

Design approach for a MERUS™ MA12070 based musical instrument bass amplifier

DEMO_BASSAMP_60W_MA12070



About this document

Scope and purpose

This document describes the practical and electrical design of a wall-adaptor or battery-powered, 60 W, professionally featured and ultraefficient pocket-sized bass instrument amplifier. It is modeled after classic vacuum-tube bass amplifier topology. It utilizes the exceptional audio quality and best-in-class efficiency of Infineon's MERUS™ amplifier technology to amplify every nuance of a genuine vacuum-tube pre-amplifier.

Intended audience

This document is for musical audio amplifier design engineers, audio system engineers and portable audio design engineers.

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1 Introduction

In the music industry, specifically for amplifying electric guitars and bass guitars, vacuum-tube amplifiers (tube amps) are often regarded as superior in sound to solid-state amplifiers. The practical drawbacks of using vacuum tubes are obvious which are namely, high power consumption, high voltages, questionable reliability, poor mechanical stability, large size, heavy weight and high costs.

Digital emulation (DSP) of tube amplifiers has been designed to overcome many of these drawbacks, but while being very reliable, flexible and comparable in sound, digital emulations seem to miss some characteristics and the feel of a real tube amp.

Hybrid amplifiers combining vacuum-tube and solid-state circuitry have been produced. These amplifiers often cater to the low- to mid-price segment of amplifiers. Use of a tube is often more just for looks and sometimes even not electrically included in the circuit. It is not so much for sound.

Designing an amplifier for musical instruments is quite a different task from designing a hi-fi amplifier. The general consensus on designing a good hi-fi amplifier is that the amplifier should be made so as not to color the sound in any way: having very little total harmonic distortion, very flat frequency response, very wide bandwidth and excellent transient capability. With an electronic magnifying lens.

Not so for the musical instrument amplifier. The musician wants to use the amplifier as a sound-shaping tool, and often to shape the sound in a new and different way. This generally requires the amplifier to exhibit the diametrically opposite qualities to a hi-fi amplifier:

- Instrument amplifiers help shape and create sounds
- Hi-fi amplifiers play back and reproduce sounds

To exemplify this, consider what makes the sound different between a piano and a guitar playing the same note, e.g., A-flat. The A-flat note has a fundamental frequency of 440 Hz. A piano playing an A-flat note sounds very different to a guitar playing the same A-flat note. The harmonic spectrum of a piano is very different to the harmonic spectrum of a guitar as it distorts the fundamental 440 Hz tone in a different way, thus creating the sound of a piano rather than the sound of a guitar.

Musicians often like tube amps for amplifying their instruments. Tube amps sound fuller and more complex with more pleasant overtones, especially when overdriven. This is due to the inherent high distortion characteristics and somewhat slower dynamic behavior of the vacuum tube, especially the triode vacuum tube, where even harmonic distortion components dominate the spectrum. The human ear generally prefers even harmonic distortion components over uneven harmonics in the fundamental tone.

The Infineon MERUS™ MA12070 musical instrument bass amplifier presented here represents a different approach to hybrid amplifier design. It combines the ultrahigh fidelity and musicality of the MA12070 power amplifier with the characteristics of a 12AU7 triode vacuum tube pre-amplifier set up for real-signal class-A amplification. The 12AU7 triode tube is run at low plate-voltage, excluding high-voltage generation circuitry.

Compared to a classic tube amp, the power consumption, cost, size and weight are dramatically reduced. Therefore, reliability and safety are correspondingly dramatically enhanced.

2 Features and performance

The key features and performance of the MA12070 musical instrument bass amplifier are as follows:

- One classic tube sound bass instrument channel
- 1 x 60 W at 4 Ω speaker output
- Powered by off-the-shelf regulated wall adapter (+24 V DC/3 A)
- Unparalleled power efficiency – with very low power losses and cool operation
- No external heatsink (full volume, bass instrument playing)
- Dual 12AU7 triode class A pre-amp run directly on adapter voltage for genuine tube sound
- Passive instrument input jack with -12 dB input pad switch for active instruments
- Gain and volume controls for tube overdrive
- Bright switch for slap-bass sound
- Dynamic “breathe and feel” when fully dimmed
- Classic three-band passive Baxandall tone control: treble, middle, bass
- Stereo 3.5 mm AUX input for practicing/street accompaniment
- XLR DI: frequency-compensated, true balanced output for live PA/mixing desk (phantom power safe)
- XLR DI ground switch
- Protection: power supply reverse polarity and hot-plug, thermal, DC and speaker short-circuit
- Speaker jack output with low-cost LC filter
- DC barrel input jack
- Low idle power consumption even with vacuum tube (2.7 W)
- Small dimensions: 185 mm x 60 mm x 30 mm

This amplifier platform can be scaled for different variants of power and features. As suggested here, it can be powered by a regulated +24 V DC off-the-shelf regulated external power supply (wall adapter). This could also be a mains supply or a battery pack. The supply voltage and loudspeaker impedance determine the output power, and the circuit topology is very flexible for enabling or disabling features.

It can be used as a standalone unit or in combination with a loudspeaker in a combo format. This eases the requirements for the output filtering, and cheap ferrite beads and twisted speaker wires are often enough for passing the EMC requirements.

The bare minimum bill of materials (BOM) cost, excluding switches, potentiometers and jacks, is relatively low. This enables the design to be used in professionally featured products at a competitive cost.

Design approach for a MERUS™ MA12070 based musical instrument bass amplifier



Features and performance

Table 1 **Electrical specifications**

Power input	+24 V DC, 3 A regulated, positive tip 2.1 mm, DC barrel
Idle power consumption	2.7 W at 24 V input
Power input at 10 W _{rms} output	15.3 W at 24 V input
Output power	60 W _{rms} at 5 percent THD, 4 Ω
Output load impedance	1 x 4 Ω to 16 Ω, 6.35 mm jack
Instrument input sensitivity/impedance	25 mV/1 MΩ, 90 mV/65 kΩ, 6.35 mm mono
AUX input sensitivity/impedance	400 mV _{rms} /200 mV _{rms} , mono/stereo, 4.7 kΩ, 3.5 mm jack
Bass control range	±12 dB at 40 Hz
Treble control range	±14 dB at 4 kHz
Middle control range	11 dB at 380 Hz
DI output level	True balanced: -6 dBm, ground lift
DI output frequency response (-3 dB)	55 Hz to 8 kHz, 6 dB/oct

3 User interface

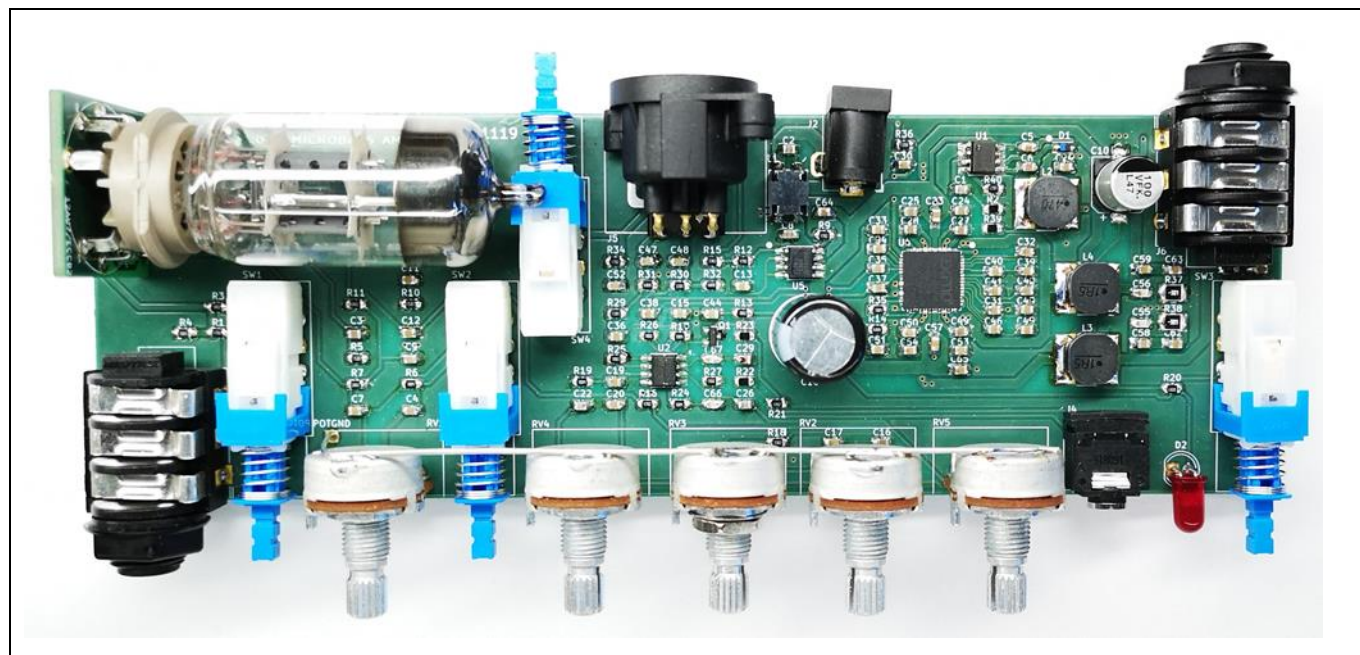


Figure 1 MA12070 musical instrument bass amplifier board

Table 2 User controls interface descriptions

Front of PCB (left to right):	
1. INPUT: Instrument input jack	Connect a shielded ¼ in. mono jack cable from the instrument to this jack. 1 MΩ/65 kΩ input impedance.
2. PAD: -12 dB input pad switch	When using active instruments or instruments with a high output level, use this switch for matching the input sensitivity of the amplifier for a clean sound. 65 kΩ input impedance when engaged.
3. GAIN: Gain control	Adjusts the signal amplitude from the first tube gain stage into the second tube gain stage. Combined with the master volume control (8) it is possible to overdrive the tube for genuine tube distortion.
4. BRIGHT: Bright switch	Boosts the higher treble harmonics of the instrument when engaged. Works in conjunction with the gain control (3). Most effective when the gain control is at its lower settings.
5. TREBLE: Treble tone control	Adjusts the treble frequencies of the instrument. Passive Baxandall type with the capability of both boosting and cutting treble frequencies of approximately ±15 dB at 4 kHz. Set to middle position yields a flat treble response.
6. MID: Middle tone control	Adjusts the insertion level of the Baxandall tone control. Perceived as boosting or cutting mid-range frequencies compared to treble and bass frequencies. Set to middle position yields ±14 dB of range of the treble control, and ±12 dB range for the bass control.
7. BASS: Bass tone control	Adjusts the lower frequencies of the instrument. Passive Baxandall type with the capability of both boosting and cutting bass frequencies with ±12 dB at 40 Hz. Set to middle position yields a flat bass response.

User interface

8. VOLUME: Master volume control	Adjusts the overall output volume of the amplifier. Combined with the gain control (3), one can overdrive the tube for genuine tube distortion while still controlling the output volume of the amplifier.
9. AUX IN: Auxiliary input	3.5 mm stereo input jack for connecting a phone, MP3 player or other sources for accompaniment or practicing along. Post master volume input.
10. POWER ON/OFF: Power on/off switch and LED	Switches the amplifier on and off, with the red LED indicating on when lit.
Back of PCB (left to right):	
11. SPEAKER: Speaker output jack	Connect this to a speaker cabinet (4 Ω min.) via a ¼ in. mono jack cable. Do not connect to ground.
12. POWER INPUT: DC power input barrel	Connect +24 V DC/3 A wall adapter with positive tip into this socket.
13. DIOUT: Balanced XLR speaker simulated DI output	In a live situation, connect this frequency-compensated output to the front-of-house (FOH) mixing desk. In a recording situation, use this output for direct recording. Post master volume, and phantom power safe. The output cuts the extreme highs and lows for more realistic sound when going into live or recording full range systems.
14. GROUND LIFT: Ground lift switch	If experiencing ground-loop hum or noise in a live or recording situation, press this switch to disconnect Pin 1 in the XLR from the amplifier ground. This will in many cases remove hum or noise. Be aware that the amplifier ground is now floating from the rest of the system.

