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High-End Audio on the Raspberry Pi

Use the Raspberry Pi for Audio and Music Creation Without Breaking the Bank

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element14 is a Community of over 800,000 makers, professional engineers, electronics enthusiasts, and everyone in between. Since our beginnings in 2009, we have provided a place to discuss electronics, get help with your designs and projects, show off your skills by building a new prototype, and much more. We also offer online learning courses such as our Essentials series, video tutorials from element14 Presents, and electronics competitions with our Design Challenges.

It's reasonably well-known that the Raspberry Pi single board computer has built-in audio capabilities, but one doesn't necessarily associate it with high-end audio. However, when paired with the right add-on hardware and software, the Pi can become an audio powerhouse that delivers strong performance at a very reasonable price. This eBook will discuss using the Raspberry Pi for high-end audio, some useful peripherals for this purpose, making music with the Pi, and more.

element14 Community Team

CHAPTER - 1 What Is High-End Audio?

When it comes to high-end audio, people tend to think of expensive systems, such as a Rega Planar 10 turntable paired with a Cambridge Audio AXA 35 integrated amplifier with a pair of McIntosh XR100 speakers. Or maybe they envision Cambridge's DacMagic 200M DAC/Amp coupled with a set of Sennheiser Momentum headphones. But most don't think of the Raspberry Pi as a high-end audio solution, and yet it can be, with a bit of help from add-on boards and fidelity software.

High-end audio is an ambiguous term, and is usually a moniker aimed at audiophiles who prefer esoteric or novel sound reproduction technologies. It can also refer to the price of expensive audio hardware, the quality of the components, or the quality of sound reproduction. Of course, "sound" is a subjective term that doesn't signify "one sound fits all," as music reproduction isn't the same sonically for everyone. Some prefer a prominent bass tone, while others go for mid and high tones; but what they all have in common is the clarity and fidelity of the music.

HD audio, high-resolution audio, and high-definition audio are marketing terms used by music retailers and high-fidelity sound reproduction equipment vendors. There is no standard definition for high-resolution audio. Still, the term is generally used to describe audio signals with bandwidth and dynamic range more significant than that of Compact Disc Digital Audio (CD-DA). This includes PCM (Pulse-Code Modulation) encoded audio with sampling rates at 44,100 Hz and above, with bit-depths greater than 16, or their equivalents using other encoding techniques such as PDM (Pulse-Density Modulation).

When it comes to fidelity assessment, a few factors come into play:

- The fidelity of sound reproduction may be assessed aurally or using measurement equipment to gain FR (Frequency Response), THD (Total Harmonic Distortion), noise, and other characteristics.
- Measurements such as FR, THD, and noise can be deceiving, however, as high or low figures of specific technical characteristics do not necessarily offer a good representation of how the equipment sounds to each person.
- The human sense of hearing is subjective and difficult to define, as humans perceive sound differently.
- Sound reproduction using particular hardware and equipment, such as speaker wire and connectors, is also subjective, as the validity of those products is often questioned.

The last bullet point can be validated in terms of noise reduction and audio throughput, as it's well known that wire produced with copper, silver, or gold can affect fidelity. Still, most casual listeners may not perceive a difference in sound quality between the metals or other exotic materials. That said, the human hearing range for healthy persons ranges from 20 Hz to 20,000 Hz, and most can't hear higher than 15,000 Hz.

CHAPTER - 2 Digital Audio Basics

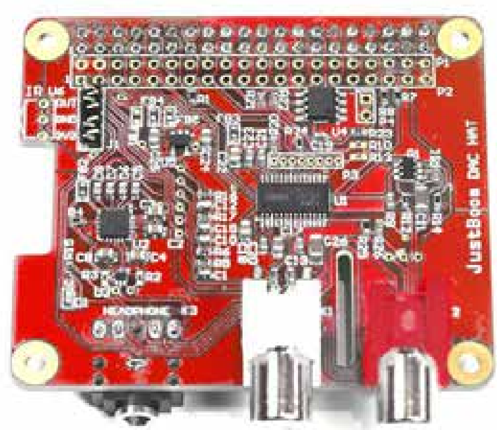
Digital audio has matured over the years, and with its improvements it has seen increases in **sampling frequency** and **bit depth.**

