Application note for KIT_ARDMKR_AMP_40W

Design of an Arduino compatible audio amplifier platform

About this document

Scope and purpose

This document describes the design principles of an audio amplifier platform that is compatible with Arduino boards supporting I^2S audio playback. More specifically, this application note will discuss the design of the KIT_ARDMKR_AMP_40W board on both hardware (PCB design) and firmware (Arduino code). The board contains Infineon's **MA12070P** multilevel amplifier, which will be discussed in more detail. The content should enable both professional engineers as well as DIY's to build prototypes, reproduce the design, or pick up the design for further development as part of the product design process. The design is generic in principle and can be used in combination with any audio board that supports I^2S audio playback.

Intended audience

This document is intended for anyone interested in building audio systems, professional engineers, DIY's or for educational purposes.

Table of contents

1 Introduction

The Arduino project started in 2005 as a student program at the Interaction Design Institute Ivrea, in Ivrea, Italy, aiming to provide an affordable and easy way to create devices that interact with their environment while using advanced microprocessors, controllers, sensors and transducers.

Since 2005, Arduino boards have been steadily growing in popularity among makers and DIY enthusiasts, who have developed a broad range of projects, from gaming consoles and drone controls to various smart home automation projects.

Arduino boards are based on open-source hardware and software, licensed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL), enabling board manufacturing and software distribution by anyone. This extends the development of high-performance embedded computing power to a much wider audience – including people without alo professional hardware or software background.

When looking at the types of DIY projects, it is interesting to see that many revolve around audio connectivity, e.g., IoT audio interaction or stand-alone audio players. Until recently it was necessary to add several separate boards or "shields" together to realize such a system.

This has changed since the release of the MKR family, where Arduino has now added audio features such as an I^2S bus, SD card audio read/write and Alexa voice-control compatibility. This also makes the Arduino platform a perfect demonstration vehicle for Infineon's high-performance integrated class D audio ICs.

By releasing a fully compatible amplifier board with enough output power to drive a variety of speakers – all with best-in-class audio performance, low power consumption and high efficiency – Infineon is providing yet another useful building block in the Arduino ecosystem.

The Infineon Arduino board has the following key parameters and features:

- Equipped with MERUS™ **MA12070P** proprietary multilevel amplifier
- Power input: 5 V/2.5 A – sourced from the same single USB-C power supply or battery pack
- No need for external or extra power supplies
- Up to 40 W instantaneous peak output power with a USB-C power supply or battery pack
- Compatible with Arduino MKRZERO and MKR1000 Wi-Fi
- Full hardware control, customization and error monitoring through the Arduino programming framework

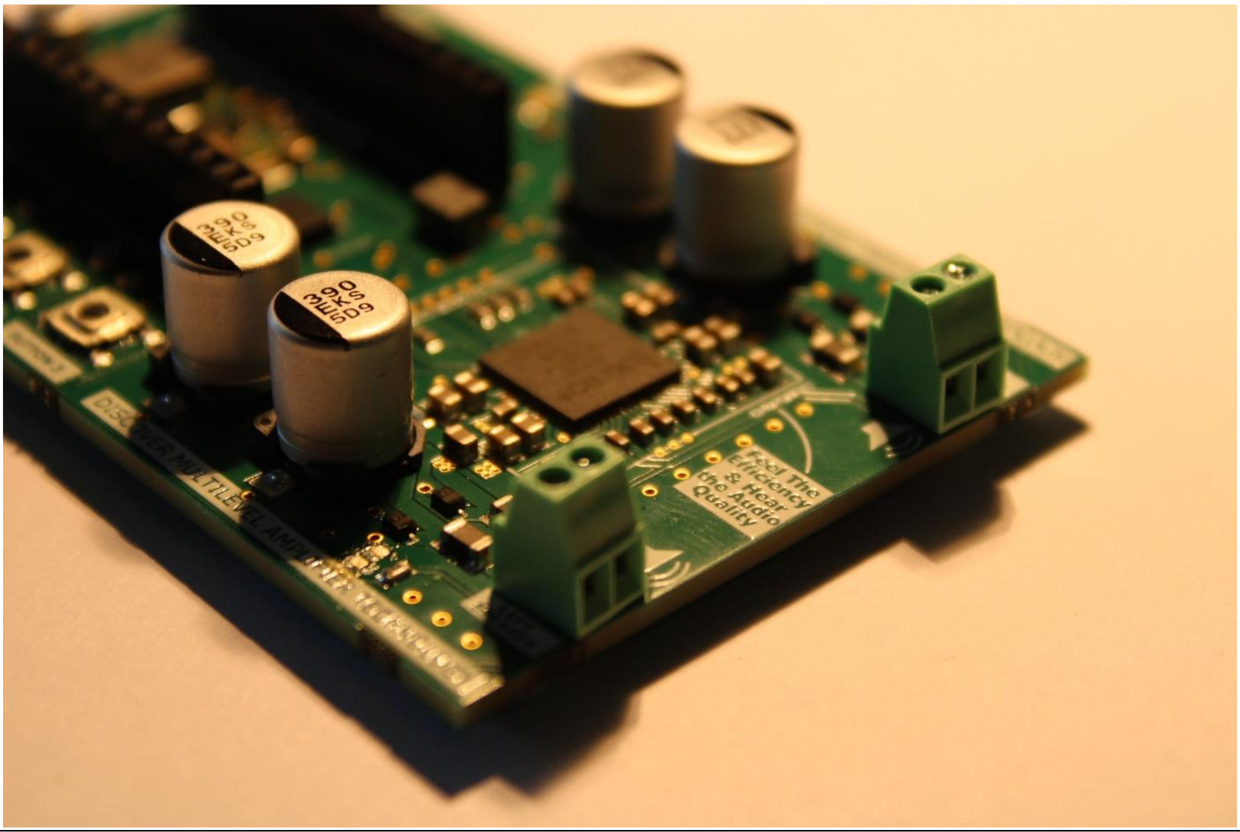

Figure 1 KIT_ARDMKR_AMP_40W

With this, Arduino fans around the world are now finally able to build their own high-end wireless audio players – and with the recent addition of Arduino Amazon Alexa Skill, it is even possible for them to connect Alexa to their Arduino IoT cloud projects with no additional coding required.

Consequently, fully fledged Alexa-powered wireless speakers can now be added to the list of popular DIY projects.