4 Amplifier topology

There are many tube amp designs and topologies. Some designs have proven more successful than others. An American amplifier company from New Jersey relied on a certain topology though, and this is still regarded as one of the best and most classic tube bass amplifiers. The MA12070 musical instrument bass amplifier closely follows this topology:

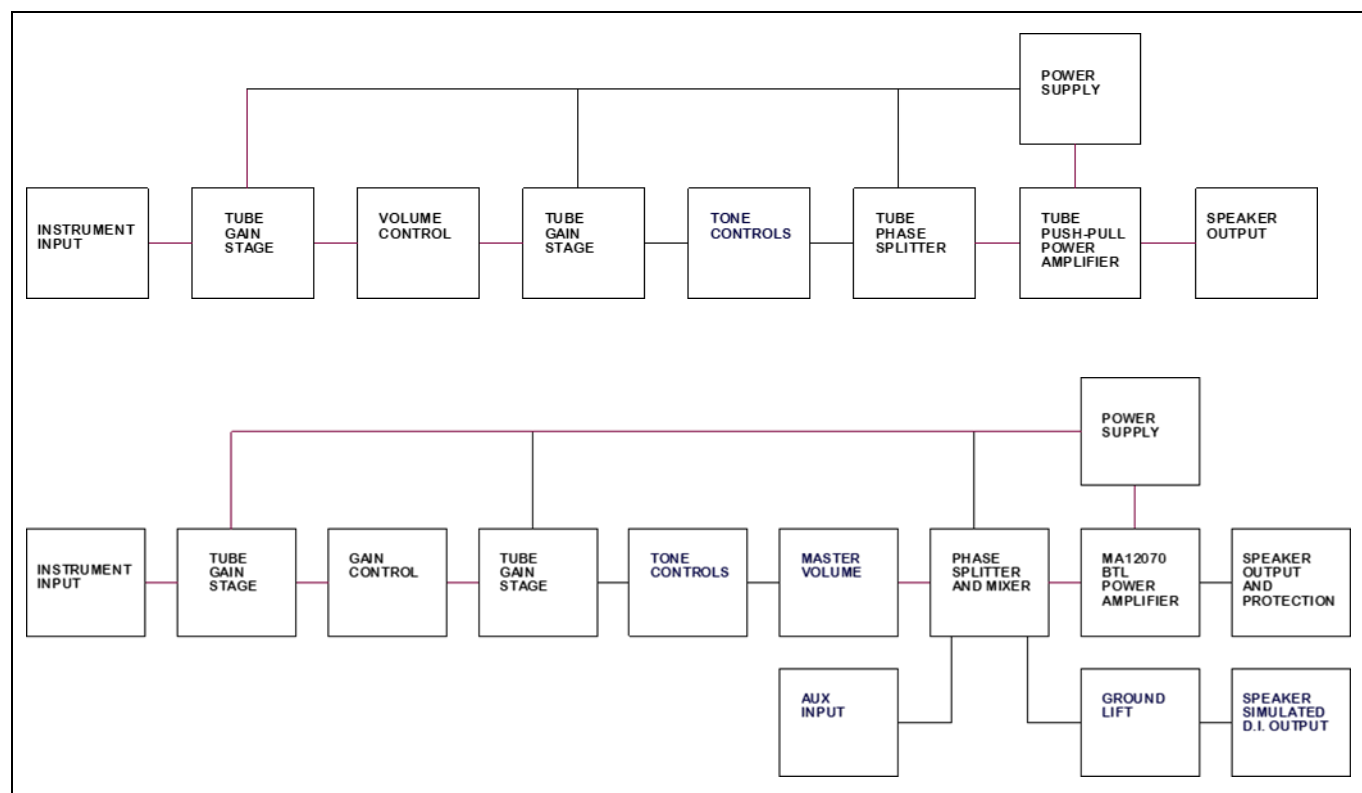


Figure 2 Classic American tube bass amplifier (top) and MA12070 bass amplifier (bottom) topologies

Amplifier topology

The amplifier can be divided into four main blocks:

Table 3 MA12070 musical instrument bass amplifier blocks

1. Power supply	EMC input filter
	On/off switching, reverse polarity and hot-plug protection
	+23 V (V_{DD}) filtered tube plate and op-amp supply derived from P_{VDD}
	$\frac{1}{2} V_{DD}$ op-amp bias supply (V_B)
	+5 V supply for MA12070 analog (A_{VDD}) and digital (D_{VDD}) blocks
	+6 V (FIL) supply for tube filaments
2. MA12070 power amplifier	MA12070 amplifier in P-BTL mode with LC output filter
	Mute and de-pop circuitry
	Short-circuit and thermal protection
3. 12AU7 tube pre-amplifier	Input with -12 dB pad
	Low plate-voltage 12AU7 dual-triode class-A amplifier stages
	Gain control with bright switch circuitry
	Three-band Baxandall tone control with boost and cut
4. Phase-splitter and mixer	Differential drive for MA12070 amplifier
	Stereo AUX input mixer
	Frequency-compensated differential XLR DI output with ground lift and phantom power protection

5 Circuit description

Figure 3 MA12070 musical instrument bass amplifier schematic

Circuit description

5.1 Power supply

From the [Table 3](#), it is visible that the power supply section can be divided into several discrete blocks.

5.1.1 EMC input filter

The EMC input filter is a balanced common-mode filter in series with the external power supply input:

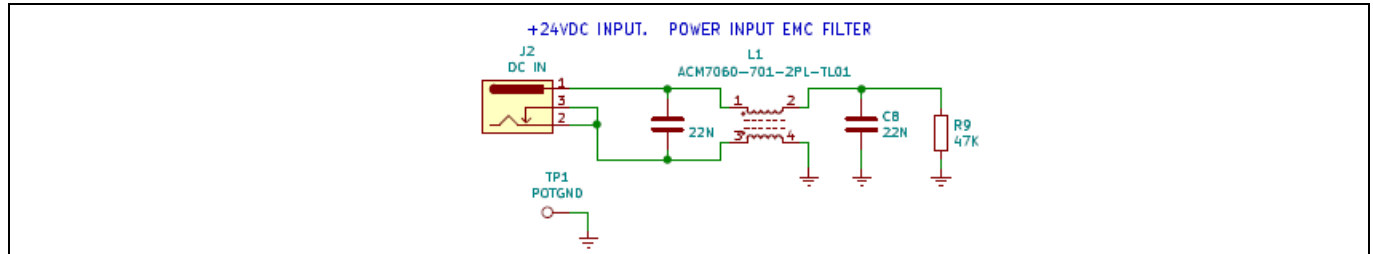


Figure 4 EMC input filter

The MA12070 uses a switching output stage. Although the MA12070 uses a very advanced multilevel switching scheme, it still produces some out-of-band switching components, which extend into MHz frequencies. These should be filtered out to pass EMC regulations. As the MA12070 bass amplifier is powered by a remote power supply, long leads in excess of 2 m are to be expected. These lines will act as radiating antennas. The same holds for the connecting speaker wires.

For information on filter recommendations, please see [EMC output filter recommendations for MA120XX \(P\)](#).

The EMC input filter uses a balanced common-mode topology as there is no ground reference at the primary (DC-in) side. The DC input should not be amplifier-ground referenced externally.

5.1.2 On/off switching, reverse polarity and hot-plug protection

The system power on-off switching is handled by back-to-back MOSFETs in series with the supply power line:

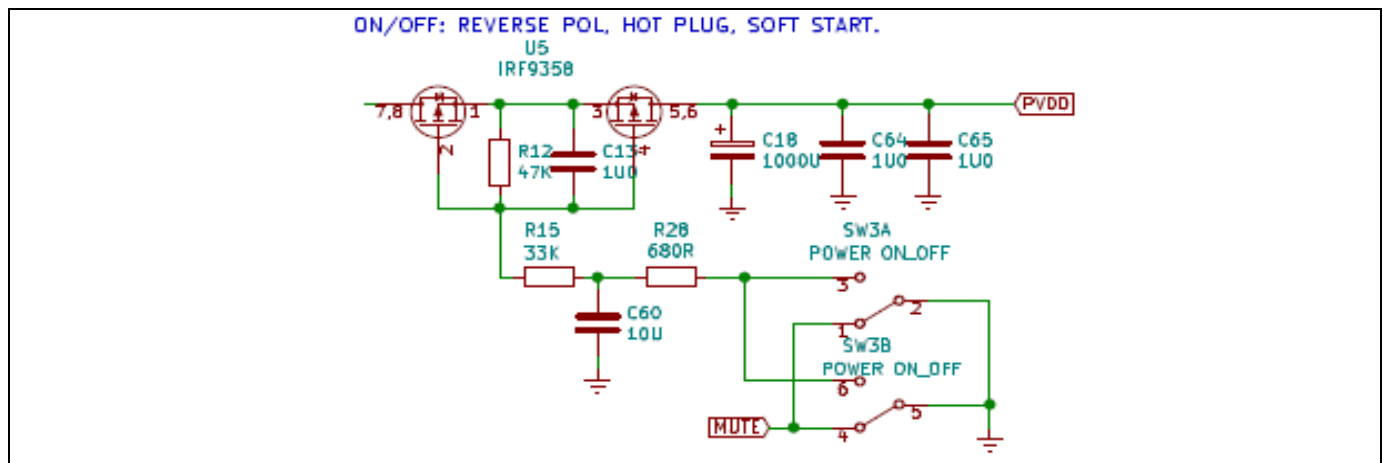


Figure 5 On/off switching, reverse polarity and hot-plug protection circuit

When the amplifier is driven to its maximum output, a relatively large current is drawn from the power supply. This requires power line switching capable of handling such currents. Mechanical switches could be used in series with the power line but would be large and expensive. By using comparable cheap back-to-back MOSFETs, a small low-current mechanical switch can be used to steer the large supply current. As coupled in the above schematic the MOSFETs also act as ideal diodes, protecting the amplifier against accidentally wrong power supply polarity. The MOSFET used is the dual Infineon international rectifier MOSFET [IRF9358PBF](#).

Circuit description

External power supplies with some length of connecting wire are to be expected for this application. These wires effectively create a series of inductance with the amplifier board. Combined with low-impedance decoupling of the supply line on the amplifier board, large peaks/ringing will occur when connecting the external power supply due to this L-C circuit. This hot-plug problem is further explained here: [Portable power management](#).

The large dV/dt and magnitude of these peaks can trigger the ESD protecting circuitry in the MA12070 device, leading to fatal destruction of the silicon. Slowing down the transition on-time of the MOSFETs makes the P_{VDD} rise slowly and eliminates this problem. This is done by an R-C time constant on the V_{GS} of the MOSFETs.

With the mute feature of the MA12070 device, click-and-pop-free operation is also achieved this way.

5.1.3 Bulk supply capacitance

In order to maintain a good dynamic behavior when the amplifier is run at high and transient output power levels, a rather large bulk supply capacitance should be placed on the P_{VDD} line:

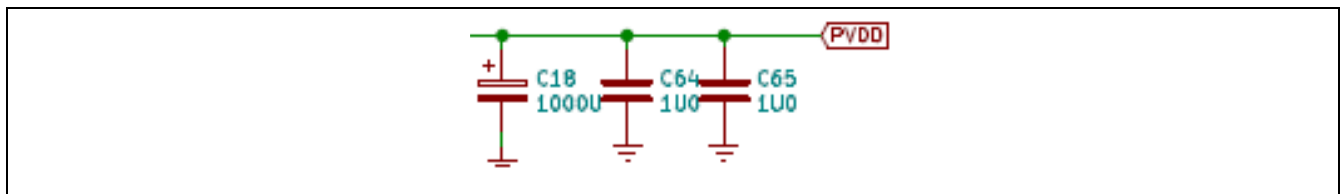


Figure 6 Bulk supply capacitance

This is done by a single high-value electrolytic capacitor placed not too far away from the supply pins of the MA12070 power amplifier. The value has been empirically selected when playing a loud bass instrument at maximum power output level with a crest of approximately 5 dB.