The **sampling frequency (or sample rate)** is the number of times that samples of the signal are taken per second during the analog-to-digital conversion process. According to the Nyquist theorem, the sample rate should be at least twice the frequency of the highest audible frequency, in order to avoid aliasing. Additionally, analog-to-digital converters use an anti-aliasing filter, a low pass filter, that filters out everything above a certain frequency to eliminate any signals that might cause aliasing into the audible range. CDs have a sample rate of 44.1 KHz, enabling them to reproduce frequencies as low as 0 Hz and as high as 22,050 Hz, making them adequate for reproducing the frequency range that most people can hear.

Proponents of higher sample rates argue that 44.1 kHz is insufficient, because certain instruments generate harmonics well above the 22 kHz limit, yet have an audible effect on the sound. Many digital music files have sample rates of 88.2 kHz or 96 kHz and higher, allowing anti-aliasing filters to be set much higher, letting more of the high frequencies through.

Bit depth describes the resolution at which the audio is sampled. Higher bit depths translate to a more accurate audio signal. Soundwise, it means more dynamic range; more of the quiet signals can be heard, rather than disappearing into the noise floor. For every 1 bit increase, the dynamic range increases by 6db. CDs are 16 bit, translating to a dynamic range of 96 db. 24 bit audio files have a theoretical dynamic range of 144 db; however, at these levels, the limitations of the analog components driving the converter start to show themselves.

The above describes sampling frequency and bit depth for PCM. PDM is a different encoding process and has its own specifications, with lower bit depth samples at much higher frequencies. One form of PDM, Sony's Direct Steam Digital (DSD), stores 1-bit samples at 2.8 Mhz or 5.6 Mhz.



JustBoom's JBM-001 DAC/Amp HAT

A high-end digital-to-analog converter for the Raspberry Pi that provides audio at 32-bit/384 kHz.

CHAPTER - 3 Can the Raspberry Pi Do High-End Audio?

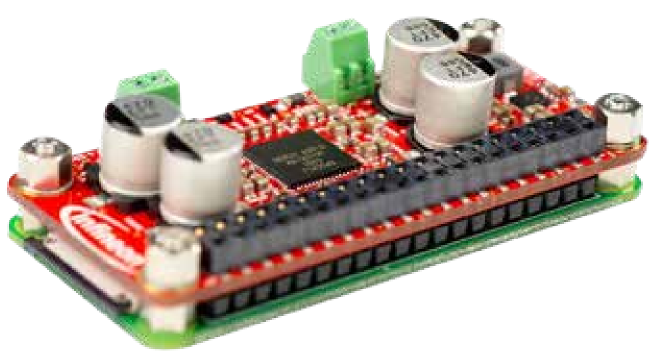
While there has been rising interest in analog sound systems with the resurgence of vinyl records, the same is genuine for media centers, which can handle streaming HD audio with minimal loss. This brings us back to the Raspberry Pi, as some have used the popular development board to create HD audio platforms that some serious enthusiasts are noticing. By itself, the Raspberry Pi isn't particularly well suited to pump out HD audio, due to its composite jack being somewhat noisy. Another limitation is that the Pi has only one other audio I/O, which is digital (HDMI). The latest board in the series, the Raspberry Pi 4, features the same analog audio found on the Pi 3, which was prone to crackling when using the 3.5mm jack. The problem has since been rectified on the Pi 4 via PWM and a driver update. The bottom line – HD audio enthusiasts will not get great audio using the Pi by itself.