2 General overview

2.1 Board overview

The KIT_ARDMKR_AMP_40W board is an audio amplifier board compatible with the MKRZERO board from Arduino and built around Infineon's MERUS™ **MA12070P** multilevel amplifier. In **Figure 2** the following main system components are identified:

1. USB-C power input
2. Boost converter
3. Bulk capacitance
4. Audio amplifier
5. User interface
6. Arduino microcontroller

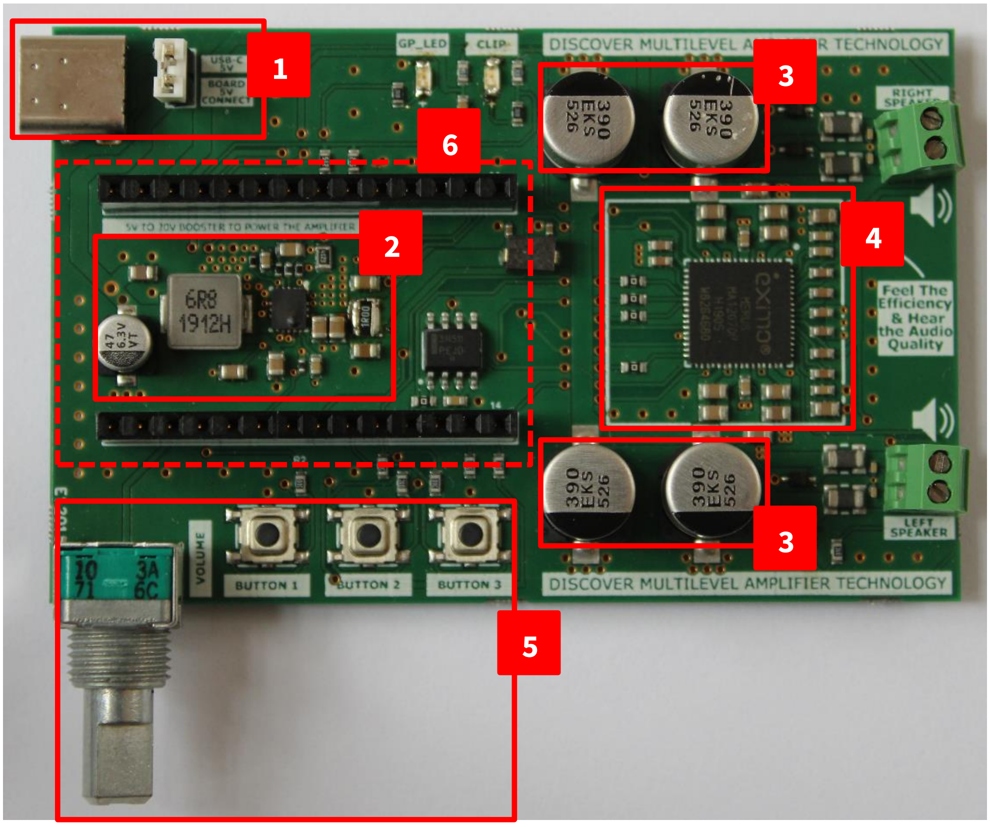

Figure 2 **Board overview**

The board has been primarily designed to offer good audio quality and easy compatibility with the Arduino MKRZERO boards. More specifically, the boards cater for applications such as portable speakers, smart speakers, DIY Hi-Fi speakers, or any kind of consumer-oriented audio prototyping.

Infineon's MERUS™ **MA12070P** multilevel amplifier is specifically suited to these applications, as the amplifier emphasizes efficiency for "moderate" average output power levels while being able to deliver "high" peak output power levels.

2.2 System overview

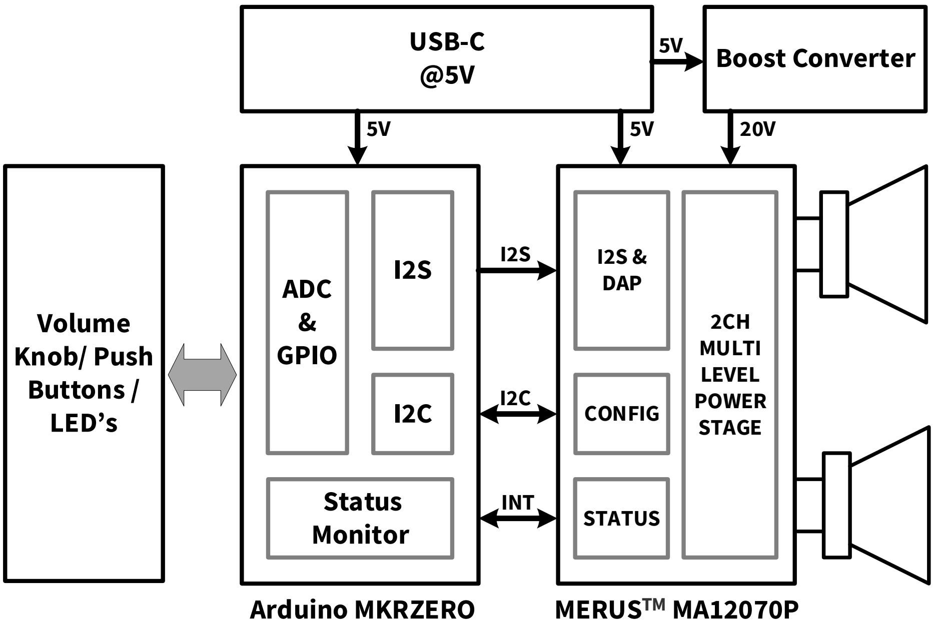

Figure 3 System overview

A more detailed system overview is shown in **Figure 3**. The power section has been designed to alleviate common issues associated with audio design, i.e. enough continuous power in combination with peak output power and sufficient voltage headroom. To this end, the board incorporates a boost converter that boosts the voltage from a simple USB-C input power adapter or battery from 5 V to 20 V. The boosted 20 V is used as the power supply for the power amplifier section, while the bulk capacitance stores peak energy for short-burst peak power delivery.

MERUS™ **MA12070P** is configured to drive two speakers. The power section and amplifier can deliver up to 20 W instantaneous peak power per channel (40 W total). Nominal speaker impedance can typically vary from 4 to 8 Ω. Lower or higher impedances are in principle also possible under specific conditions, which are described in a later section. The amplifier has a digital front end including volume control and limiter functionality. The latter is useful when input power is limited, as discussed in a later section. Finally, the amplifier configuration has registers and status registers that can be accessed using the I^2C communication protocol.

The main processor unit in the system is the Arduino MKRZERO (or a similar board from the same family). This microcontroller board can stream I^2S audio while at the same time taking care of housekeeping functions such as amplifier register configuration over I^2C and interrupt-based status monitoring. Additionally, some user interface functions have been implemented, such as volume control, generic push buttons and LEDs, by using the ADC and GPIOs.

