RABID MANTIS

CHEAPAMP

Low-cost low component count class-D audio amplifier

Features

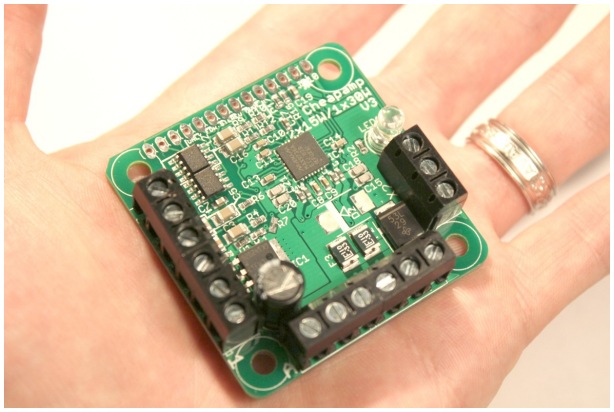
Stereo 15W / Mono 30W output
Up to 88% efficiency
No heatsinking required, even for continuous operation
Single-ended supply, 7-20V
Reverse polarity and overvoltage protection
Low cost, ≈ 13$ BOM cost
0.04% *THD @ 4W*
96dB SNR

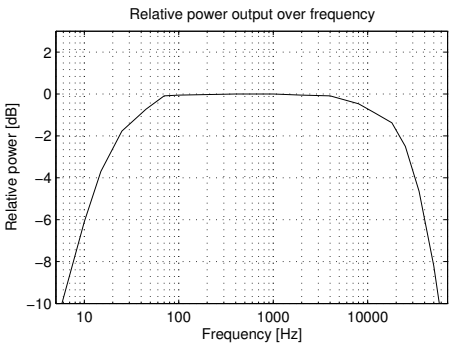
Description

The Cheapamp amplifier is a compact general-purpose — though audio-oriented — class-D power amplifier with analog volume controls and a pin-header for full digital control. It is based on the MAX9736A/B[a] monolithic amplifier.
The board design is heavily centered around the filterless recommended design shown in the datasheet, and is configurable for either mono (bridged) or stereo applications.

[a] http://www.maxim-ic.com/datasheet/index.mvp/id/5688

Overview





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Hardware Revision History

1.0 Initial version.

1.1 Reduced noise with long potentiometer cable with capacitive buffer, added constant volume mode.

1.2 Further reduced output noise with added input filter. Component count reduced.

Documentation Revision History

1.0 Initial version, applies to hardware revision 1.0.

1.0.1 BOM restructured, title page document ID syntax updated.

1.0.2 PCB manufacturing requirements (table 3) added.

1.1.0 Initial version for hardware revision 1.1.

1.1.1 Updated erronous component placement details in figure 1.

1.2.0 Initial version for hardware revision 1.2.

Absolute Maximum Ratings

PARAMETER	RATING
Power input voltage	-30V to $+20/+30$V[a]
Signal input voltage	$\pm$10V or $\pm$10mA, whichever occurs first
Output short circuit	Indefinite

[a]Note: Tolerated input voltage range depends on choice of overvoltage protection. See Assembly.

Assembly

Cheapamp consists of mostly surface mount components with a few hole-mounted supporting components. The most difficult component to mount is the MAX9736 amplifier, which is in a TQFN package with exposed center pad. This must be done using a reflow oven, hotplate, or equivalent to ensure the center pad establishes a good thermal connection to the PCB for cooling purposes. All other components are relatively simple, being mostly SO8, 0603, and 1206 packages.

For operation as an audio amplifier, mount components matching the values shown in Bill of materials at the locations shown in figure 4, following the pin usage in Pin Description. For other uses see Operation.

There is an optional overvoltage protection function that can be disabled by not mounting D2. In this case input voltages of up to 30V can be tolerated, otherwise the input voltage should be limited to 20V (and not exceeding 21V during normal use).

The board can be mounted in either a stereo or mono configuration. Some components are only needed in stereo mode, these are marked with a line grouping them together and noted with the text "Stereo mode" (these components are R1, R2, C21, C22, R15, C23, C25, R16, IC4).

Additionally, the board can either be mounted for use with volume-adjusting potentiometer(s) (one potentiometer when mounted in mono configuration, two when mounted in stereo configuration) or in a constant-volume mode. If there is no need for adjusting the volume the device may be mounted in constant volume mode; in which case the screw terminal X1 is not mounted and the resistors R11 and R15 are mounted. Note that assembling for constant-volume mode **will** result in high speaker volume levels for moderate inputs!