To help rectify those auditory issues, companies have designed unique HAT (Hardware Attached on Top) add-on boards to provide excellent audio equipped with everything from DACs (Digital-to-Analog Converters) to amplifiers. JustBoom's

JBM-001 DAC/Amp HAT is an excellent example of an add-on board that provides HD audio. The board comes outfitted with a DAC (digital-to-analog converter) and a headphone amplifier that provides a 32-bit/384 kHz frequency. It also includes line-level RCA and headphone amplified 3.5mm jack outputs, volume control, and draws its power directly from the Pi. The board also provides a 112dB signal to noise ratio (SNR) and -93dB total harmonic distortion (THD +N at -1dB), and can be used with the Raspberry Pi A+, B+, and 2B. Audio enthusiasts have used the JBM-001 to design multi-room audio players, media center stations, and stand-alone HD audio players.

Infineon's MERUS audio amplifier HAT is another great add-on board designed for the Raspberry Pi Zero, and is geared more for sound amplification. The board is equipped with Infineon's MA12070P multi-level amplifier that provides up to 40 W of peak power. The add-on board draws its power from the Raspberry Pi and provides 24-bit/48 kHz audio playback. Complete hardware control, customization, and error monitoring are done via Linux Alsamixer. Because of its size, users have tasked the amp for portable Pi projects, including players and speakers. The MERUS can run a myriad of streaming apps that are compatible with the Pi, including Volumio, Max2Play, and the JustBoom player.

If full-house HD audio is the goal, then Micro Nova's AmpliPi multi-room/zone audio controller is a great solution. The system is designed around a Raspberry Pi Compute Module 3+ and comes packed with PCM5102A and CM6206 audio DACs. The Pi can also communicate via I2C to an STM32F030 MCU integrated on a preamp board to control muxing (multiplexing) and amplification systems. The AmpliPi is capable of streaming four independent sources to 6 stereo output zones, which can be expanded up to 36 stereo output zones through daisy-chained extender units. It can also drive up to 12 speakers, with up to 79 W per speaker.