2.3 Features and electrical specifications

- Equipped with MERUS™ **MA12070P** proprietary multilevel amplifier
- Power input: 5 V/2.5 A – sourced from the same single USB-C power supply or battery pack
- No need for external or extra power supplies
- Up to 40 W instantaneous peak output power with a USB-C power supply or battery pack
- Compatible with Arduino MKRZERO and MKR1000 Wi-Fi
- Full hardware control, customization and error monitoring through the Arduino programming framework

Table 1 Electrical specifications

Input power	5 V USB-C power adapter or battery pack – min. 2 A
Speaker impedance	2 x 4 Ω to 2 x 16 Ω
Idle power consumption	1 W at 5 V input
Power input at 1 W output	1.2 W at 5 V input
Instantaneous peak output power	20 W per channel
Burst output power	10 W per channel at 100 Hz (one cycle)
Continuous output power	5 W per channel
Max. SPL	110 dB at 1 m – with 86 dB sensitivity reference speaker

3 Hardware design

3.1 Schematic

The main board schematic for the design is shown in **Figure 4**. For convenience and readability the schematic design is split into the following sub-designs:

- Power and board interface
- Boost converter
- Class D amplifier and configuration
- User interface

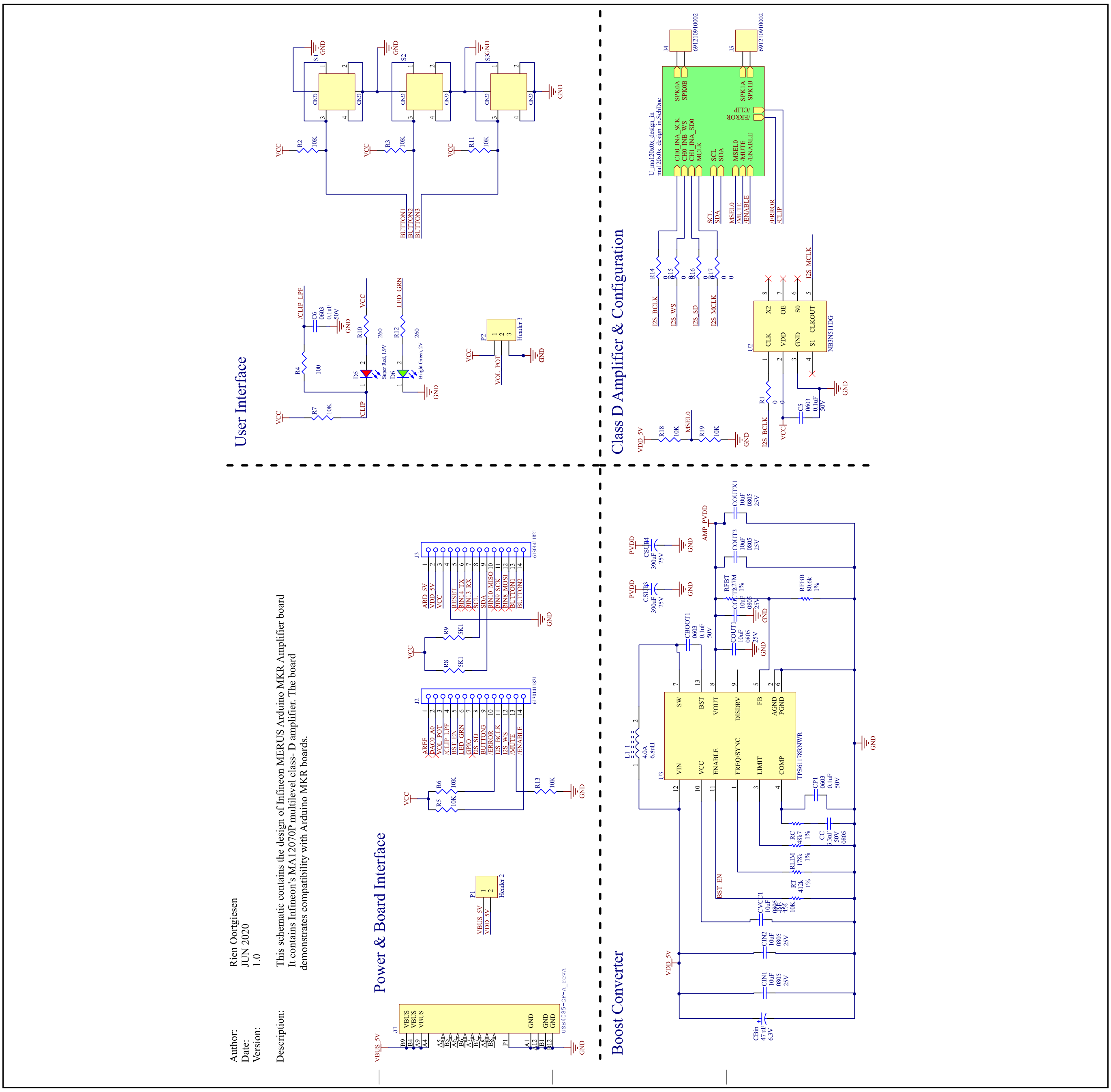

Figure 4 Main board schematic

3.1.1 Power and board interface

The schematic section for input power and the interface connection to the Arduino MKRZERO board are shown in **Figure 5**. The schematic design shows that from the USB-C connector only the power connections are utilized. This means no USB data communication or power delivery negotiation is possible. The reason for choosing USB-C is because of increasing availability of USB-C power supplies at 5 V. Additionally, by using USB-C, it is possible to get enough power from a standard power bank (used for cell phone charging), which can turn the prototype or project into a true wireless solution.

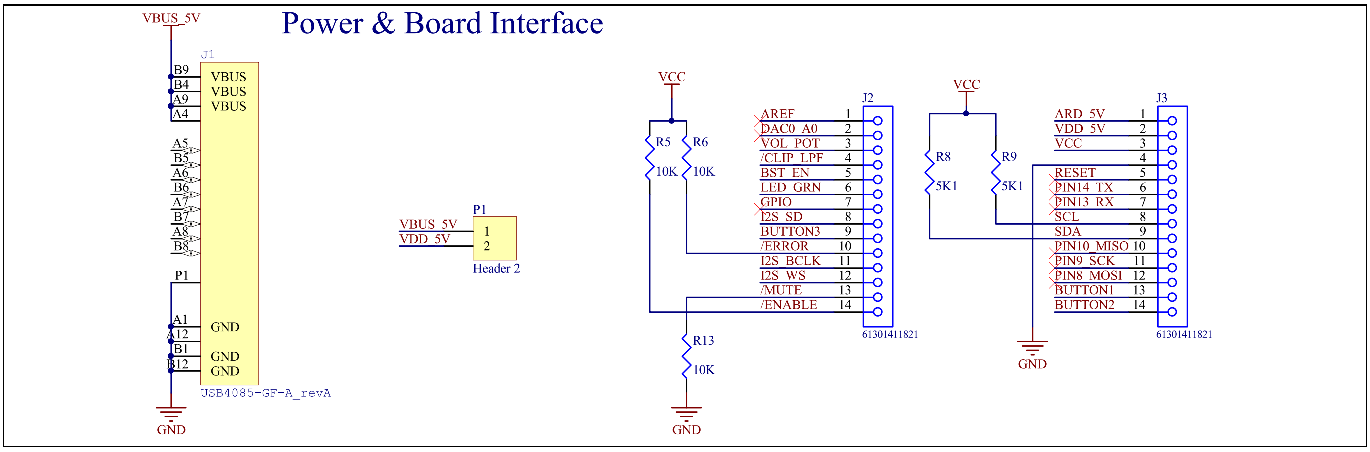

Figure 5 **Power and board interface schematic**

3.1.2 Boost converter

The boost converter section is primarily built around the TPS61178 fully integrated synchronous boost converter. The converter has been specifically chosen for its boost capability from 4.5 V to 20 V, and light load efficiency, which makes it a perfect match for this application. The full schematic design is shown in **Figure 6**. Design guidance in TPS61178 application notes has been followed. The output current limit has been set to 4 A peak and 500 mA RMS current, which matches the available input power when using a generic USB-C power adapter. The surrounding components are selected according to this specification. More output current is possible.