There are solder bridges on the bottom of the PCB that **must** be programmed before use as follows;

Mono mode Activate all mono mode solder bridges (short JP2,JP3,JP4,JP9 and enable JP7) if the device is to run in mono mode (one output). The left volume potentiometer controls the system gain and the speaker should connect to the left outputs. The left and right inputs are mixed equally. If a mono input signal is used connect it to either the left or right input and leave the other floating (unconnected). Leave the right potentiometer terminal connections floating.

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Constant volume mode Short JP8 and JP10 (in addition to leaving X1 unmounted and mounting R11 and R15) to bring the device into constant volume mode. This will give a fixed output volume. Leave JP8 and JP10 unshorted, R11 and R15 unmounted, and mount X1 for normal, adjustable volume, mode.

Spread spectrum (recommended: ON) Activate JP6 to enable, this should typically be enabled unless additional external inductive filters are used. **This is at slight cost of efficiency**, but keeps EMI below EN55022B EMC radiation limits when used without external filters and a cable below 1m in length. Note that is is possible to run the amplifier using a traditional LC filter on the output, if so do not mount L2, L3, L4, L5, C9, C13, C15, C16 and place an LC filter as described in the datasheet directly after the output(s).

Internal regulator (recommended: OFF) Activate JP5 and short JP1 to enable. This enables the internal 5V regulator and may be used only if the LM317 regulator is not mounted. As the MAX9736 IC does not specify the allowed load on it's 5V output and the operational amplifiers are powered by the 5V rail **this feature has not been tested**. Use with caution!

Note; there are two types of solder jumpers; jumpers with two conductors are shorted by soldering both together, while jumpers with three conductors are programmed to one of two states by shorting the center conductor to either one of the two outer conductors. NEVER SHORT ALL THREE CONDUCTORS AS THIS MAY POTENTIALLY DESTROY THE DEVICE ON POWER-UP!

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Pin Description

For the most basic use, all connections are made through the terminal blocks around the device. Where more fine-grained control is required, additional functions can be accessed on the 2.54mm pitch header (Header D) on one side[1]. Connections are as follows;

HEADER	PIN	DESCRIPTION
Header A	GND	Power ground connection.
	PWR SUP	Power positive voltage input.
	OUTL+/MONO+	Positive left / mono output, connect one terminal of the left / mono load here.
	OUTL-/MONO-	Negative left / mono output, connect the other terminal of the left / mono load here.
	OUTR+	Positive right output, connect one terminal of the right load here (if in stereo mode), leave unconnected in mono mode.
	OUTR-	Negative right output, connect the other terminal of the right load here (if in stereo mode), leave unconnected in mono mode.
Header B	AGND	Analog ground for input signal. Connected to GND_IN on one point on the board via a trace.
	INL/MONO	AC coupled input for left/mono.
	INR/MONO2	AC coupled input for right (mixed equally with left input when in mono mode, may be left unconnected).
Header C *Note; Header is not mounted in constant volume mode.*	POTL/MONO+	Left/mono potentiometer positive terminal (if the wiper is placed close to this terminal the gain is maximized).
	POTL/MONOW	Left/mono potentiometer wiper terminal.
	POTL/MONO-	Left/mono potentiometer negative terminal (if the wiper is placed close to this terminal the gain is 0 ($-\infty$ dB)).
	POTR+	Right potentiometer positive terminal (if the wiper is placed close to this terminal the gain is maximized). Leave unconnected in mono mode.

[1] This header is intended to be used as an expansion port, for example with a microprocessor and DAC as an embedded audio player .

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HEADER	PIN	DESCRIPTION
	POTRW	Right potentiometer wiper terminal. Leave unconnected in mono mode.
	POTR-	Right potentiometer negative terminal (if the wiper is placed close to this terminal the gain is 0 ($-\infty$ dB)). Leave unconnected in mono mode.
	Note; Use a logarithmic potentiometer somewhere in the range of $10 - 100k\Omega$.	
Header D	PWR SUP	Connected to the main input voltage, after the reverse polarity, overvoltage and fuse protection section.
	GND	System ground.
	5V	Internally generated 5V output. Current availability limited by the power dissipation of the LM317 regulator, which depends on the input voltage. Generally this is moderate, in the range of 30-100mA or so (untested!).
	$\overline{\text{SHDN}}$	Input to amplifier, bring low to shut down the amplifier (and reduce quiescent current). Note there is a 1uF capacitive load on this line. Leave unconnected or connect to 5V to turn on.
	$\overline{\text{MUTE}}$	Input to amplifier, bring low to mute the amplifier. Leave unconnected or connect to 5V to unmute.
	AGND	Analog input ground (connected to system ground at one point on the board).
	INL/MONO	Identical to INL on header B.
	INR	Identical to INR on header B.
	POTL+ through POTR-	Identical to the equivalent pins on header C, do not connect to when in constant volume mode.

