart TVs would revert to being non-smart, remote control access would be lost and so on. These issues arise because the intelligence of intelligent agents is not in the local device but the cloud; and when the link to the cloud is broken, the local intelligence disappears. Data breaches are also possible, which endangers the privacy of the user. Sadly, this could have life-threatening implications if the device controls things such as security and HVAC systems. As the level of automation increases, the risks also become more pronounced. [25]

CONCLUSION

The Amazon Echo Dot, being a small compact-sized device, has made a large impact on the smart home devices market. It incorporates various functions and automation capabilities, is popular in both homes as well as offices for personal as well as professional use. It has features that definitely make everyday life easier, which is the major reason for its popularity. Alexa is one of the very few voice-activated assistants that is mostly untethered from a full-featured computing device. The Echo Dot is a hands-free step towards integrated virtual home assistants; it is only a matter of time before users can issue voice commands for all household chores from the moment of waking up to the moment of going to bed. [21] Thanks to the Echo Dot, fully automated smart homes are beginning to seem real.

The improvement areas of the device include the speaker system and connectivity options. The speakers could be made better, with a woofer or a tweeter to enhance sound quality. The connectivity could be wireless, which would give rise to greater portability and use. The device can be expanded to markets such as healthcare, automotive and transportation, as well as to agriculture, oil and gas and energy to perform menial tasks such as storing data and setting up reminders – leaving personnel to concentrate on the more complicated tasks associated with these industries.

The case study on the Echo Dot portrayed the applications of many topics covered in the course. The Echo Dot and other smart home devices incorporate Wireless and Bluetooth technologies, power management, microcontrollers, and embedded design. The products are being increasingly used by a large number of people in recent times, and this number is only bound to increase in the

[25] Smart Homes: The Power, the Pleasure and the Pain

future. The ease of use and attractive features that simplify and automate everyday life are the advantages of these devices. This case study is inspiring and leads the path for studying and working on more advanced technology and products. By inspecting the circuity, the working of the device and its components could be inferred, and this is attributed to the learnings obtained from the course. Most of the chips had labels that had to be demystified using datasheets, which led to better understanding of the working of specific components of the device. Technical information regarding some components of the device was relatively difficult to obtain, especially MediaTek components, since MediaTek, unfortunately, does not provide datasheets or technical briefs for their microchips on their website. [20] The Echo Dot is an example of the need for embedded engineers across all fields, which is inspiring. Overall, it is an intricate design that serves the purpose of device longevity, while increasing usability.
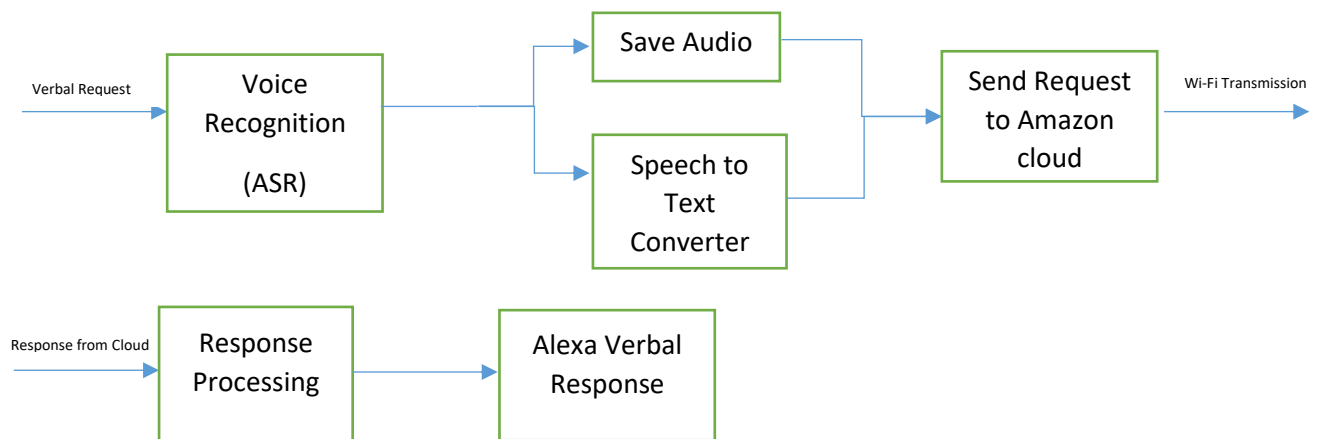
APPENDIX
BLOCK DIAGRAM WITH INTERFACE DESCRIPTIONS