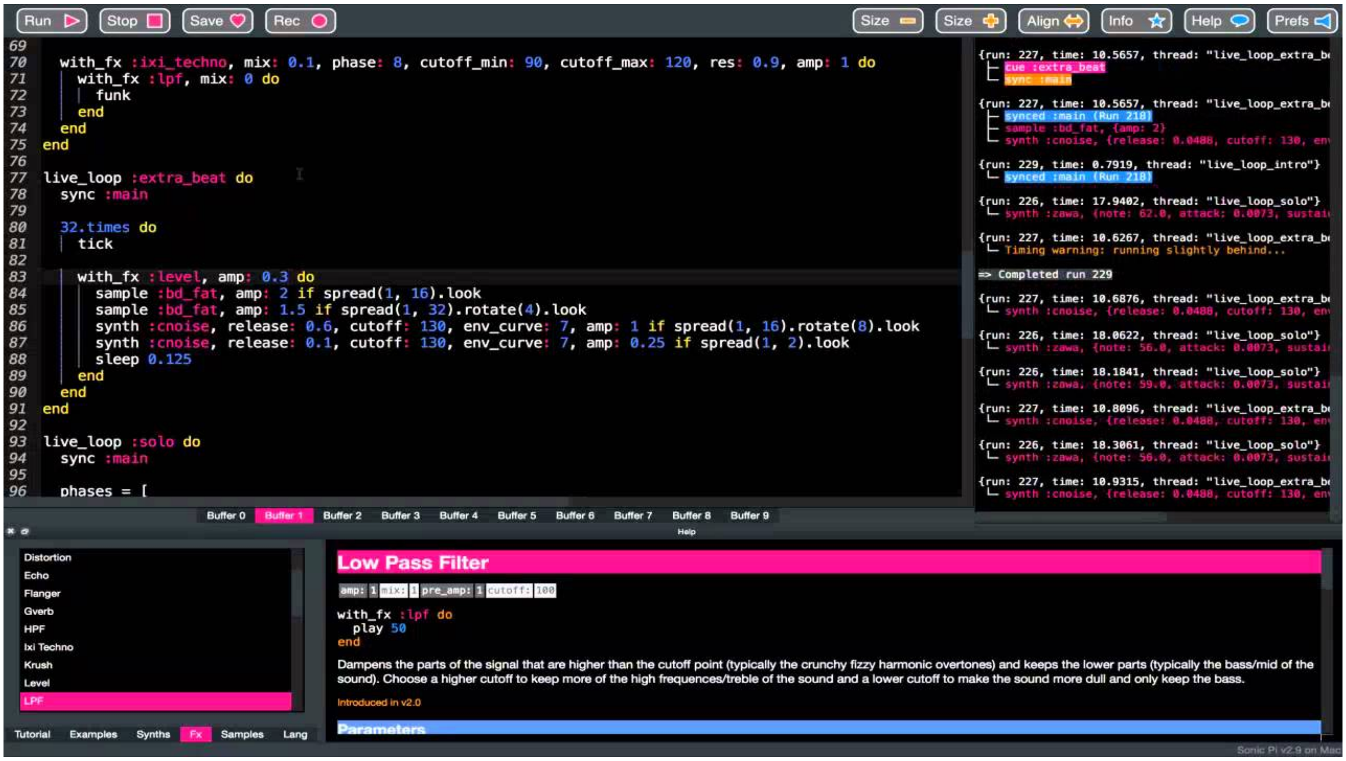
Infineon's MERUS Audio Amplifier HAT

Outfitted with the company's MA12070P multi-level amplifier, it provides up to 40 W of peak-level power at 24-bit/48 kHz.

CHAPTER - 4 Gettin' Your Groove on with Pi

These were just a few hardware examples available to enthusiasts and music-lovers alike that are great for adapting the Raspberry Pi for high-end audio streaming and DIY projects. The Raspberry Pi is also an excellent platform for music creation, and in this arena, it relies more on the software side than hardware.

The Raspberry Pi was created to be a learning tool for kids in school to become familiar with electronic hardware and coding, and has evolved using those principles to create and produce music. While hardware plays a significant role in creation and production, the software is key to making them a reality. One of the better tools on the market that



Sonic Pi is a live coding platform for music production and performance, and has been used as a learning tool in schools for computing and music lessons. (Image credit: Sonic Pi)

many artists have utilized is the open-source platform Sonic Pi, a live coding environment based on Ruby.

Users can use the platform to compose and perform music in different styles, from classical to EDM, and learn to code along the way. Users can create new sounds, synthesizers, and samples via text inputs, translated into algorithmic compositions using MIDI note numbers. Sonic Pi also lets users loop their creations, switch synths on the fly, enter and create samples, incorporate FX, and more. Sonic Pi is a versatile tool, complete with walkthroughs, video tutorials, and even project outlines for educators.