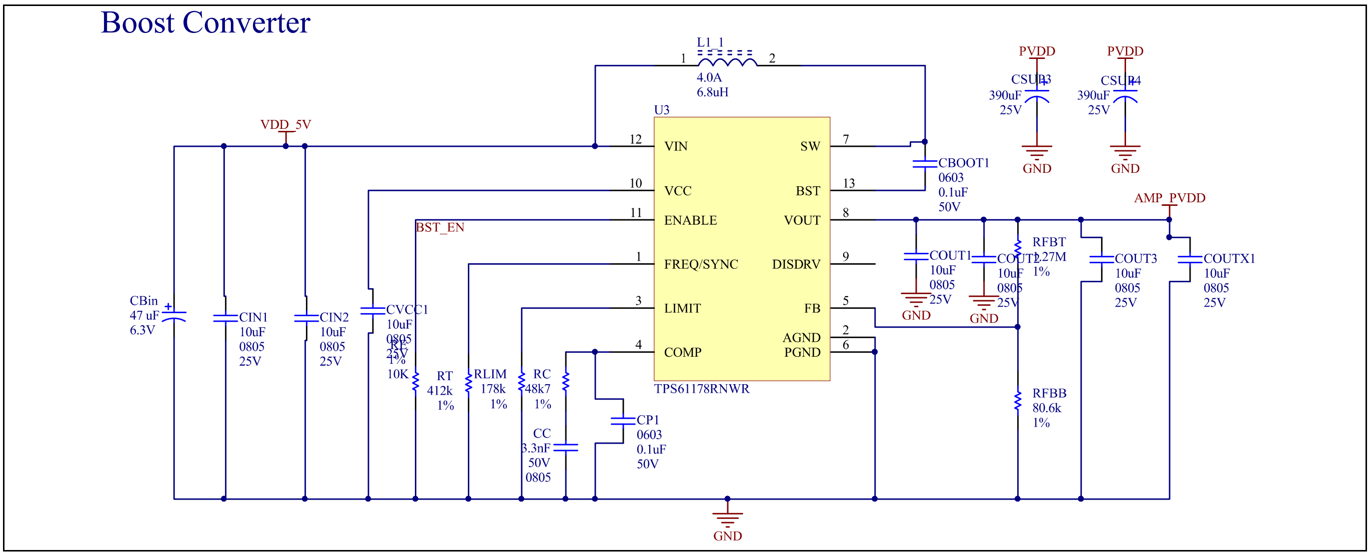

Figure 6 **Boost converter schematic**

3.1.3 Class D amplifier and configuration

The class D amplifier is the section of the design that is responsible for delivering electrical energy to the speaker. The speaker will in turn transform this electrical energy into membrane movement to move the air around you such that you can hear music. Music signals are very dynamic, i.e. there is a high ratio between the peak value and the average value of a typical music signal. This means the amplifier needs to be able to deliver peak power, while the power consumption in “idle” (i.e. at average output power levels) should be low. This makes an audio system considerably more efficient.

Infineon’s multilevel **MA12070P** class D amplifier is a perfect match for this application because of its low idle power consumption (400 mW at 20 V) and LC filterless implementation. The latter makes the total solution size small and keeps the bill of materials (BOM) cost low.

The schematic configuration and design-in details are shown in **Figure 7** and **Figure 8** respectively.

Interfacing connections to the Arduino board are: I^{2}S audio interface and I^{2}C (SCL, SDA), /MUTE, /ENABLE, /ERROR and /CLIP for **MA12070P** configuration and status monitoring. The resistors in series with the I^{2}S data and clock lines are used to dampen “ringing” caused by line impedance mismatch. Typical values for these resistors are in the range of 33 Ω.

MSEL0 is connected in the schematic to a pull-up and a pull-down resistor. In the final board, only one resistor is mounted (pull-up is the default). This pin sets the output configuration for the amplifier to two-channel bridge-tied-load (BTL) (MSEL0 = pull-up) or single-channel parallel-bridge-tied-load (PBTL) (MSEL0 = pull-down). PBTL configuration gives more output power when connecting two BTL channels in parallel – see the **MA12070P datasheet** for more details.

Additionally, the design contains a “clock doubling” component in the form of NB3N511DG. The purpose is to double up the bit clock (I2S_BCLK) that is coming from the Arduino I^{2}S transmitter. Currently, this clock frequency is limited to 32 times the sample frequency (F_S). This clock frequency is too low to be used as the master clock for **MA12070P**, which requires at least 64 times the sample frequency. NB3N511DG contains a high-quality configurable PLL to provide this clock to **MA12070P**.