GENERAL BLOCK DIAGRAM

FIRMWARE BLOCK DIAGRAM
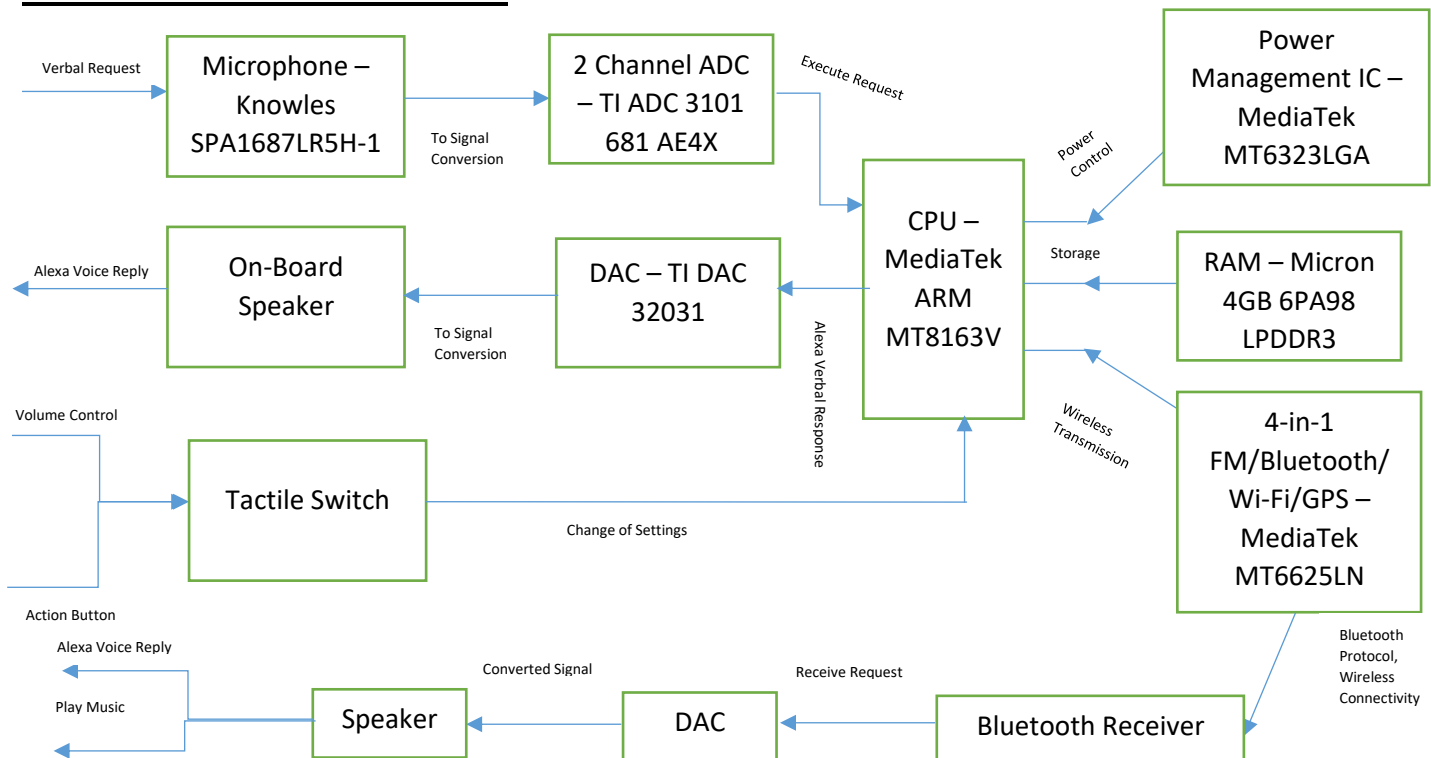

HARDWARE BLOCK DIAGRAM

Figure 1 The Echo Dot V2 [26]