5.1.4 Filtered tube plate and op-amp supply

The 12AU7 tube pre-amplifier plates and op-amp phase-splitter and mixer is fed directly on the remote power supply (switched P_{VDD} line). It is expected that not all external switching power supplies used with the MA12070 musical instrument bass amplifier will exhibit low supply ripple at its output. The MA12070 output stage draws large switched currents from the power line, creating ripple. An active series filter circuit is used to remedy this problem:

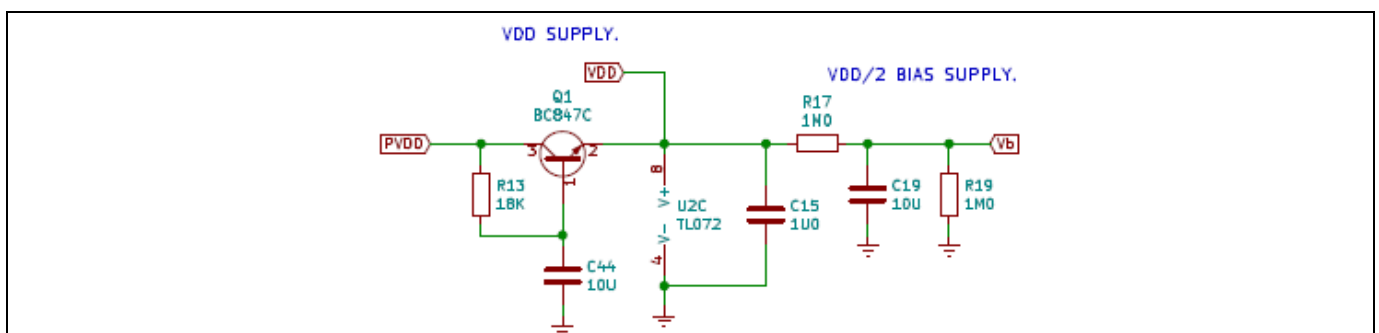


Figure 7 Series filter plate and op-amp supply

A capacitance multiplier is used, consisting of a series pass transistor with its base filtered by a rather large R-C network. By this and capacitive decoupling along the V_{DD} line, the V_{DD} supply is effectively filtered. A negligible voltage drop in the magnitude of V_{BE} is expected, lowering the plate and op-amp supply (V_{DD}) to approximately +23 V DC.

Circuit description

The whole amplifier is powered by a single-ended power supply line, and the op-amp phase-splitter/mixer needs a bias supply (V_B) to bias its outputs to $\frac{1}{2} V_{DD}$ for symmetrical output drive. This is done by a simple resistor voltage divider on V_{DD} . As the inputs of the op-amp phase-splitter/mixer are directly connected to this, it needs to be low noise. This is done by using relatively high resistor divider values and a relatively large capacitance for large AC decoupling.

The op-amp used for the phase-splitter/mixer is of the J-FET input type, exhibiting very low input current, and will not create a shift in bias voltage by DC loading the high-value resistor divider.

5.1.5 Low-voltage supplies

The MA12070 requires a +5 V supply for its analog and digital circuit blocks. The 12AU7 requires a filament voltage in the region of +6.3 V AC or DC. A buck converter connected to P_{VDD} converts the +24 V supply to +6 V DC:

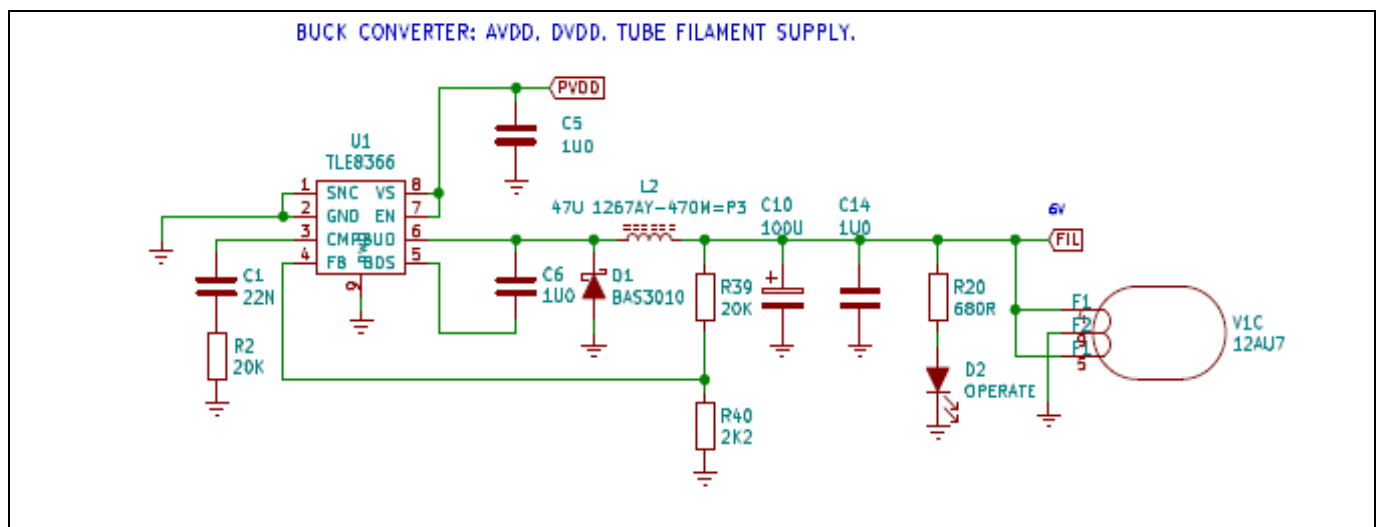


Figure 8 Tube filament, analog and digital buck-converter supply

The supply is built around the adjustable output voltage DC-DC buck converter Infineon **TLE8366EV** with integrated switch. It employs a feed-forward topology with a fixed switching frequency of 370 kHz and has been set up to deliver +6 V with a maximum continuous output current of 500 mA. Decoupling is done close to the device, and traces carrying switching currents are kept very short. The feedback path 20 kΩ/2.2 kΩ resistors are kept close to the feedback pin for minimum noise interference.

Key components are the inductor, output capacitor and Infineon diode **BAS3010**.

The detailed design procedure can be found here: [TLE8366 Buck converter application note](#)

The 12AU7 dual-triode tube requires a filament supply in the region of 6.3 V/300 mA DC or AC. By using a DC supply filament induced noise is dramatically reduced compared to the usual AC filament voltage applied in traditional tube amplifiers. The +6 V DC filament supply for the tube is within the recommended operating conditions for the 12AU7 tube.

The DC-DC buck converter ensures high efficiency for the tube filament and MA12070 analog/digital supply.

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Circuit description

With a supply voltage of +24 V the MA12070 power amplifier delivers 60 W_{rms} into a 4 Ω loudspeaker load. Most music program material has a crest factor. The crest factor is the ratio between peaks in the program material (e.g., a bass drum beat or a chopping keyboard key) and the average level of music. Typically, this ratio of peak power and average power for broadband music program material is 1:8. The duration of peak power is typically 1/10 of the time. The crest factor is somewhat lower for an instrument amplifier like the MA12070 bass amplifier at 1:2. Bass frequencies (below 300 Hz) also have considerably higher energy levels compared to mid and treble frequencies in the musical spectrum.

This lower crest factor and higher energy levels must be taken into account when doing the thermal design of the amplifier. In this application the MA12070 device is set to a PBTL output configuration. This lowers the output impedance of the amplifier (paralleling the output devices' R_{DS(on)}) for lower device dissipation and eliminates the need for an external heatsink.

Please see section 9-5 in [MA12070 01_00 Datasheet](#) for output configuration.

The QFN EPAD-down package of the MA12070 device should be thermally connected to a larger copper area on the PCB used as a heatsink. This is usually done by thermal vias connecting the device PCB layer to intermediate or opposite PCB layers. In this application it is done by a number of thermal vias connected from the top-layer PCB copper to the bottom-layer PCB copper. The heatsinking copper layer should be kept as unabrupt from other copper tracks as possible. A copper thickness of 35 μm is used. For different applications, a copper thickness of 70 μm can be used for better heat transfer and cooler operation.

Please see the thermal design note on MA120xx amplifiers on how to design adequate heatsinking: [Thermal Design](#).

Using a lower supply voltage yields a correspondingly lower output power. This may be useful in an application requiring a lower output power for a scalable product. Supply voltages of down to +18 V can be used with the amplifier, enabling e.g., power tool batteries to be used. The MA12070 device is capable of operating on P_{VDD} voltages down to +4 V. For the tube to operate correctly in this application, a minimum supply voltage of +18 V is required, though.

Further scaling of output power can be realized by using higher load impedances such as 8 or 16 Ω speaker loads. The MA12070 musical instrument bass amplifier is designed for a minimum speaker load impedance of 4 Ω with a +24 V supply voltage.

The MA12070 bass amplifier is intended for low to mid output power bass applications. The maximum output power of 60 W may be quickly reached and the amplifier may run into clipping. For certain sounds this is desirable, and the amplifier exhibits very good output clipping and recovery behavior. The MA12070 device incorporates a clipping detector, though, and output directly correlates to the distortion of the output signal. It is a duty cycle output at Pin 15 /CLIP. This pin is an open-drain output and gets pulled lower as the distortion arises in the output stage. An effective output limiter can be realized using this pull-down, e.g., by a resistive optocoupler placed in the feedback loop of the first op-amp in the phase-splitter and AUX mixer (see [Section 5.4](#)). The drive for the optocoupler can be a connection between Pin 15 and the +6 V FIL supply. Attack and release time constants can be realized by adequate RC filtering surrounding this drive. The /CLIP Pin 15 can sink up to 25 mA.

Please see Table 4-1 and section 8 “/CLIP pin and soft clipping” in the [MA12070 01_00 Datasheet](#).

The MA12070 device has a number of automatic protection features built-in: thermal protection, over-current, short-circuit and DC out protection. This makes the MA12070 bass amplifier virtually electrically indestructible. The speaker output is floating at P_{VDD}/2 (12 V) and should not be connected to GND under any operating conditions. The only external factor that can cause damage to the amplifier is a too high of a supply voltage. The MA12070 has an absolute maximum supply voltage rating of +27.5 V and a recommended maximum operating voltage rating of +26 V.

Circuit description

Please see section 8 “Protection” and sections 5 and 6 for ratings in the [MA12070 01_00 Datasheet](#).