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Usage

Cheapamp aims to be simple to use, mount components and program the device with the solder-bridges as described in Assembly and Pin Description. Power should be delivered with some type of DC power supply (with voltage as per Electrical Characteristics). Connect the speaker(s) to the output headers, keeping the cable to the speakers as short as possible. To stay within EN55022B EMC limits keep the cable below one meter in length. Be sure to use wire with a conductor cross-section of $\geq$ 1mm^2, both for input DC power as well as to the speaker(s). Use shielded cables (such as a shielded microphone cable) for the input signal and potentiometer connections. Try to keep the cables connecting Cheapamp to the speaker(s) as far away as possible from the input signal and potentiometer cables – the switching noise in the output signal will otherwise couple to the low-level input signals and raise the noise level and amount of distorsion.

Cheapamp is designed to be able to achieve full volume when driven by line-level signals of approximately 1Vpp, while tolerating signals of up to $\pm$10V, and contains both input DC and RF blocking filters.

For other uses of Cheapamp such as; a general-purpose DC-coupled amplifier; an amplifier whose volume, mute/standby functionality is controlled by external circuitry; a low-EMI amplifier; and so on, see Operation.

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Bill of materials

Note; A value of 4n7 corresponds to a value of 4.7n, and in the case of a capacitor corresponds to 4.7nF. The suggested part number is only that — a suggestion — and may be replaced with any other equivalent matching the specifications listed under value, rating, and type. 2-way jumpers are referred to as "short on" to activate, while 3-way jumpers are referred to as "set on" or "set off" – short the center pad to either the "on" or "off" side pad to enable/disable a function. Components within paranthesis, eg. (C23) are only mounted in stereo mode.

Component name	Value	Rating	Type	Suggested Part No.
C1	100uF	50V	8mm can, 3.5mm pin grid	50ZLH100MEFC8X11.5
C10,C12,C14,C19,C20,(C23)	1uF	16V	SMD 0603, X5R	MCCA000529
C17,(C21)	10uF	25V	SMD 1206, X5R	12063D106KAT2A
C18,(C22)	4n7	50V	SMD 0805, X5R	MCCA001280
C24,(C25)	120p	50V	SMD 0805, NP0 or C0G	MCCA000331
C2,C3,C4,C5,C7,C8	1uF	50V	SMD 0603, X5R	GRM188R61H105KAALD
C9,C13,C15,C16	330pF	50V	SMD 0805, NP0 or C0G	MCCA000339
D1	Schottky diode	30V, 5A	SMD SMC package	SSC53L-E3/57T
D2	SMCJ20A	20V, 3000W TVS zener diode	SMD SMC package	3.0SMCJ20A-13
F1,F2	1812L110/33MR	1.1A PTC fuse	SMD 1812	1812L110/33MR
IC1	LM317MABDT	LM317	DPAK package	LM317MDT
IC2	MAX9736AETJ+	30W audio amplifier	SMD TQFN	MAX9736AETJ+
IC3,(IC4)	ADA4692-2R	Rail-to-rail audio op-amp	SMD SO-8	ADA4692-2ARZ
JP1		2-way jumper	Programming jumper	Short for internal 5V reg
JP2,JP3,JP4,JP9		2-way jumper	Programming jumper	Short for mono mode
JP5		3-way jumper	Programming jumper	Set on for internal 5V reg
JP6		3-way jumper	Programming jumper	Set on for spread spectrum
JP7		3-way jumper	Programming jumper	Set on for mono mode
JP8,JP10		2-way jumper	Programming jumper	Set on for constant-volume mode
JP11			2.54mm x 14-way pinheader	Generic pinheader