Figure 2 The bottom of the Dot with the cushioning pad removed reveals the four Torx screws. [26]
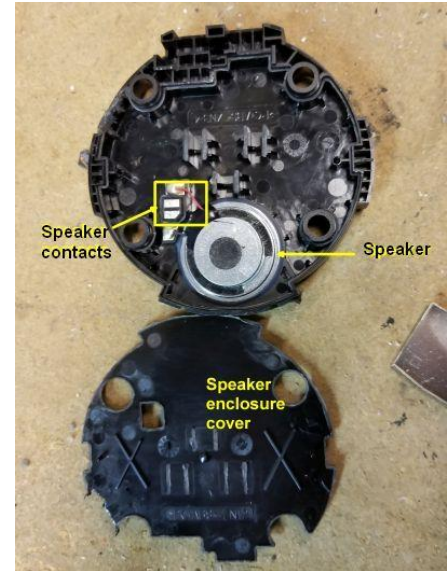

Figure 3 The Speaker, exposed [26]
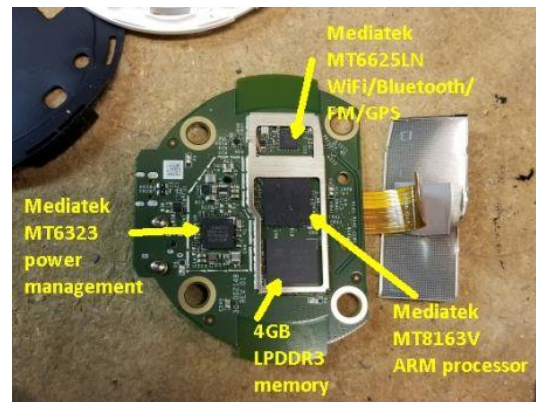

Figure 4 Top of Motherboard [26]

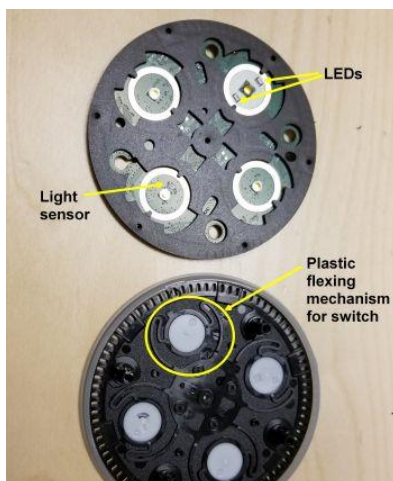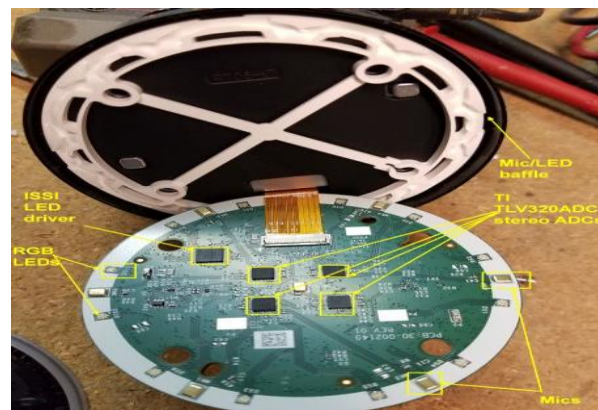Figure 5 Bottom of Motherboard [26]

Figure 6 Top of Control Board [26]

Figure 7 Bottom Of Control Board [26]

[26] Teardown: Inside Amazon's Echo Dot