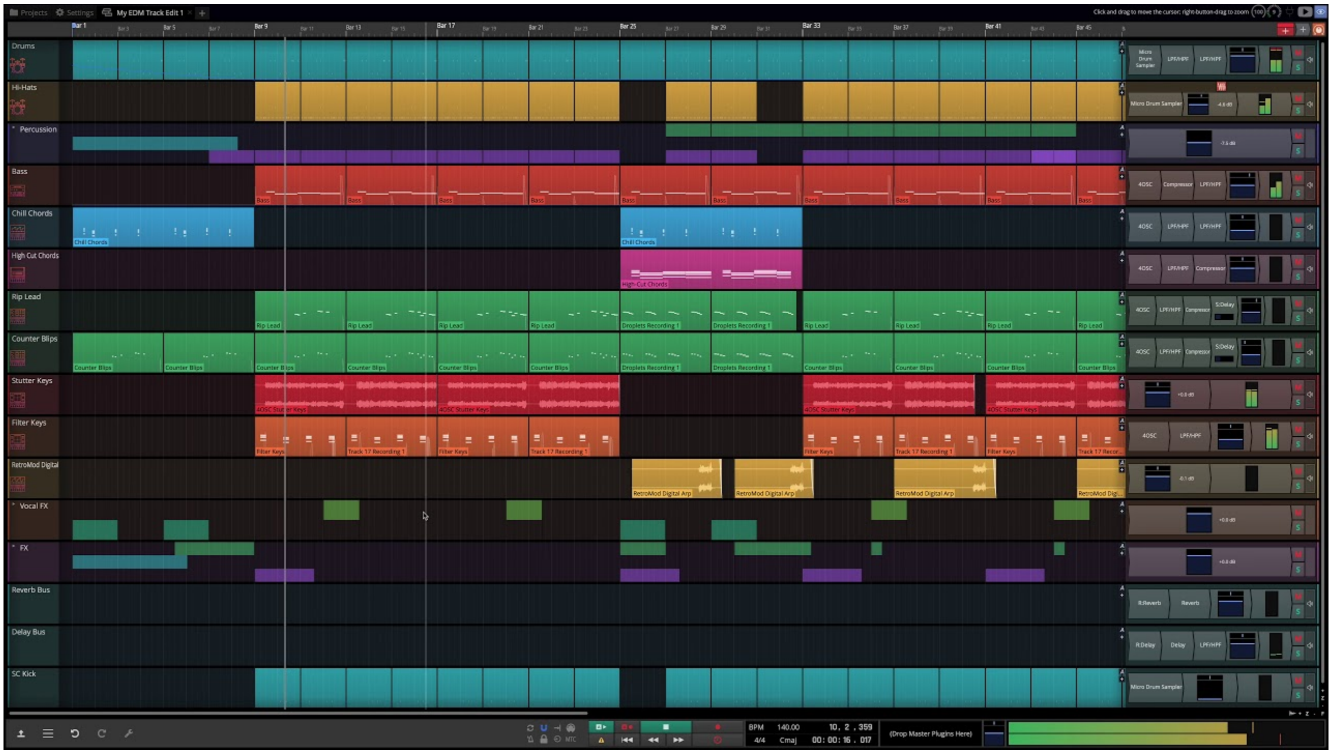
MilkyTracker is another free tool for composing music using the Raspberry Pi, which acts as a sequencer to position musical notes on a timeline using several channels. The software uses model tracking, which is done via control of multichannel sample playback. An instrument is created by arranging one or more audio samples across a keyboard range. That instrument is then sequenced on a monophonic track that contains note, volume, and effects. Those inputs are then used to create a pattern in a series of tracks that are played back simultaneously. Users can then create songs by arranging the compiled patterns. For example, users could create a melody on one channel, add in different synth sounds on another channel, and create percussive beats on a third.

Tracktion Software's Waveform DAW is one of the easier-to-use platforms for creating and editing music using the Raspberry Pi. Waveform is designed to be transparent and intuitive, using drag-and-drop system filters, allowing users to track object controls and parameters for each input or musical sound. Users can add effects, MIDI

Raspberry Pi 4 Model B - 2GB

instruments, and other software objects to tracks, or even apply them directly to individual audio and MIDI clips using filters. Complex chains of filters can be created and stored for later use as rack effects, if needed.

Waveform comes in two versions – Free and Pro, with the latter allowing for full band recording, complete with vocals, a full suite of effects plug-ins, and content resources. Think of it as a complete studio in a package. Users can also purchase add-ons, including synthesizer packages, virtual instruments, and different sound/FX packs to create their sonic masterpieces.



Tracktion Software's Waveform DAW is designed for recording and editing audio and MIDI tracks using instruments, effects, samples, clips, and more. (Image credit: [Tracktion Software Corporation)](#)

CHAPTER - 5 Pi Audio Project Examples

The Raspberry Pi Looper

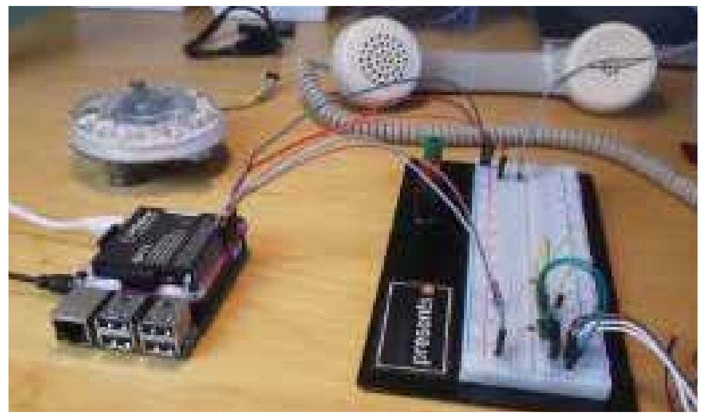
Toby Hendricks, an electronic musician known as otem rellik, became dissatisfied with the iPad he had been using in live performances and decided to build his own device using Raspberry Pi. The result is reminiscent of classic loop stations and MPCs, which have been a part of many genres of electronic music and hip-hop for decades.