5.2.1 Speaker output and L-C filter

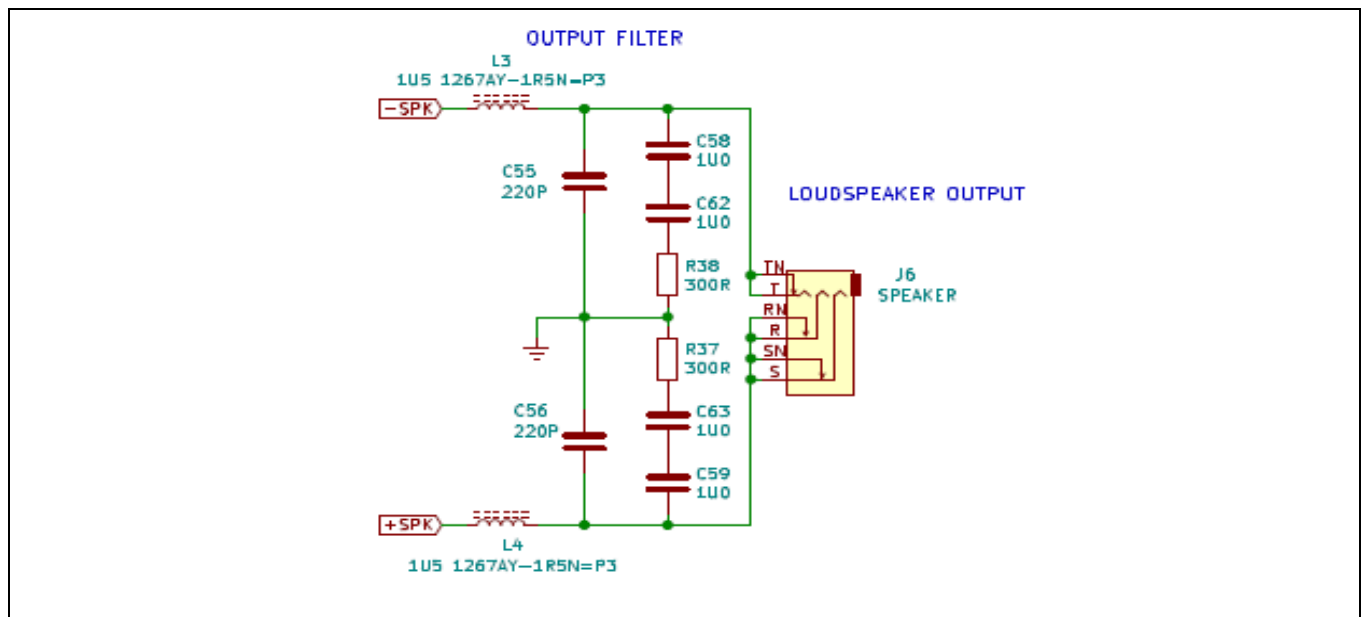


Figure 11 Output filter

The MA12070 uses a switching output stage. Although the MA12070 device uses a very advanced multilevel switching scheme, it still produces some out-of-band switching components, which extend into MHz frequencies. These should be filtered out to pass EMC regulations.

The MA12070 musical instrument bass amplifier can be used as a standalone unit or in combination with a loudspeaker in a “combo” format:

- As a combo amplifier, where the amplifier is placed in the same cabinet as the loudspeaker and speaker connecting cables are short (less than 60 cm)
- As a standalone amplifier head, where speakers are connected via comparable long speaker jack cables to a remote speaker cabinet (longer than 60 cm)

The combo format eases the requirements for the output filtering and cheap ferrite beads, and twisted speaker wires are often enough for passing the EMC requirements. The speaker chassis should be connected to GND.

The standalone amplifier head needs a dedicated output filter. This is realized here by a second-order LC low-pass filter with a snubber network placed in series with each output node of the amplifier.

When designing this LC filter, care should be taken to observe that the current ratings of the inductors are not exceeded (saturation current less than peak current), as well as voltage ratings and ESR of the capacitors (only use ceramic capacitors such as COG, NPO, X5R or X7R).

Also, damping the response of a peaking filter should be done by snubber networks. Observe the energy absorbed in this network. A too-low -3 dB point of the filter can cause high-frequency audio signals to be dissipated in the snubber network.

Please see [EMC and output filter recommendations for MA120xx \(P\) devices](#).

5.2.2 Power stage capacitor selection

The multilevel switching output power amplifier of the MA12070 relies on a stacking-up voltage-switching scheme. This is done by charging and de-charging capacitors, here called flying capacitors (CFx).

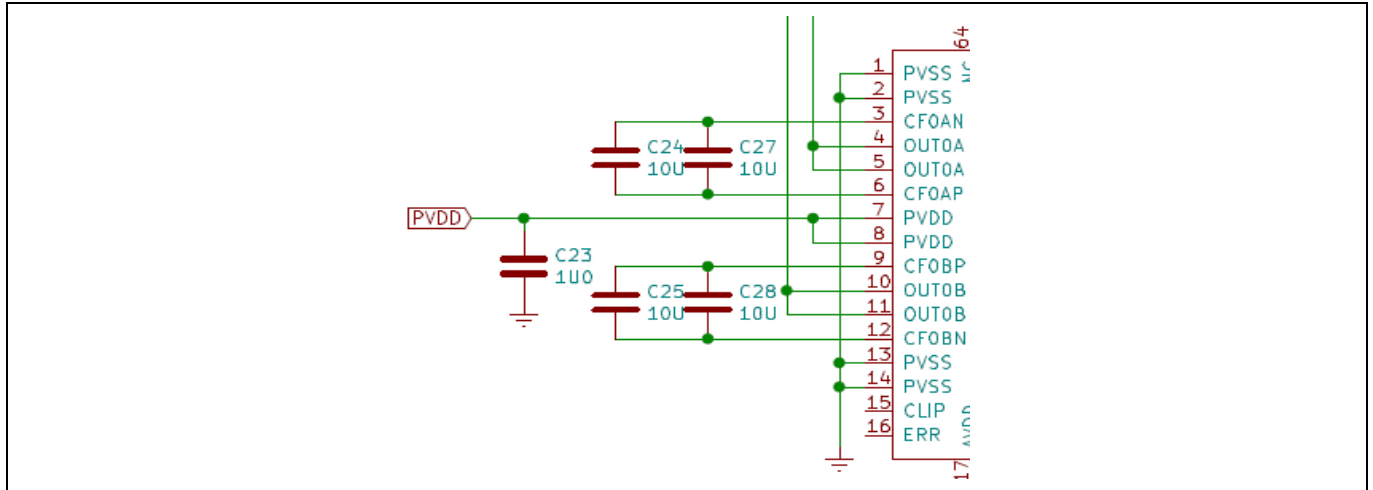


Figure 12 Power stage flying capacitors

The minimum required capacitance for each capacitor node is 4 µF. In this application, it is built up by paralleling 10 µF capacitors. The flying capacitors are charged to $\frac{1}{2} P_{VDD}$ and attention should be paid to de-rate these with respect to capacitance at working voltage. Some ceramic capacitor types can lose as much as 80 percent of their initial (0 V DC) capacitance at full voltage. Low-ESR ceramic capacitors such as X7R or X5R types should be used.

Please see section 8-5 “Power supplies, Flying capacitors” in the MA12070 datasheet: [MA12070 01_00 Datasheet](#)

5.2.3 Mute and enable circuit

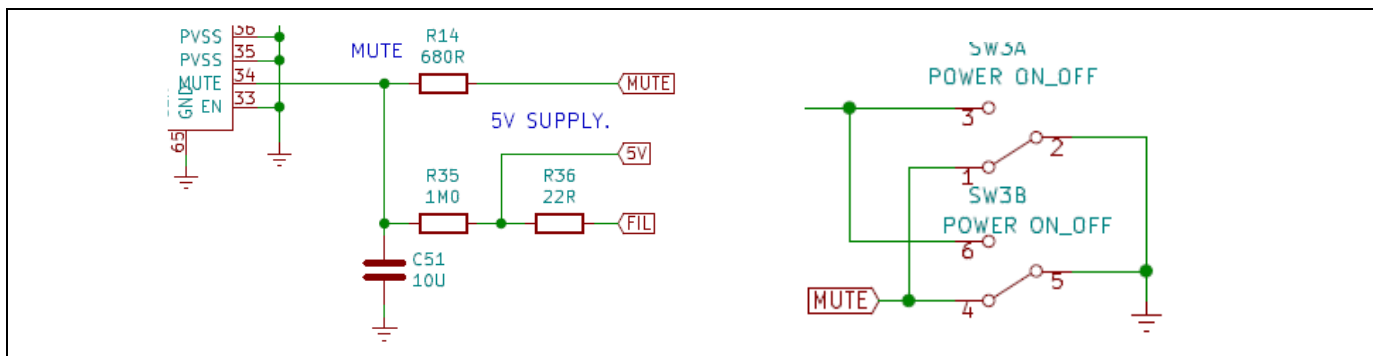


Figure 13 Mute/enable and power on/off switch

The MA12070 device has built-in enable and mute functions. The enable feature sets the device in a very low-current power-down mode when disabled, and the mute feature mutes or unmutes the audio output. These two features combined make for a click-and-pop-free operation of the amplifier when powering up and down.

The sequence at power-up should be: first enable, and then un-mute after all circuitry has been stabilized. The sequence at power-down should be: muting of the audio signal first, and then disable the device (low power-down mode). This function is realized by RC time constants around the mute pin and the on/off switching circuit in [Figure 5](#) and the amplifier power on/off switch. Seamless and noise-free power on/off operation is achieved in this way.

5.3 Tube pre-amplifier

The heart of the MA12070 musical instrument bass amplifier tone-generating stage is the 12AU7 tube pre-amplifier. It relies on the excellent low plate-voltage operating characteristics of this type of tube, readily available today from several manufacturers. Passive filters and tone controls shape the frequency response of the pre-amp.

From the findings of [Table 3](#), the pre-amplifier section can be divided into several discrete blocks.

5.3.1 Input jack with -12 dB input pad

The input to the amplifier is done via an industry-standard 6.35 mm mono jack combined with a switchable -12 dB input pad:

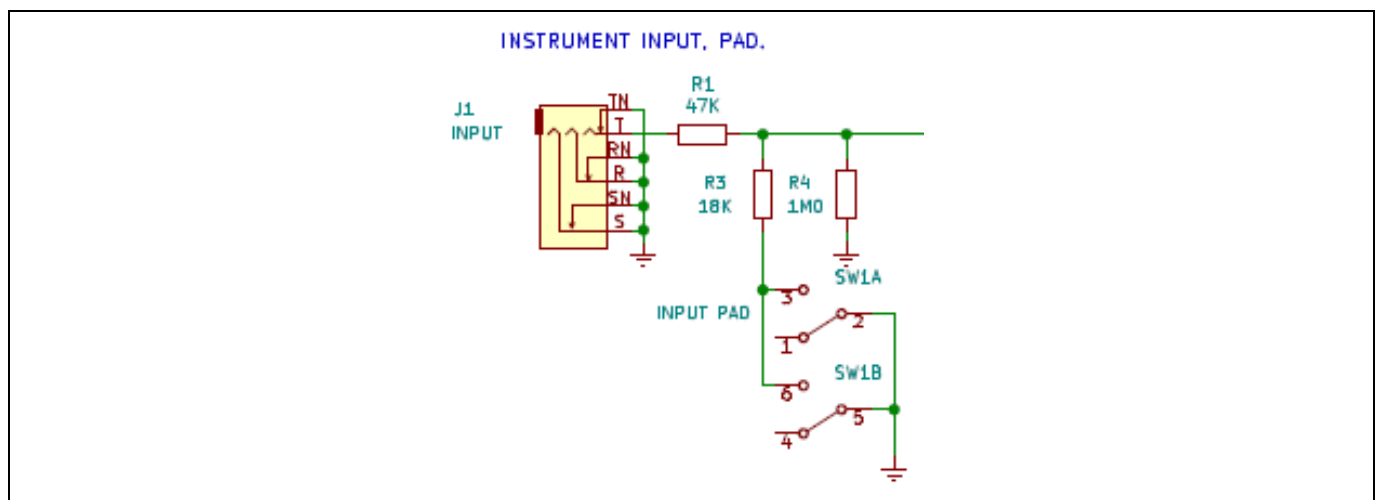


Figure 14 Input jack and pad circuitry

The jack is of the switched type, so when the instrument cable is unplugged, a switch shortens the input to GND for minimum noise.

The input impedance is set by the series resistance of the 47 k Ω + 1 M Ω resistors. This is a classic tube amp input impedance that is only minimally loading a typical instrument pick-up (5 k Ω to 20 k Ω) for maximum output. An input pad can be switched in series with the input signal. Done by a voltage divider with 47 k Ω + 18 k Ω resistors, this dampens the input signal by 12 dB. This feature is often used for matching the input sensitivity of the amplifier to a higher output instrument with built-in active electronics for getting a clean sound. Having a 65 k Ω input impedance when engaged, this can also have an effect on instruments with passive electronics. The 65 k Ω loads a passive pick-up, altering the peaking response of the inductive output for a different response.