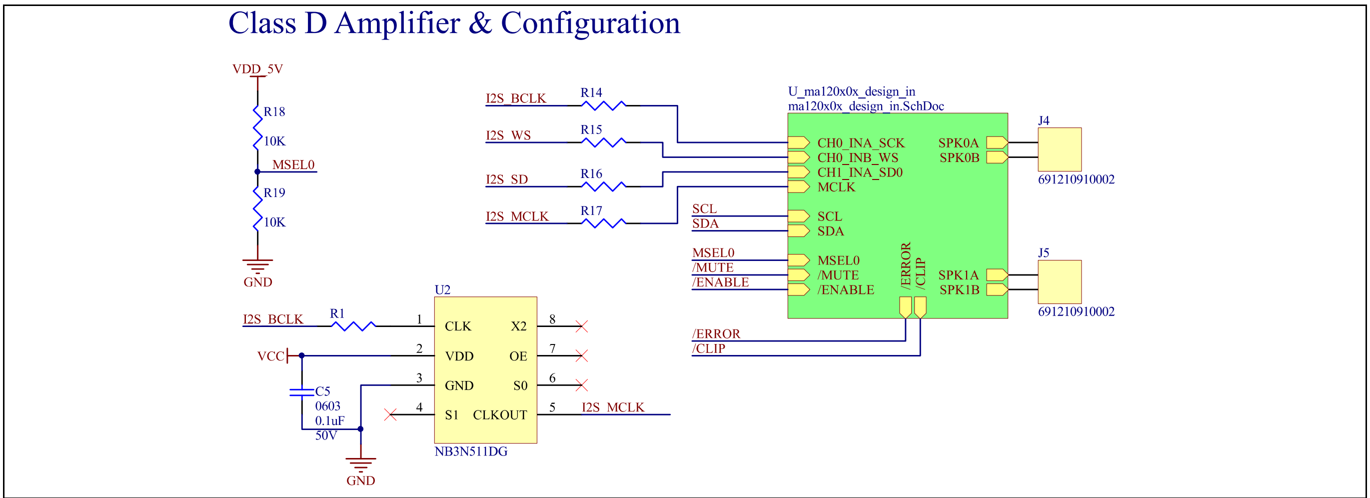

Figure 7 **Class D amplifier and configuration schematic**

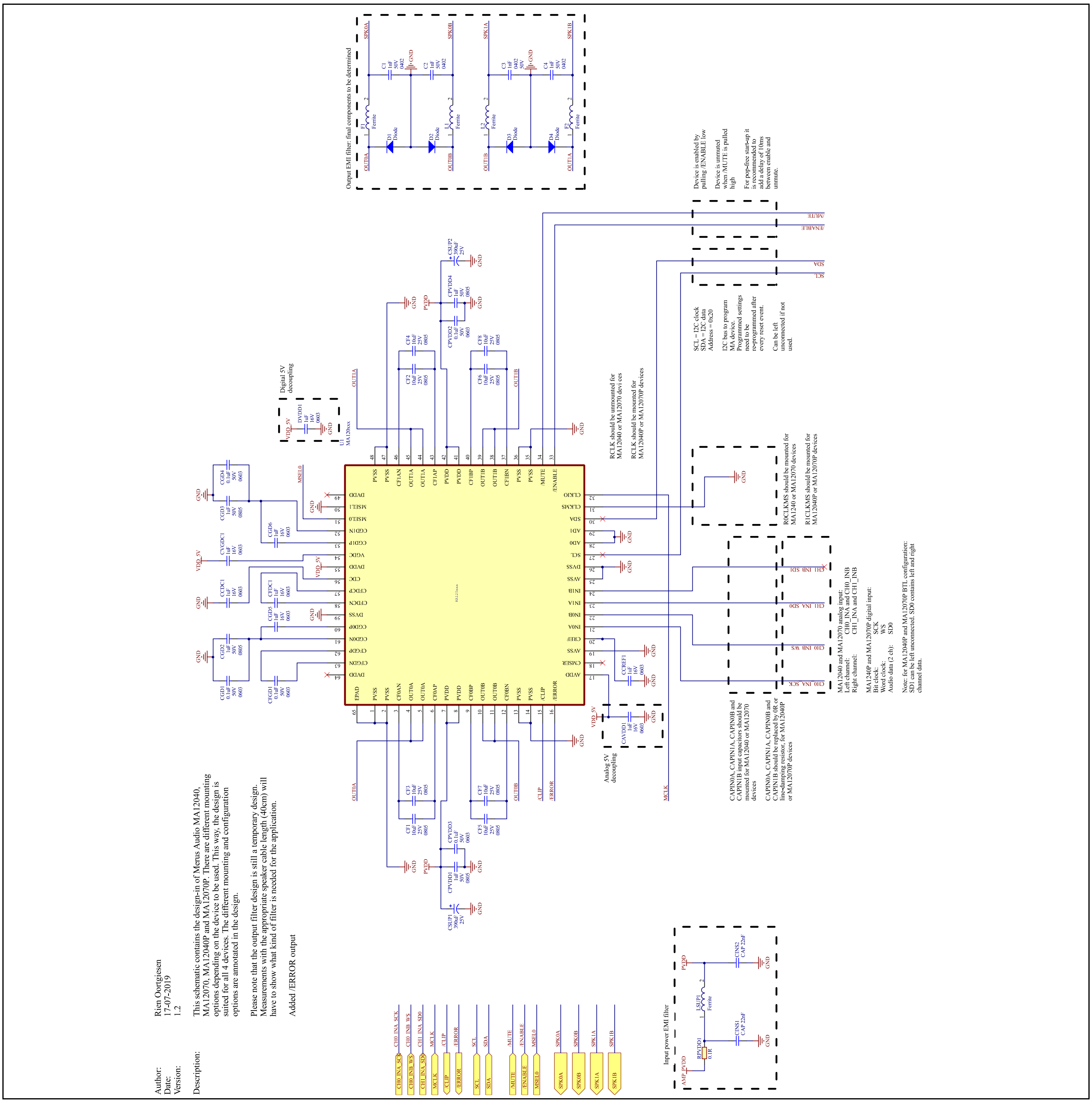

Figure 8 MA12070P design-in schematic

3.2 PCB design

The PCB design is relatively straightforward, as shown in **Figure 9**, **Figure 10**, **Figure 11** and **Figure 12**. The amplifier design for MA12070P (both PCB design and schematic) is taken exactly from the reference design **REF_AUDIO_D_MA12070P**.

The board design is built on two layers, with standard 1 oz. copper thickness. Care must be taken during the design to ensure enough thermal relief for the amplifier and boost converter. The PCB copper is the main heatsink for the amplifier and boost converter – primarily through the bottom layer. Therefore, sufficient vias and heat flow must be guaranteed. Thermal performance can be enhanced when using thicker copper (2 oz.) or a four-layer PCB design (where additional layers can be used as a heatsink).