These devices give the musician access to touch pads, knobs, and faders to record and perform, and they're useful both in writing songs and performing them. With these tools, the loop station practically becomes a music production computer without the computer, in that it can be used to record performances as MIDI information, create sequences by organizing the existing performances into a song that can be played back and changed on the fly, and to control numerous parameters within the song project. With his Raspberry Pi-based looper, Hendricks gave himself not only the flexibility inherent in this type of electronic instrument, he also used his hacking skills to create a device with exactly the features he needed.

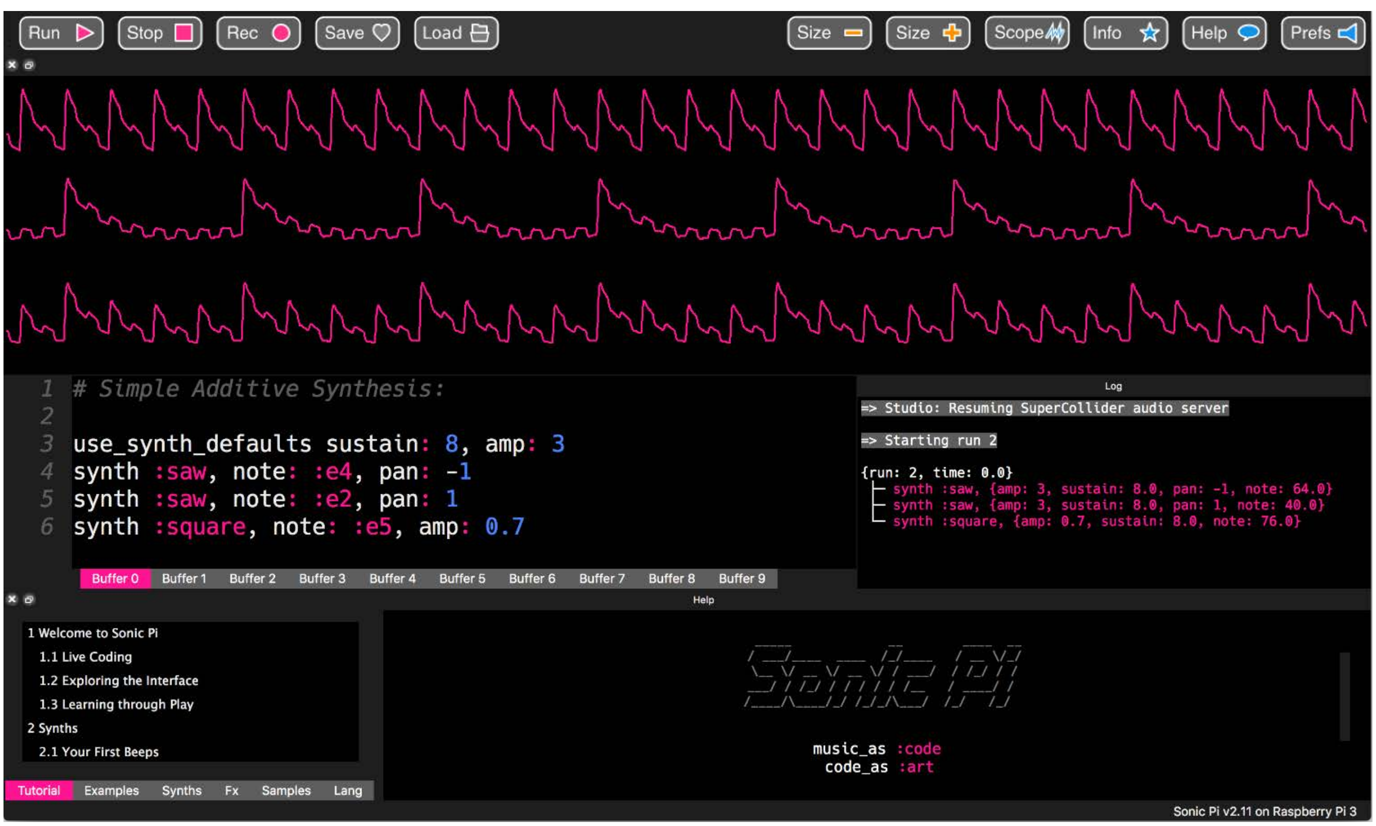
The Pi Rotary

Enrico Miglino's build for element14's monthly Project14 competition showcases both the Pi's abilities with audio and its uses in upcycling, as it remakes a way out-of-date rotary phone into something that is both practically useful and a clever artistic commentary on technology. "The goal of this upcycling was to use the features of an old appliance, but with a completely new behavior," Enrico says in his blog.

His Pi Rotary is thus a mix of the old and the new, and he faced the unique challenge of translating the original rotary dialer's workings into something intelligible for a modern single board computer. Wanting to mostly maintain the phone's classic look (with some LED updates), he had to find room in its innards for the Pi, a Pi Juice HAT power supply, a modern amplifier board, and more. The project also brings something very modern to an antiquated piece of technology, as it can answer the user with natural language processing, and this function can be localized for various regions with some simple code changes.



Playing Daft Punk with Code, Using Sonic Pi



Using the Sonic Pi software discussed earlier in this eBook, Sebastien Rannou covered a favorite song of his, "Aerodynamic," by one of electronic music's most iconic bands, Daft Punk, from their seminal 2001 album *Discovery*. "It's a bit like you're writing a recipe with a pencil and, at the same time, instantly getting the result in your food," Sebastien says, describing using Sonic Pi to create music.