For good shielding and chassis connection, all potentiometers are grounded via a 16 AWG copper wire directly soldered on to the brackets and connected to ground near the input jack.

5.3.2 12AU7 gain stages

The 12AU7 triode has two identical triode sections built-in. Both triode halves are used for AC signal amplification. They are both set up for low plate-voltage operation:

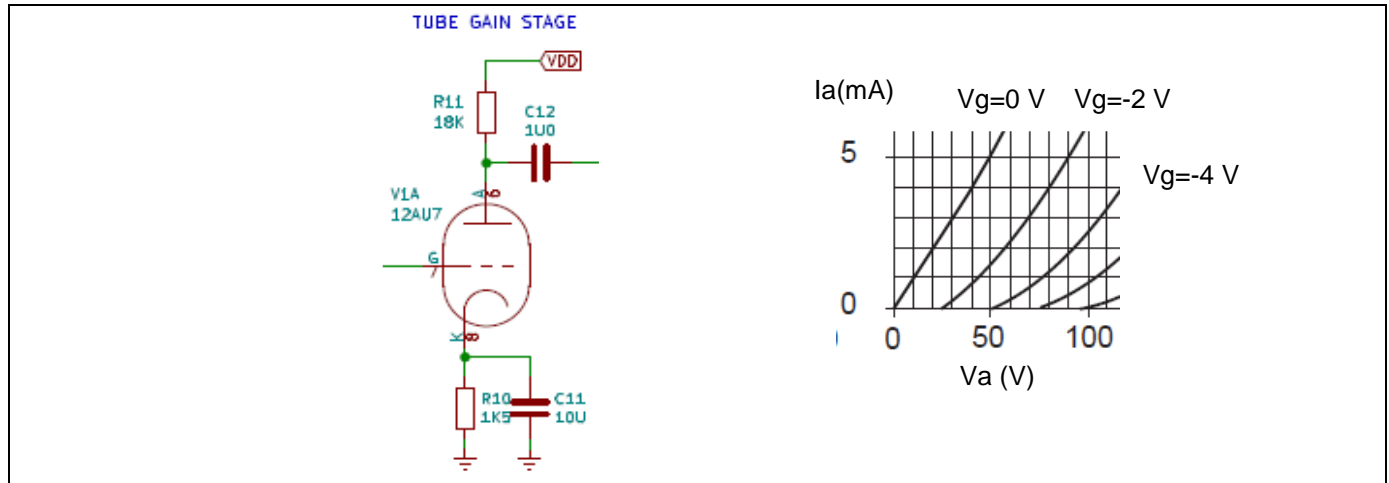


Figure 15 12AU7 gain stage and V_a/I_a characteristic

The operating points for the two stages are set up equal and are configured to operate in a cold-biased class A. With the values shown for an anode load of 18 kΩ and a cathode resistor of 1K5, the operating point is set at 280 μA/18 V. DC-wise this is much like a single-ended grounded-gate J-FET amplifier, but having vastly different AC behavior due to the triode/grid characteristics. The operating point has been set for best sound by use of a bass guitar being played through the stages. The gain of each stage is approximately +15 dB.

The two gain stages have been cascaded with a passive gain control placed between them. One can vary the signal amplitude from the first gain stage into the second, thus overdriving the pre-amplifier for a complex distortion sound (see distortion spectrums in Figures 15 and 16).

5.3.2.1 Distortion and dynamics in the tube pre-amplifier

There are several distortion-generating elements in the 12AU7 pre-amplifier.

- Asymmetric gain of positive and negative halves of the grid input signal, due to the non-linear nature of the triode characteristics. Subtle even harmonic distortion components rise with input amplitude.
- Grid-distortion, by driving the input grid of the triode positive with respect to its cathode. The grid starts to attract electrons from the cathode and input impedance falls rapidly. More abrupt and creates clipping of the lower part of the output waveform with strong even harmonic distortion components.
- Anode clipping by driving the grid so negative, that the plate runs out of supply voltage. The upper half of the output waveform is clipped with strong even harmonic distortion components.

The second gain stage alters the first gain stage's AC conditions (amplification) by loading of the falling input impedance of the second grid when overdriven, creating more asymmetric clipping and compression.

Combining positive grid and anode clipping distortion yields more uneven distortion components as the input amplitude rises, e.g., plucking a string on a bass guitar harder. That way the musician can vary the distortion content by different playing styles, creating a very dynamic sound with varying harmonic content.

Other effects of clipping/dynamic compression in a cascaded configuration include blocking distortion and shifting bias point distortion, all contributing to the dynamic feel of the amplifier.

Circuit description

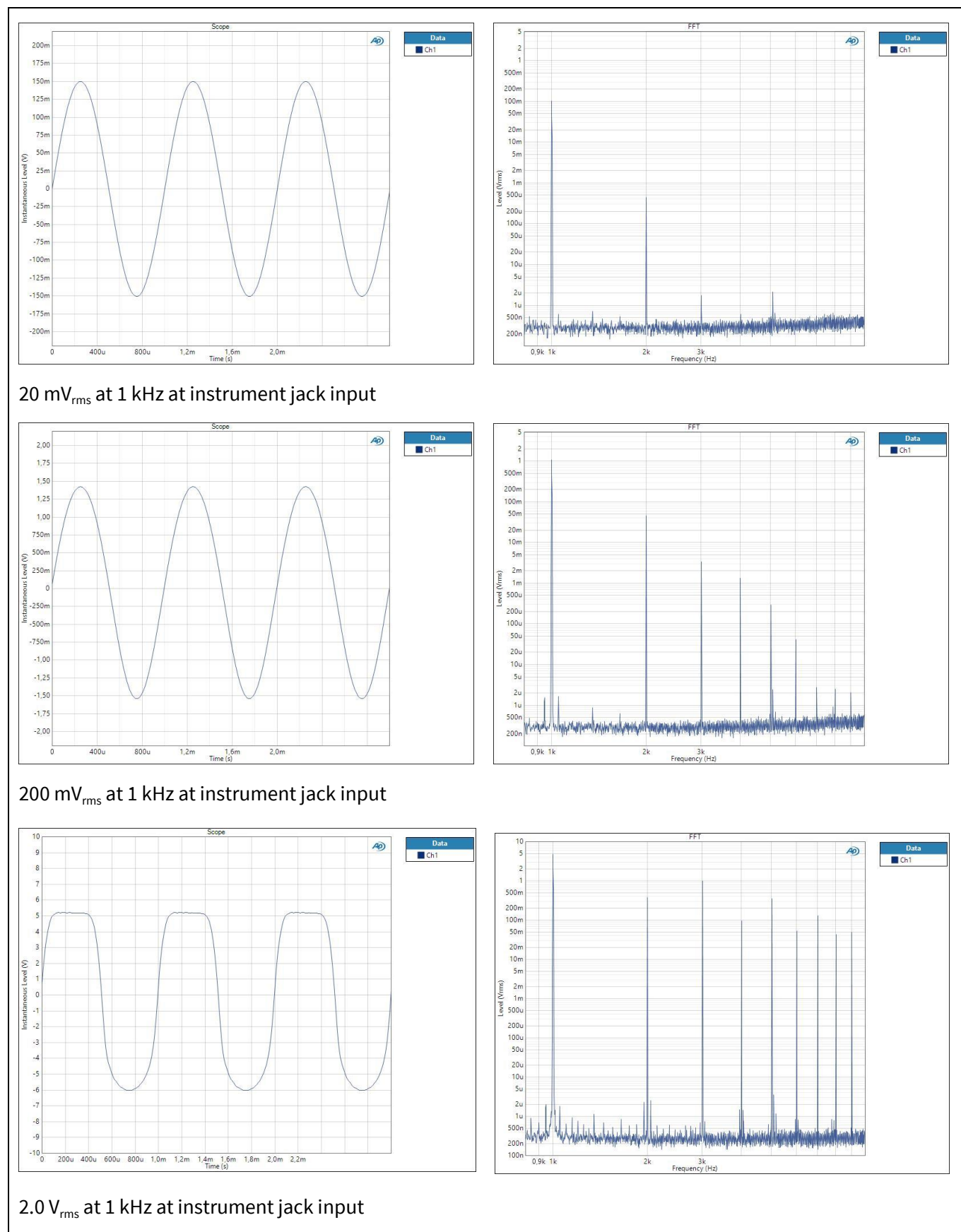


Figure 16 Waveforms and FFT distortion spectrums for the first triode gain stage – no input pad

Circuit description

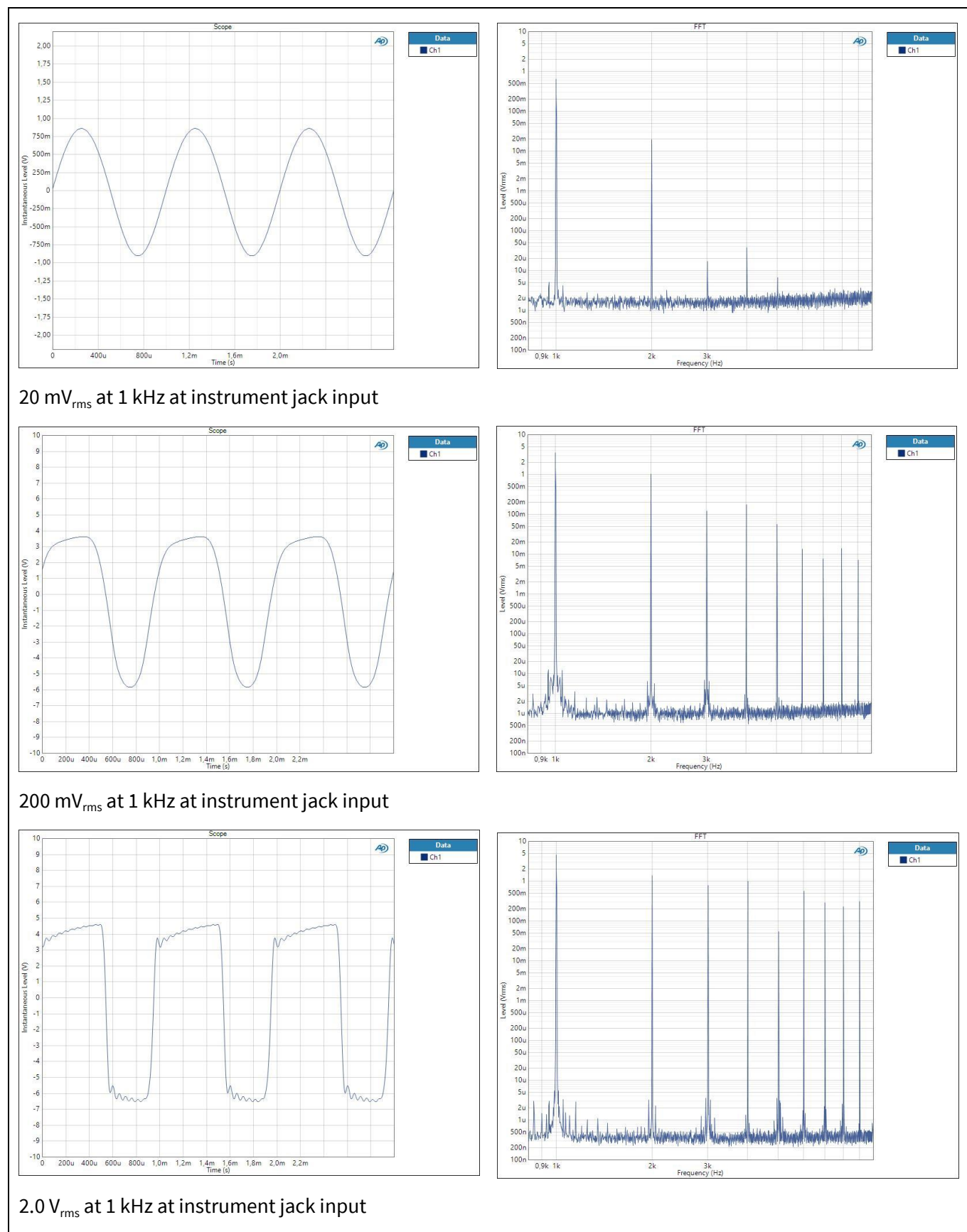


Figure 17 Waveforms and FFT distortion spectrums for the second triode gain stage – max. gain