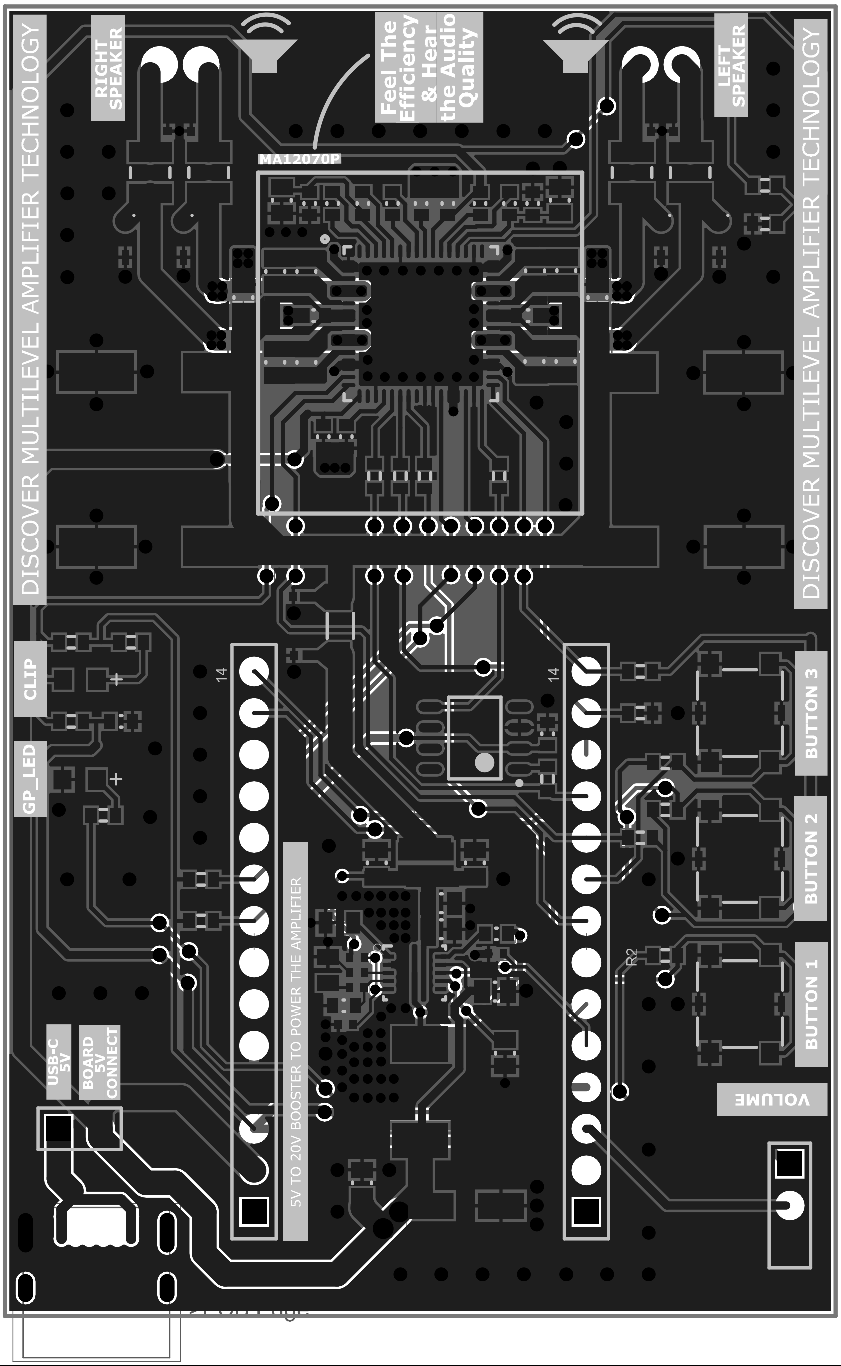

Figure 9 PCB layout – stacked

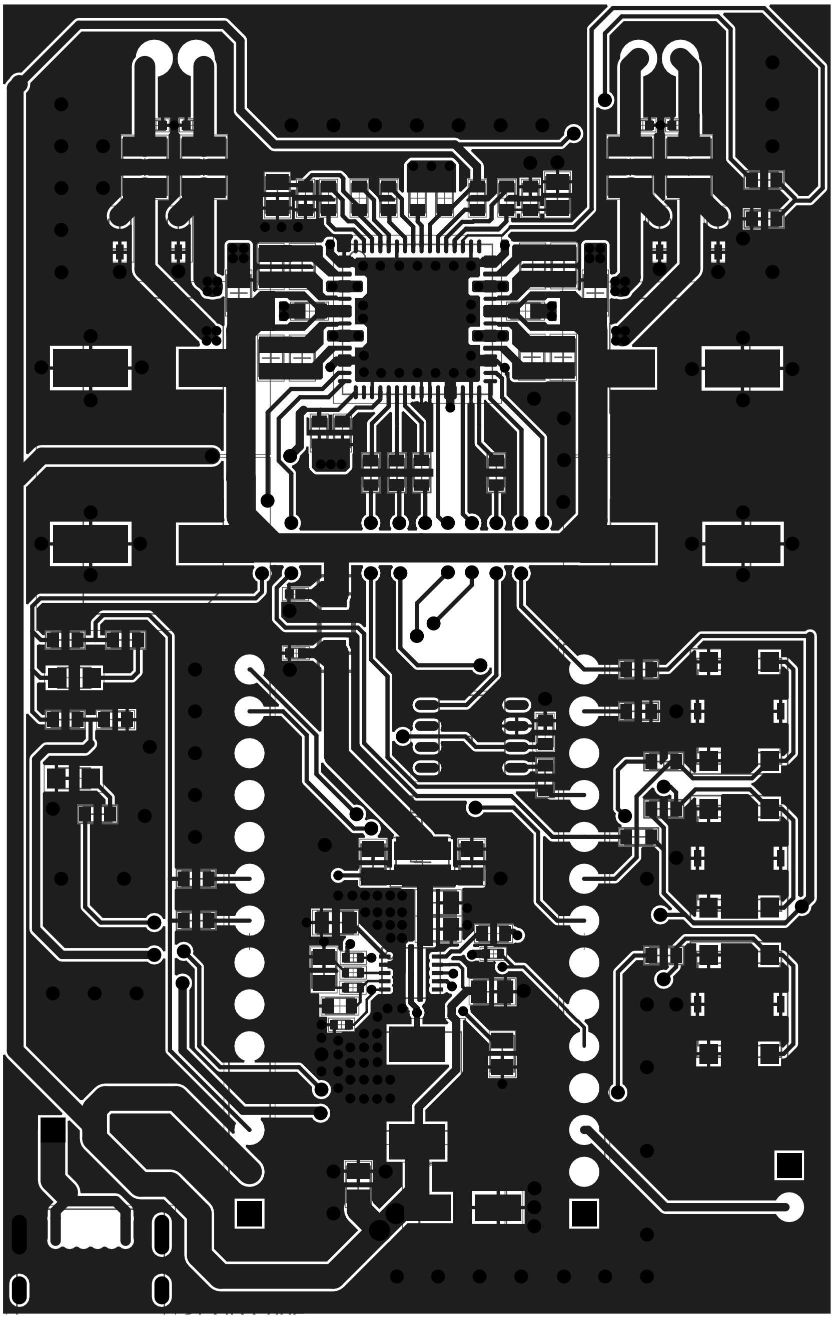

Figure 10 PCB layout – top layer

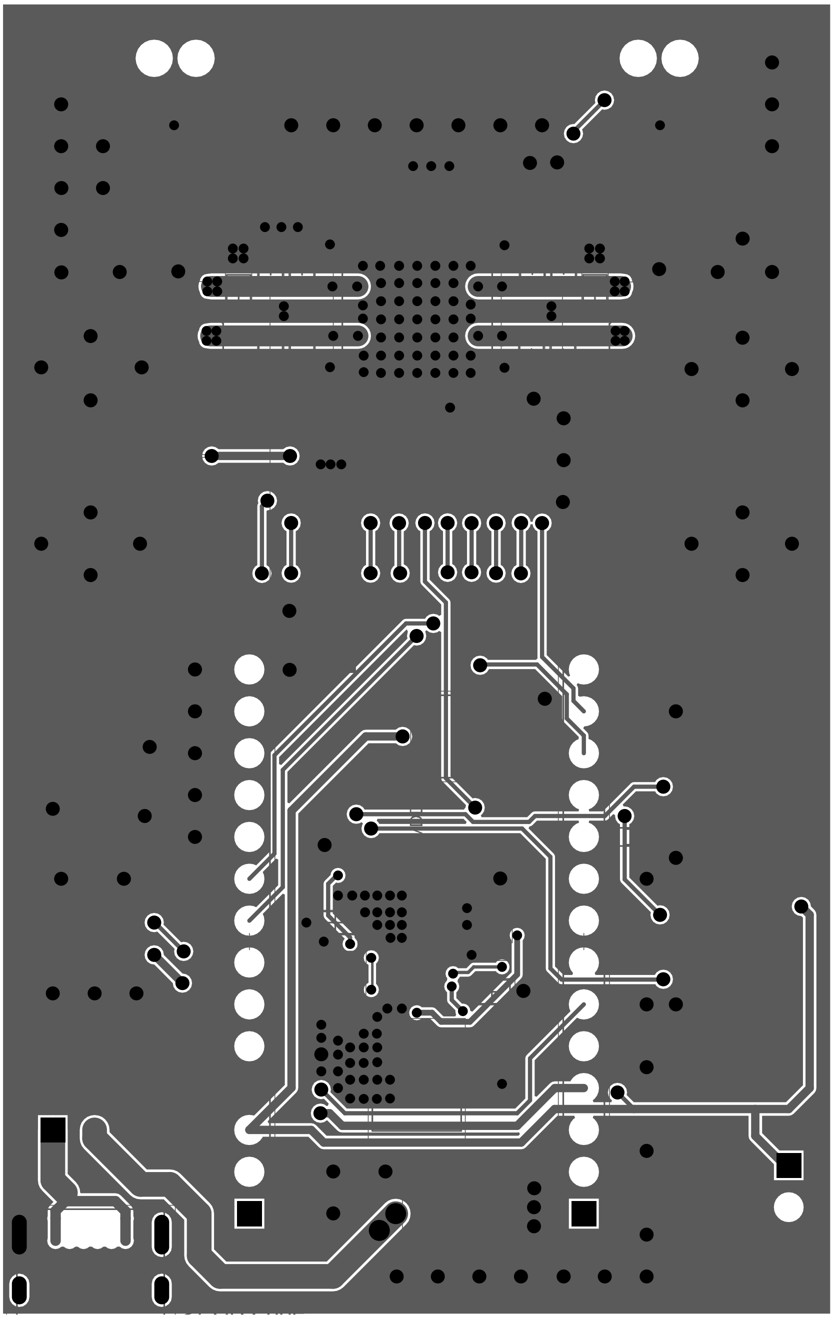

Figure 11 PCB layout – bottom layer

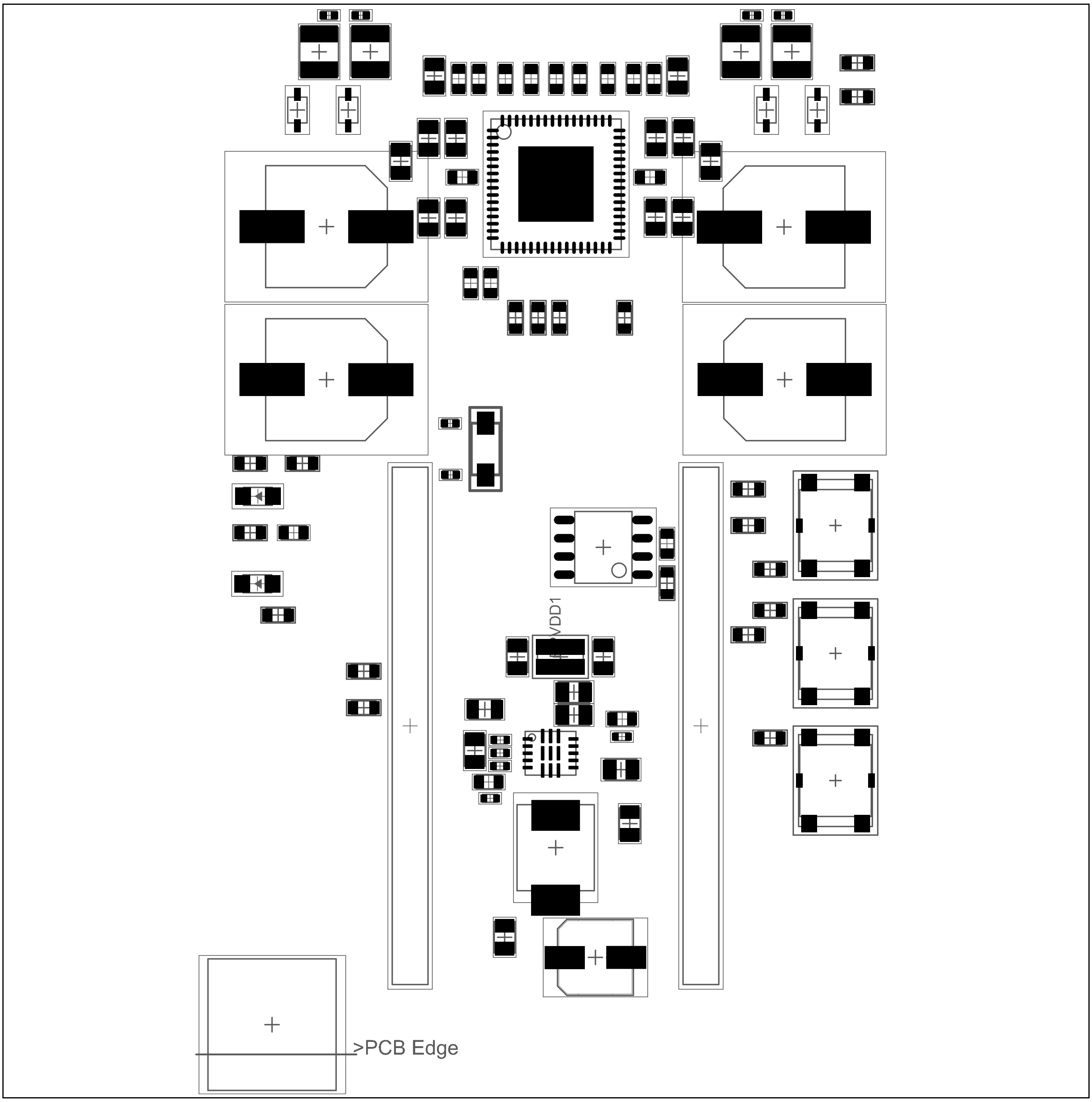

Figure 12 PCB layout – component layer

3.3 Bill of materials

Table 2 Bill of materials for the board

Designator	Description	Manufacturer	Part no.	Quantity
U2	3.3 V/5.0 V 14 MHz to 200 MHz PLL clock multiplier	On Semi	NB3N511DG	1
S1, S2, S3	5 x 5 mm SMD with ground terminal WS-TASV, height 1.5 mm, 160 GF	Würth Elektronik	431181015816	3
U3	20 V_{OUT} fully integrated synchronous boost converter with 8 A switch current, RNW0013A	Texas Instruments	TPS61178RNWR	1
RC	0402 [1005 metric], 48.7 kΩ, MCMR series, 50 V	Multicomp	MCMR04X4872FTL	1
RFBB	0402 [1005 metric], 80.6 kΩ, CRCW e3 series, 50 V	Vishay-Dale	CRCW040280K6FKED	1
CBin	Aluminum electrolytic capacitor, 47 µF +/-20 percent, 16 V	Multicomp	MCVVT6R3M470DA1L	1
CSUP1, CSUP2, CSUP3, CSUP4	Aluminium electrolytic capacitor 390 µF, 25 V	Panasonic	EEEFK1E391SP	4
CINS1, CINS2	Capacitor, 0.022 µF, ± 10 percent, X7R, 50 V, 0402 [1005 metric]	Murata	GRM155R71H223KA12D	2
C5, C6, CBOOT1, CFGD1, CGD1, CGD4, CP1, CPVDD2, CPVDD3	Capacitor, 0.1 µF, ± 10 percent, X7R, 50 V, 0603 [1608 metric]	Multicomp	MC0603B104K500CT	9
CGD2, CGD3, CPVDD1, CPVDD4	Capacitor, 1 µF, 50 V, ± 10 percent, X5R, 0805 [2012 metric]	Multicomp	MC0805X105K500CT	4
CAVDD1, CCDC1, CCREF1, CFDC1, CGD5, CGD6, CVGDC1, DVDD1	Capacitor, 1 µF, ± 10 percent, X5R, 16 V, 0603 [1608 metric]	TDK	TMK212BJ105KG-T	8