COMPONENT NAME	VALUE	RATING	TYPE	SUGGESTED PART NO.
L1,L2,L3,L4,L5	BLM18SG221TN1D	2.5A, 220Ω	SMD 0603	BLM18SG221TN1D
LED1	20mA LED	Chip LED	SMD 1206	KPT-3216YC
(R1),R3,R5,R6,R10,R13	1k	1%, 0.1W	SMD 0603, thick-film resistor	CRCW06031K00FKEA
R12,(R16)	100R	1%, 0.1W	SMD 0603, thick-film resistor	CRCW0603100RFKEA
(R2),R4,R11,(R15)	10k	1%, 0.1W	SMD 0603, thick-film resistor	CRCW060310K0FKEA
RGND	(Do not mount)	N/A	N/A	Internally shorted on PCB
R7	2k7	1%, 0.1W	SMD 0603, thick-film resistor	CRCW06032K70FKEA
R8,R9	100k	1%, 0.1W	SMD 0603, thick-film resistor	ERJ3GEYJ104V
X1,X3			5mm x 6-way terminal	CTB5202/6
X2			5mm x 3-way terminal	CTB5202/3

Mechanical Description

Cheapamp is mechanically quite small, with a size of 50mm by 50mm and a build height of 16mm (controlled by power decoupling capacitor C1 choice). Mounting holes are listed in table 4 following the coordinate system in figure 1. PCB manufacturing requirements are shown in table 3, and should generally be achievable at any PCB house. **Be sure to use plastic isolation washers or plastic screws when using the two holes closest to the 14-way header!**

Connections for most use-situations are available through the terminal blocks on the sides, as shown in figure 3, with additional parameters controllable through a 14-way 2.54mm pin header. Input and output power connections should be made with wires whose inner conductor is at least $1mm^2$. No components require heatsinking, however the device must be allowed some passive convective cooling — do not cover the board with sound-damping foam or similar.

Table 3: PCB manufacturing requirements.

PARAMETER	REQUIREMENT	UNIT
PCB thickness	Any (nominal 1.6)	mm
PCB layers	2	-
Copper fill thickness/density (tested)	35/1	µm / oz/ft^2
Trace isolation (minimum)	0.2032/8	mm/mil
Trace width (minimum)	0.254/10	mm/mil
Trace to board edge (minimum)	0.25	mm
Drill to board edge (minimum)	0.4532	mm
Drill diameter (minimum)	0.3	mm
Via annular ring (minimum)	0.2032/8	mm/mil

Table 4: Mounting hole locations.

HOLE DIAMETER [mm]	POSITION X [mm]	POSITION Y [mm]
4.1	5	5
4.1	5	45
4.1	45	5
4.1	45	45

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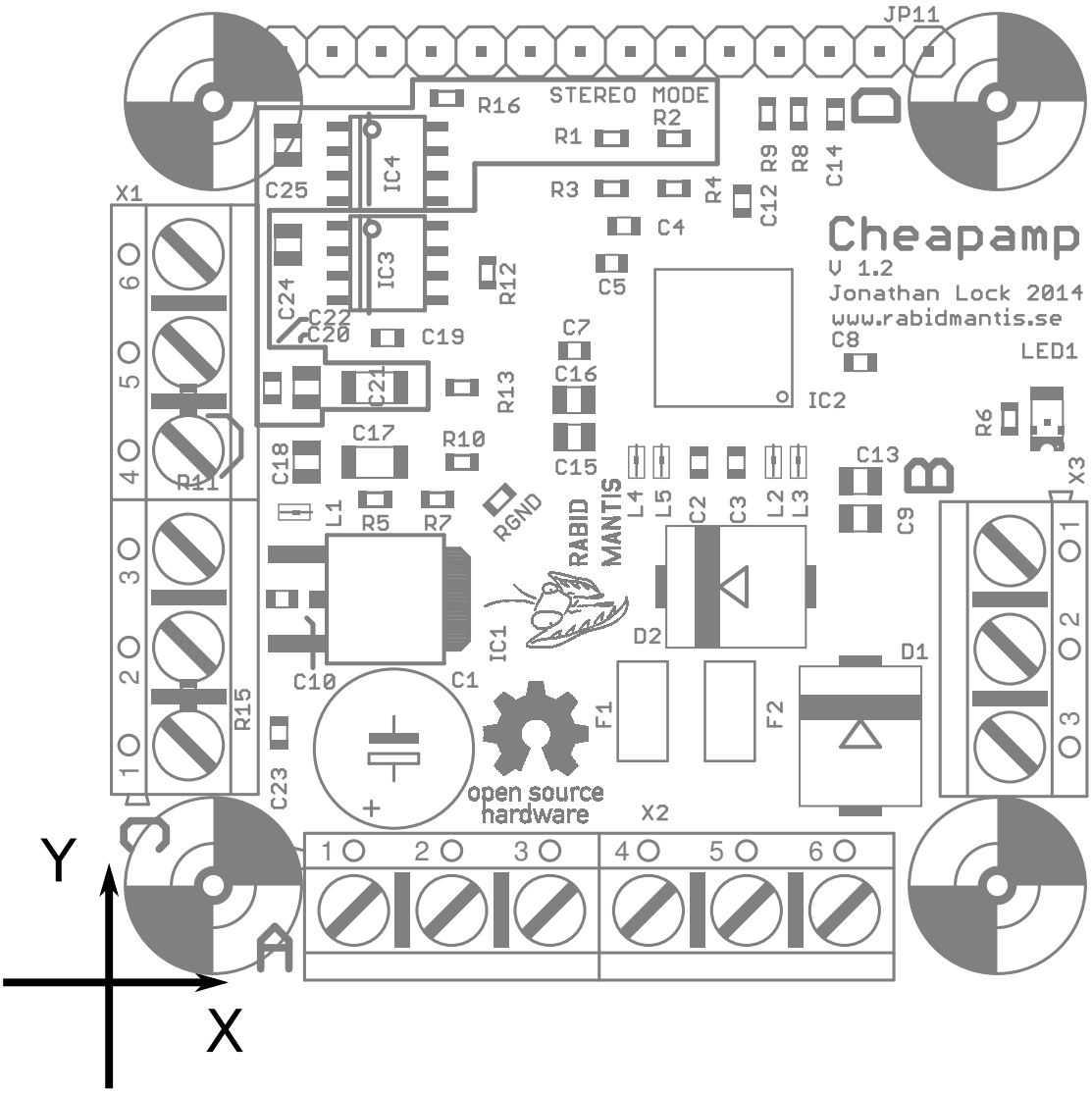