5.3.3 Gain control with bright circuitry

To control the amount of overdrive generated in the tube pre-amplifier a gain control is inserted between the two gain stages:

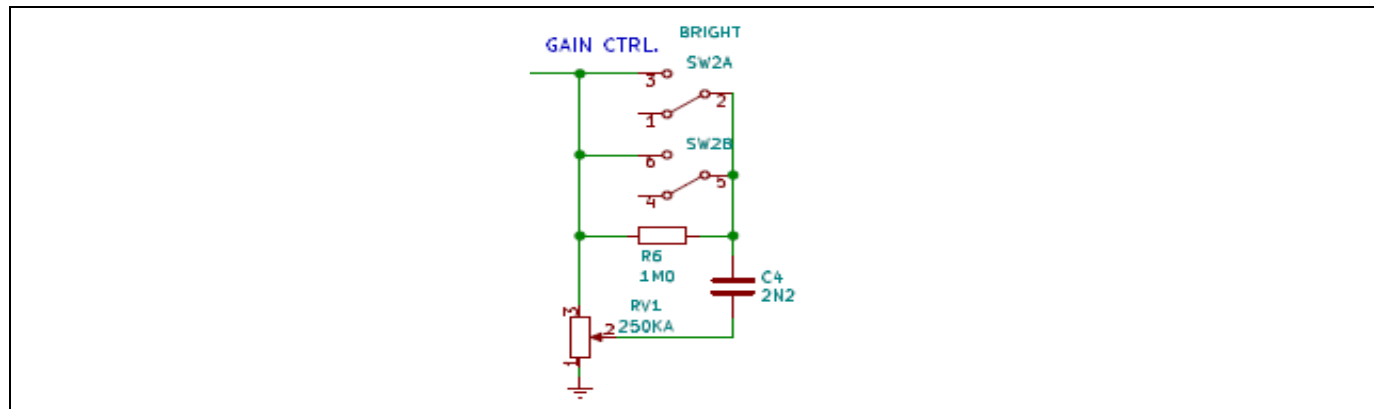


Figure 18 Gain control with bright circuitry

Across the top and arm of the gain control potentiometer is placed a switchable bright feature. The value of the bright capacitor is chosen so it accentuates the higher harmonic frequencies of the bass instrument. Combined with the gain control it forms a variable high-pass boost, having the most effect when the gain control is set between 1/3 and 2/3 of full. Crude as it may look, it is quite effective when playing slap-style bass. The value of the capacitor has been determined from classic tube bass amplifier values and bass instrument playing through the pre-amp. The 1.0 MΩ resistor acts as a bleeder, eliminating clicks and pops when switching.

5.3.4 Baxandall tone controls and volume control

This is placed after the last triode gain stage and has controls for bass, middle and treble:

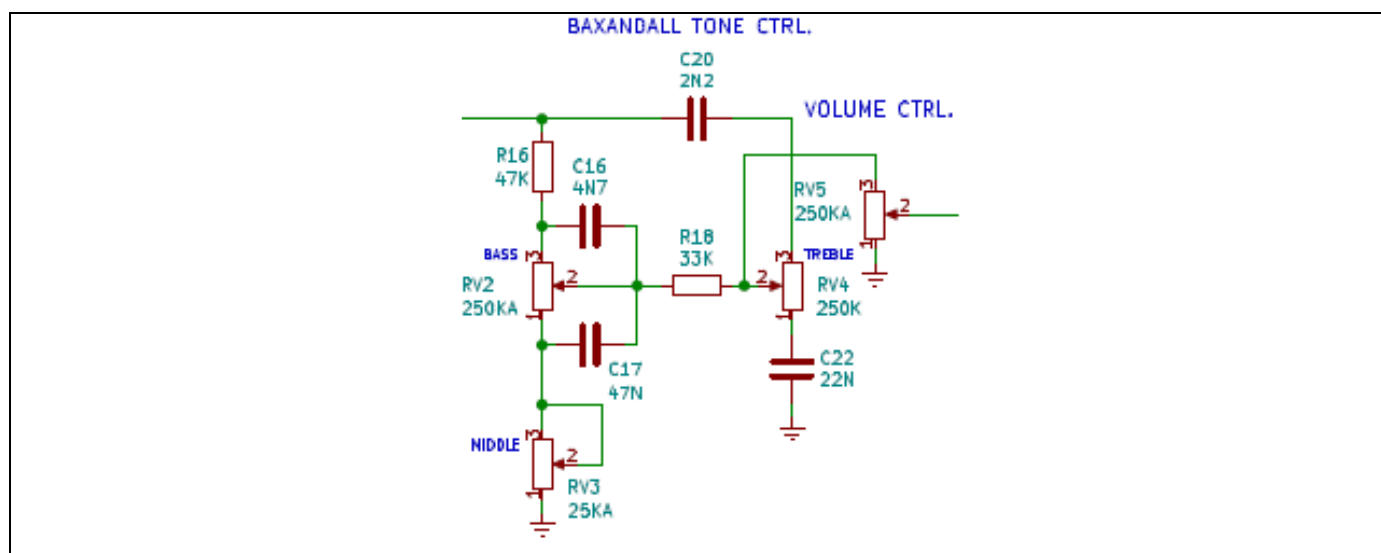


Figure 19 Baxandall tone controls and volume control

Named after its inventor, Peter Baxandall, this is a passive type of tone control, but able to both boost and cut bass and treble tones. It works by introducing a broadband insertion loss. One can boost or cut treble and bass frequencies by introducing less or more insertion loss at these frequencies. This is done by first-order RC networks, for treble frequencies, the 2.2 nF, 22 nF and 250 kΩ treble potentiometer, and for bass frequencies,

Circuit description

the combination of components surrounding the 250 kΩ bass potentiometer. The 33 kΩ resistor mixes the bass and treble signals to the 250 kΩ volume potentiometer.

The 25 kΩ middle tone potentiometer determines the broadband insertion loss of the circuit. Combined with boost or cut settings of the bass and treble tone controls, the perceived level of middle frequencies can be varied. At zero settings of all tone controls, there will be no signal passed through. Neutral setting is 12 o'clock.

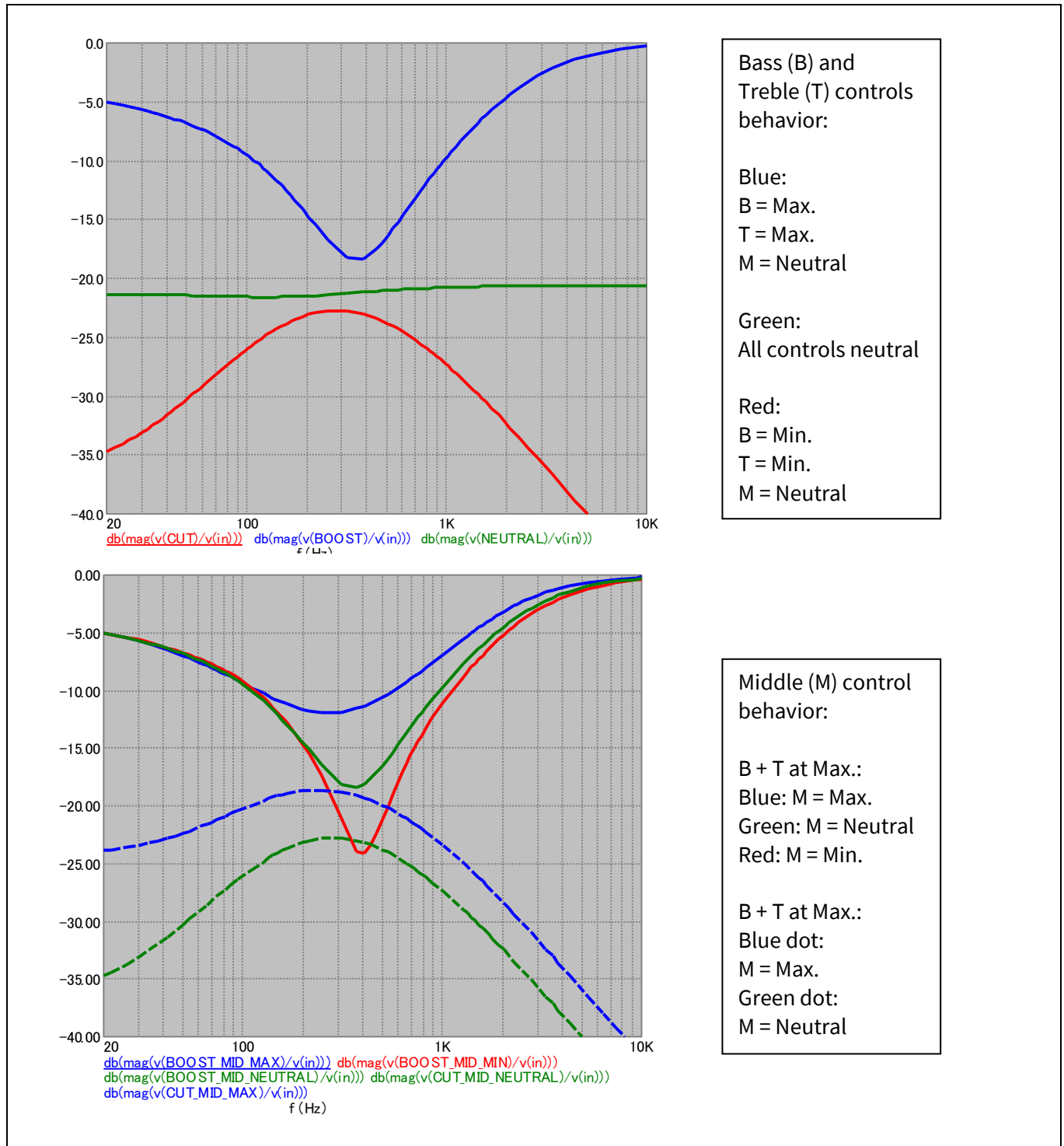


Figure 20 Bass amplifier Baxandall tone controls responses

Crude and ugly in response as it may look, this is a classic passive tonestack response found in many musical bass instrument amplifiers. Musicians expect this type of response for classic amplification.

5.4 Phase-splitter and mixer

From the volume control, the pre-amp signal enters the phase-splitter and AUX mixer.

5.4.1 Phase-splitter and AUX mixer

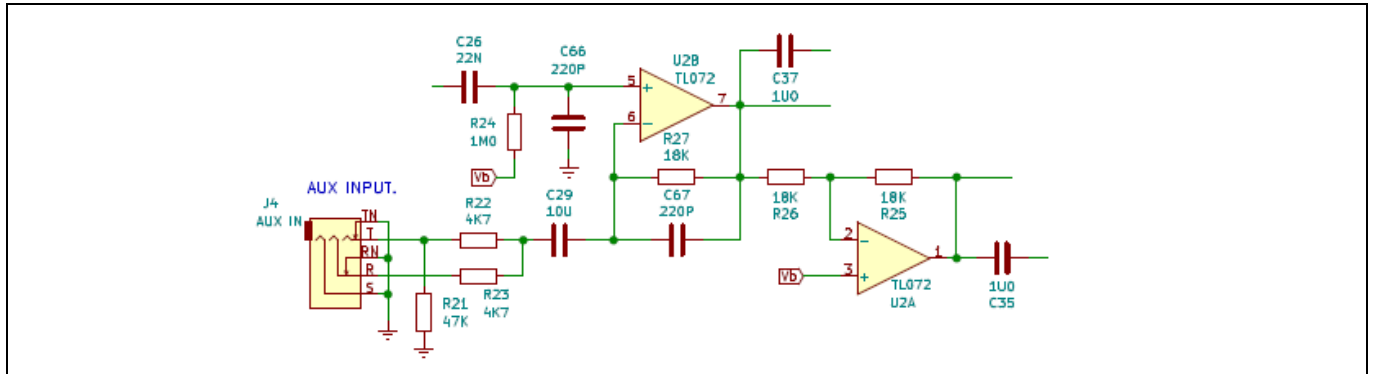


Figure 21 Phase-splitter and AUX mixer

This section has four primary functions:

- Bring up the signal level from the pre-amplifier to fully drive the MA12070 power amplifier for 60 W_{rms} into 4 Ω.
- Provide a balanced, low-impedance audio drive for the balanced input of the MA12070 power amplifier.
- Provide a balanced, low-impedance audio drive for the frequency-compensated DI output.
- Mixing in the stereo AUX input signal, and bring up the signal level for driving the MA12070 power amplifier.