"Aerodynamic" was a good choice to demonstrate the abilities of the Sonic Pi software and the Pi single board computer itself, but it was also a challenging one. Rather than being composed entirely of individual instruments recorded by the band, the original Daft Punk song takes an existing recording from the 1970s disco group Sister Sledge and reworks it using audio tech trickery, and Rannou had to then program Sonic Pi to do the closest approximation he could. The song also features instruments that aren't your bog standard synthesized bass or electric piano, things that can be found in many existing instrument libraries; "Aerodynamic" has a complex bell sound with a difficult timbre to mimic in the introduction of the song, a famous "guitar solo" that has inspired fans to dissect how it was made, and much more.

CHAPTER - 6 Coda

Two questions have been addressed in this eBook – can you use the Raspberry Pi for listening to HD music, and can you create music using this popular development board? The answer is yes to both, but with some caveats. For high-end audio, the Raspberry Pi can play and stream music at 32-bit/300 kHz and higher, but can only do so with the addition of HATs or other and-on boards. By no means is that a hindrance, even for enthusiasts, as portable and desktop DACs can cost hundreds or even thousands of dollars by themselves, even without adding speakers or headphones. Is the Pi a top-of-the-line HD solution? No, and technically it wasn't designed to be, but it does drive HD content without breaking the bank, and has the bonus of being integrated into a myriad of different audio projects.

As a music content creation and editing tool, the Raspberry Pi excels in nearly every aspect, and is only limited in processing power, depending on the model of Pi and the software being used. Compared to commercially available MIDI stations, synths, mixers, and microphones, the Raspberry Pi represents an affordable solution that can provide nearly everything more expensive systems and hardware can provide, without costing thousands of dollars. Both fledgling and A-list musicians and bands now have access to tools capable of producing studio-quality sound for less than $100, something that wasn't possible 20 years ago. Either way, music lovers can employ the Raspberry Pi to enjoy high-end audio and create original music, either at home or on the go, with minimal limitations.

For more information about high-end audio and Pi, check out our dedicated **Raspberry Pi** web page.

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