CF1, CF2, CF3, CF4, CF5, CF6, CF7, CF8, CIN, CIN1, COUT, COUT1, COUT2, COUTX, CVCC	Capacitor, 10 µF, ± 10 percent, X5R, 25 V, 0805 [2012 metric]	Murata	GRM21BR61E106MA73L	15
C1, C2, C3, C4	Capacitor, 1000 pF, ± 10 percent, X7R, 50 V, 0402 [1005 metric]	TDK	C1005X7R1H102K050BA	4
CC	Capacitor, 3300 pF, 50 V, 0805 [2012 metric], ±10 percent, X7R	Walsin	0805B332K500CT	1

U1	Multilevel class D amplifier	Infineon	MA12070P	1
L1_1	Power inductor (SMD), 6.8 µH, 4.5 A, 8 A, shielded	Bourns	SRP7028C-6R8M	1
RPVDD1	Resistor 0.1 R/1 W/1 percent	Rohm	LTR18EZPJL R10	1
RLIM	Resistor, 0402 [1005 metric], 75 kΩ, CRCW e3 series, 50 V	Vishay-Dale	CRCW04027 5K0FKED	1
R2, R3, R5, R6, R7, R11, R13, R19, R20	Resistor, 0603 [1608 metric], 10 kΩ, MCWR series, 50 V	Multicomp	MCWR06X10 02FTL	9
RE	Resistor, 0603 [1608 metric], 10 kΩ, MCWR series, 50 V	Multicomp	MCWR06X10 02FTL	1
RT	Resistor, 0805 [2012 metric], 412 kΩ, ERJ6EN series, 150 V	Panasonic	ERJ6ENF412 3V	1
RFBT	Thick film resistor, 1M27, 1 percent, 0.63 W, 0402	Vishay-Dale	CRCW04021 M27FKED	1
R4	Thick film resistor, 100 R, 1 percent, 0.1 W, 0603	Multicomp	MC0603SAF1 000T5E	1
R10, R12	Thick film resistor, 261 R, 1 percent, 0.1 W, 0603	Vishay	CRCW06032 61RFKEA	2
D1, D2, D3, D4	Schottky Rectifier, 40 V, 1 A, single, SOD-323F, 2 pins, 570 mV	NXP	PMEG4010C EJ	4
R1, R15, R16, R17, R18	SMD chip resistor, 0603 [1608 metric], 0 Ω, MCWR series, thick film, 100 mW	Multicomp	MCWR06X00 0 PTL	5
R8, R9	SMD chip resistor, 0603 [1608 metric], 5.1 kΩ, MCWR series, 50 V, thick film, 100 mW	Altium Limited	MCWR06X51 01FTL	2