The output level from the pre-amplifier varies a lot due to different settings of the passive Baxandall tone control and gain control. The MA12070 amplifier has a differential gain of +26 dB, and to fully drive the speaker to 60 W_{rms} with a +24 V DC supply voltage, it needs an input of 2.4 V_{PEAK} at each input and in the opposite phase. A voltage amplification of +19 dB for the phase-splitter was experimentally chosen by playing a bass guitar at full volume setting and at different settings of the tone control. With this amplification, the bass player had enough gain-on-tap to even overdrive the MA12070 power amplifier for a different distortion effect.

The second op-amp in the phase-splitter/mixer is set up for a gain of -1, creating the 180-degree out-of-phase signal for the inverted input of the MA12070.

The stereo AUX signal is summed into one mono signal via two 4.7 kΩ resistors at the first op-amps' inverting input. The phase-splitter/mixer relies on a low impedance (less than 200 Ω) drive from the AUX source. The input sensitivity has been chosen to be 200 mV_{rms}. The 47 kΩ resistor to GND at one of the legs of the AUX input is a DC-bleeder, eliminating clicks and pops when connecting and disconnecting AUX sources.

A wired 3.5 mm AUX input was chosen for this application. This could easily be a bluetooth receiver for wireless axillary connection instead.

Two low-pass filters, one right after the volume control and one in the feedback loop of the first op-amp in the phase-splitter, filter out unwanted out-of-band signals from the pre-amplifier and AUX input.

The op-amp type can be any reasonable dual low-noise audio op-amp capable of operating at a single supply voltage of 23 V DC. It needs to be of the J-FET/MOS input type, so as not to load the volume control and Baxandall tone control. The TL072 J-FET op-amp was chosen because it is relatively cheap, widely used and tends to have the right sonic qualities for a musical instrument amplifier of this type.

5.4.2 Speaker simulated differential DI output with ground lift and phantom power protection

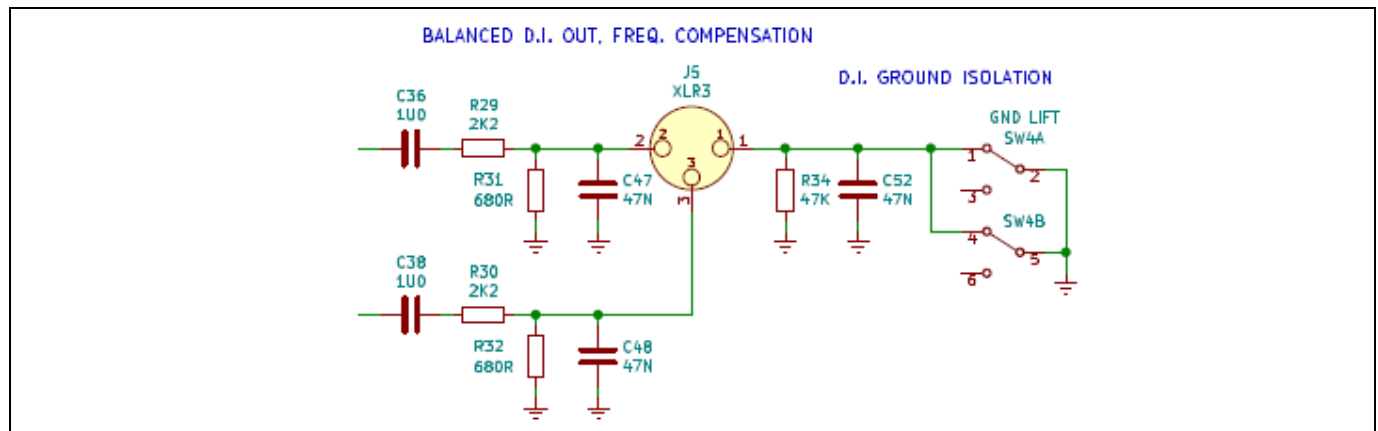


Figure 22 XLR DI output

The MA12070 musical instrument bass amplifier has a DI frequency-compensated output for going directly into a mixing console in a live situation, or in a recording media in a studio/home. Especially in live playing situations, the frequency extremes in the bass and treble frequencies are not very desirable as they tend to muddy or interfere with other instruments, e.g., drums and keyboards. The DI output of the amplifier has band-limiting filters built-in to remedy this. They are placed at 55 Hz and 8 kHz (-3 dB).

The cut-off frequencies of the filters were chosen experimentally by playing a bass instrument through the DI output connected to a PA system in a live situation.

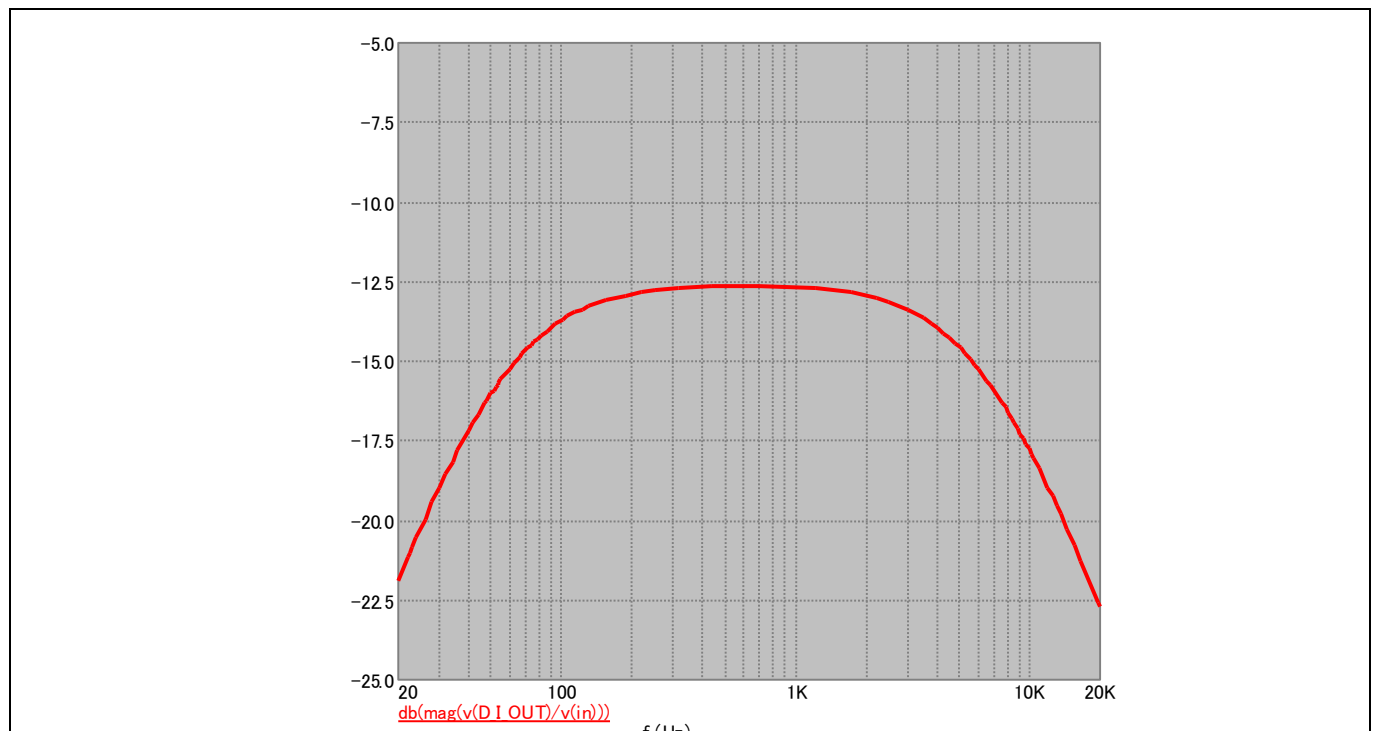


Figure 23 XLR DI output frequency response

Circuit description

For the DI output, a 3-pin XLR connector was chosen. This is the industry standard for connecting professional audio equipment. An industry-standard called phantom power is often found in professional equipment, for remote powering of e.g., microphones connected through XLR. This phantom power superimposes up to +52 V DC through a series resistance of 6.8 k Ω at Pin 2 and Pin 3 of the XLR connector (+48 V DC is most often used).

If not properly protected, the +52 V DC phantom power can severely damage any input or output circuitry of equipment if it is not made for phantom power.

The 680 Ω resistors placed on the amplifier's DI XLR output pins effectively shunt this superimposed +52 V DC to GND. In conjunction with the 6.8 k Ω series resistance of the phantom power, the voltage division results in a mere +5.2 V DC, which is not harmful to the DI circuitry of the amplifier. The 680 Ω and 2.2 k Ω resistors in the output string of the amplifier DI generates an output impedance of 520 Ω .

For further explanation of the phantom power tolerance, please see [SHURE on phantom power](#).

Another problem that can arise when connecting equipment with different ground potentials (for example questionable power lines in a live playing setup, not properly connected) is ground-loop noise. This is often heard as a loud 50/60 Hz mains hum. Also, stage lighting (which can be PWM driven) can draw very large currents from the power line, inducing noise in the ground lines. The ground lift switch on the MA12070 musical instrument bass amplifier effectively removes the amplifier GND from the XLR output connector. This makes the amplifier float with respect to the connected equipment, thus eliminating current flow from one potential to another.

The ground-loop problem is further explained here: [Wiki: Ground loop](#)

A 47 k Ω bleed resistor to GND makes up for protection if the mains supply is suddenly accidentally present, triggering a power-line HPFI breaker for false GND current detection. The 47 nF capacitor secures an effective HF ground reference.

6 BOM and PCB layout

Table 4 MA12070 musical instrument bass amplifier BOM

Designator	Description	Manufacturer	Part number	Qty
C10	Electrolytic capacitor, FK series, 100 μ F, 35 V, 8 x 10 mm	Panasonic	EEEFK1V101P	1
C18	Electrolytic capacitor, FK series, 1000 μ F, 35 V, 12.5 x 20 mm	Panasonic	EEUFR1V102B	1
C3,C9,C11,C19,C24,C25,C27,C28,C29,C30,C44,C49,C50,C51,C53,C54,C60	Ceramic capacitor, 10 μ F, \pm 10 percent, X5R, 25 V, 0805	Samsung	CL21A106KAYNNNE	17
C5,C6,C7,C12,C13,C14,C15,C23,C31,C32,C33,C34,C35,C36,C37,C38,C39,C40,C41,C42,C43,C45,C46,C57,C58,C59,C62,C63,C64,C65	Ceramic capacitor, 1 μ F, \pm 10 percent, X7R, 50 V, 0805	Samsung	CL21B105KBFNNNE	30
C1,C2,C8,C22,C26	Ceramic capacitor, 22 nF, \pm 5 percent, NP0, 50 V, 0805	TDK	C2012C0G1H223J125AA	5
C17,C47,C48,C52	Ceramic capacitor, 47 nF, \pm 10 percent, NP0, 50 V, 0805	Murata	GRM21BR71H473KA01L	4
C16	Ceramic capacitor, 4.7 nF, \pm 5 percent, NP0, 200 V, 0805	Kemet	C0805C472J2GECTU	1
C4,C20	Ceramic capacitor, 2.2 nF, \pm 5 percent, NP0, 100 V, 0805	Kemet	C0805C222J1GACTU	2
C55,C56,C66,C67	Ceramic capacitor, 220 pF, \pm 5 percent, NP0, 50 V, 0805	Vishay	VJ0805A221JXACW1BC	4
R4,R6,R17,R19,R24,R35	Resistor, 1 M Ω , 125 mW, 1 percent, 0805	Vishay	CRCW08051M00FKEA	6
R1,R9,R12,R16,R21,R34	Resistor, 47 k Ω , 125 mW, 1 percent, 0805	Vishay	CRCW080547K0FKEA	6
R15,R18	Resistor, 33 k Ω , 125 mW, 1 percent, 0805	Vishay	CRCW080533K0FKEA	2
R2,R39	Resistor, 20 k Ω , 125 mW, 1 percent, 0805	Vishay	CRCW080520K0FKEA	2
R3,R7,R11,R13,R25,R26,R27	Resistor, 18 k Ω , 125 mW, 1 percent, 0805	Vishay	CRCW080518K0FKEA	7
R22,R23	Resistor, 4.7 k Ω , 125 mW, 1 percent, 0805	Vishay	CRCW08054K70FKEA	2
R29,R30,R40	Resistor, 2.2 k Ω , 125 mW, 1 percent, 0805	Vishay	CRCW08052K20FKEA	3
R5,R10	Resistor, 1.5 k Ω , 125 mW, 1 percent, 0805	Vishay	CRCW08051K50FKEA	2
R14,R20,R28,R31,R32	Resistor, 680 Ω , 125 mW, 1 percent, 0805	Vishay	CRCW0805680RFKEA	5
R37,R38	Resistor, 300 Ω , 500 mW, 5 percent, 1210	Panasonic	ERJT14J301U	2
R36	Resistor, 22 Ω , 125 mW, 1 percent, 0805	Vishay	CRCW080522R0FKEA	1

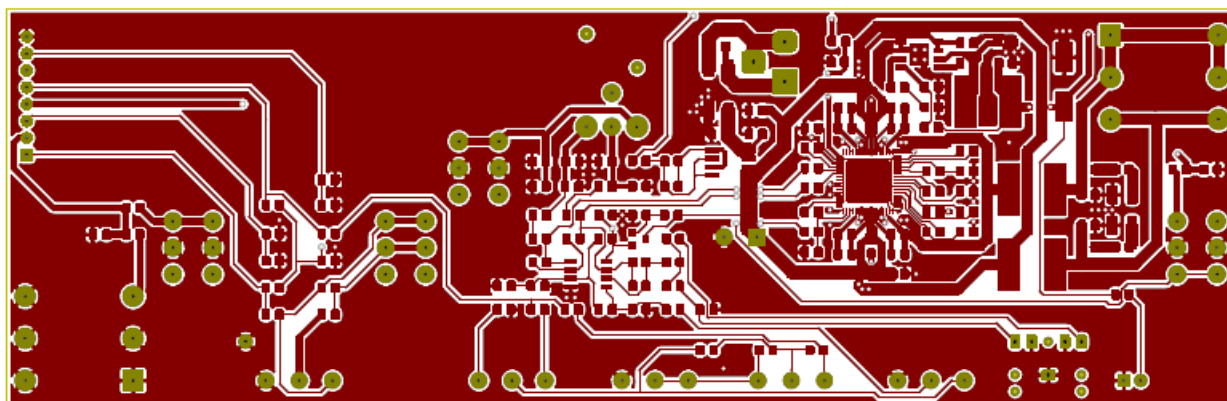
Design approach for a MERUS™ MA12070 based musical instrument bass amplifier



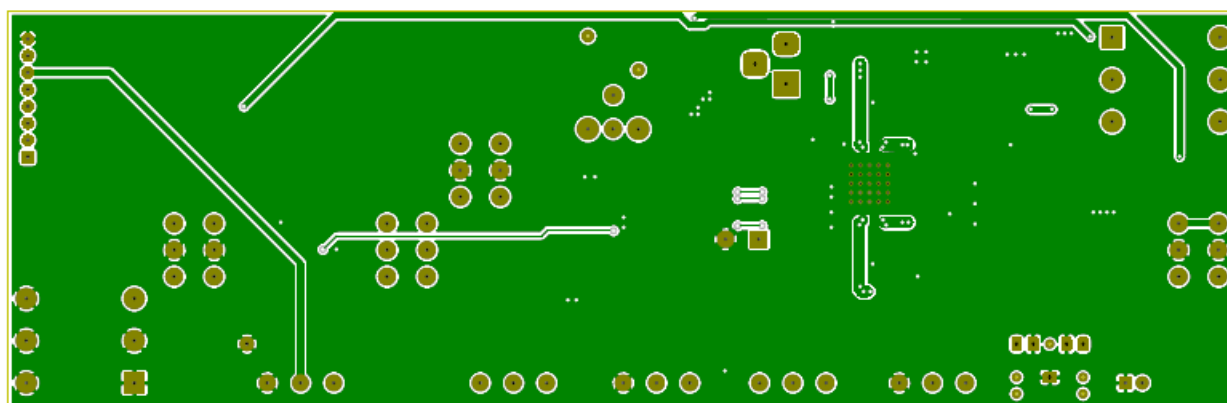
BOM and PCB layout

Designator	Description	Manufacturer	Part number	Qty
L1	Common-mode filter, 700 Ω , 4 A, 7 x 6 mm	TDK	ACM7060-701-2PL-TL01	1
L2	Power inductor, 47 μ H, 1.9 A, 8 x 8 mm	Murata	1267AY-470M=P3	1
L3,L4	Power inductor, 1.5 μ H, 7.3 A, 8 x 8 mm.	Murata	1267AY-1R5N=P3	2
D1	Schottky diode, BAS3010, 30 V, 1 A, SOD-323	Infineon	BAS3010A03WE6327HTSA1	1
D2	LED, red, 5 mm, TH, T1-3/4	Broadcom	HLMP-3301	1
Q1	BJT, NPN, BC847C, 45 V, 100 mA, SOT-23	Infineon	BC847CE6327HTSA1	1
U1	Buck controller, adjustable, 45 V, 1.8 A, SOIC-8	Infineon	TLE8366EVXUMA1	1
U2	Dual audio op-amp, TL072A, \pm 18 V	ST	TL072ACDT	1
U4	Multilevel class D amplifier, MA12070, 2 x 80 W	Infineon	MA12070XUMA1	1
U5	Dual P-channel MOSFET, IRF9358, -30 V, -9.2 A	Infineon	IRF9358TRPBF	1
RV1,RV2,RV4,RV5	Rotary potentiometer, TH, 250 k Ω logarithmic, 16 mm	TT Electronics	P160KN-0QC15A250K	4
RV3	Rotary potentiometer, TH, 25 k Ω logarithmic, 16 mm	TT Electronics	P160KNP-0QC20A25K	1
SW1,SW2,SW3,SW4	Push-button switch, TH, DPDT, 30 V, 0.1 A	Alps Alpine	SPUN191600	4
J4	Phone jack, stereo, switched, TH, 3.5 mm	Cliff	FC68133	1
J1,J6	Phone jack, stereo, switched, TH, 6.35 mm	Neutrik	NMJ6HFD2	2
J5	XLR connector, three contacts, male, TH	Neutrik	NC3MAAH	1
J2	DC power connector, jack, 5 A, TH, 2.5 mm	Multicomp	SPC21365	1
J3	Header, eight contacts, 1 row, right angle, 2.54 mm	Würth	61300811021	1
N1	Tube socket, TH, PCB, ceramic, NOVAL	Belton	VT9-PT	1
V1	Electron tube, dual triode, 12AU7/ECC82, NOVAL	Electro Harmonix	12AU7/ECC82	1

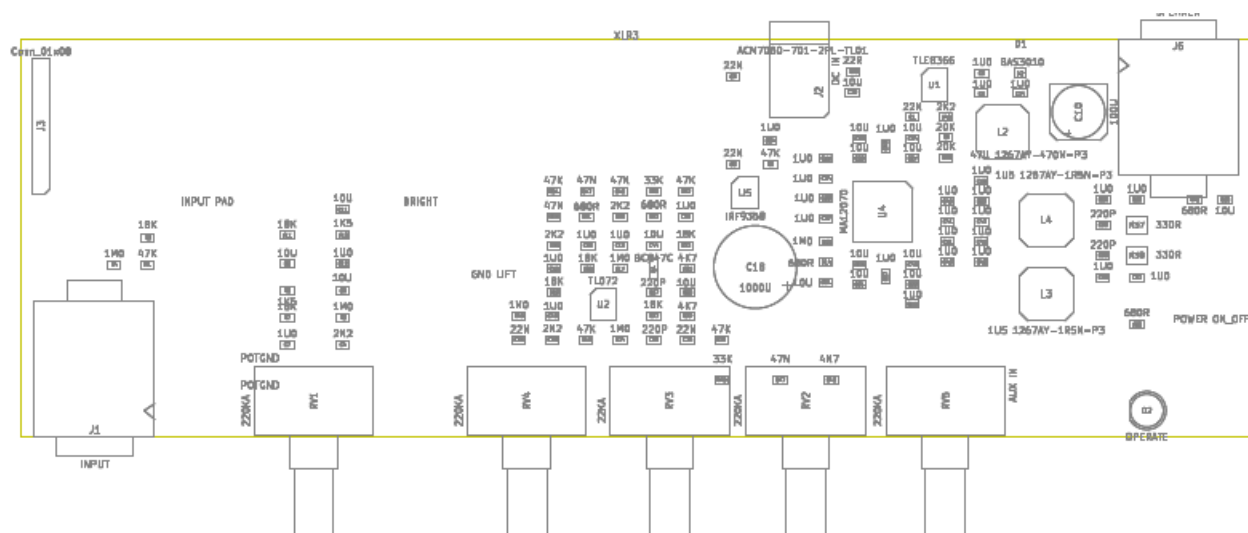
BOM and PCB layout



Top side



Bottom side



Placement

Figure 24 **Main PCB layout**

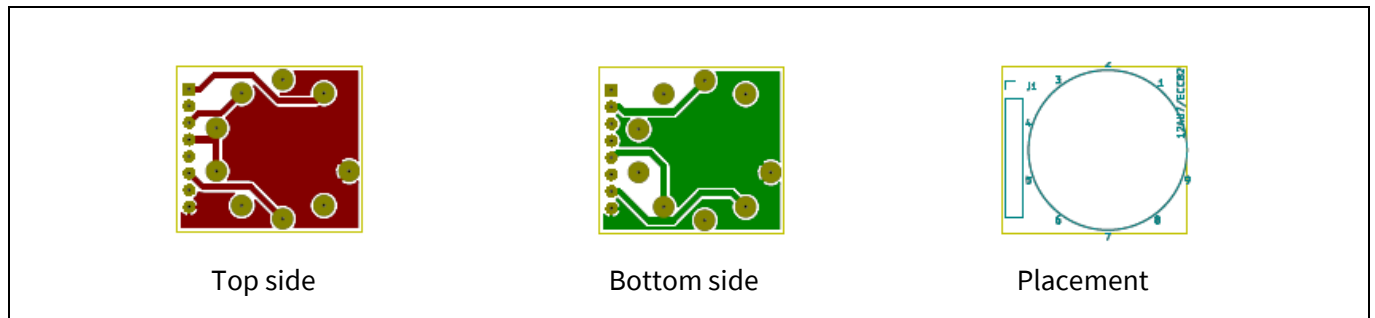


Figure 25 **Tube PCB layout**

Note: The PCB type used for the MA12070 musical instrument bass amplifier is 1.55 mm thickness, FR4, TG150, 35 μm Cu.

7 Revision history

Document version	Date of release	Description of changes
V 1.0	29-05-2020	First release

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