F1, F2, L1, L2	SMD EMI suppression ferrite bead WE-CBF, Z = 50 Ω	Fair-Rite	2512065007 Y6	4
LSUP1	SMD ferrite power bead, Z = 47 Ω	Fair-Rite	2743019447	1
J1	USB 2.0 type C receptacle dip type, PCB top mount	Global Connector Technology	USB4085-GF-A	1
D6	WL-SMRW SMD mono-color reverse-mount waterclear, size 1205, bright green, 2 V, 140 degrees	Würth Elektronik	156125VS75 000	1
D5	WL-SMRW SMD mono-color reverse-mount waterclear, size 1205, red, 2 V, 140 degrees	Würth Elektronik	156125RS75 000	1

4 Firmware

4.1 Start-up

Code Listing 1

```
// Start-up sequence
// make sure everything is disabled init state
digitalWrite(mute_n, LOW);
digitalWrite(enable_n, HIGH);
//digitalWrite(A3, LOW); //boost disable
delay(1000);
digitalWrite(enable_n, LOW);
delay(1000);
```

4.2 Main

Code Listing 2

```
volume = analogRead(VOLUME);  // read the analog input pin
if ( volume != volume_curr )
{
  volume_curr = volume;
  change_volume();
}
clip = analogRead(CLIP);      // read the analog input pin
if ( clip < 256 )
{
  //set_limiter();
}
```

4.3 Volume control

Code Listing 3

```
void change_volume ()
{
analogWrite(GP_LED, volume);
Wire.beginTransmission(byte(0x20));
Wire.write(byte(0x40));
Wire.write(byte(84-volume));
Wire.endTransmission();
}
```

Revision history

Document version	Date of release	Description of changes
V 1.0	20-07-2020	First release

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Edition 2020-07-20

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

Email: erratum@infineon.com

Document reference
AN_2007_PL88_2007_102945