Figure 1: Coordinate system for mounting holes.

Electrical Characteristics

$V_{in} = 18\text{V}$, $R_{load} = 4\Omega$, $R_{potentiometer} = 20\text{k}\Omega$ unless otherwise specified. In general, see MAX9736 datasheet for more extensive parameters. (Performance is for the most part limited by the MAX9736 IC).

PARAMETER	SYMBOL	TEST CONDITIONS/COMMENTS	MIN	TYP	MAX	UNIT
Input Characteristics						
Power Input voltage	V_{in}	Input overvoltage diode mounted	8		20	V
		Input overvoltage diode not mounted	8		28	V
AC Input impedance, adjustable-volume mode[2]	R_{in}	$f_{in} = 1kHz$		21		kΩ
AC input impedance, constant-volume mode				11		kΩ
DC Input impedance			10			MΩ
Quiescent supply current, amplfier active		Both for stereo and mono mode		50		mA
Quiescent supply current, amplifier in shutdown		Both for stereo and mono mode		10		mA
Quiescent supply current, amplifier in shutdown, 5V source externally generated (IC1, LED1 not mounted)		Mono mode		400		μA
		Stereo mode		800		μA
Output Characteristics						
Output power, THD+N = 1%	P_{out}	Spread spectrum mode enabled		27		W
THD plus noise		$P_{out} = 4\text{W}$, $f = 1\text{kHz}$, $R_{load} = 8\Omega$		0.06		%
Dynamic behavior						
DC cutoff frequency		$-3dB$ point, single pole filter		15		Hz
HF cutoff frequency		$-3dB$ point, single pole filter		28		kHz
Efficiency		$P_{out} = 8\text{W}$, $V_{in} = 12\text{V}$, $R_{load} = 8\Omega$		88		%

[2] The total input impedance is typically $R_{in} = 1\text{k}\Omega + R_{potentiometer}$

Operation

Cheapamp is, from a functionality perspective, essentially a break-out board for the MAX9736 with various supporting components. As such, the vast majority of functionality is embedded within the MAX9736 unit, making the operational description very simple. See figure 2 for a full schematic of the device, figure 3 for the PCB artwork, and figure 4 for the component placement.

The power generation section shown in the schematic in figure 2 consists of D1 acting as a reverse polarity protection diode; F2 and F3 acting as input protection fuses in the event of some over-current or overvoltage situation; D2 acting as an overvoltage protection (which starts conducting above 22V, leading to F2 and F3 triggering[3]); and C1, the primary decoupling capacitor. A 5V supply is generated by IC1,R5,R7 and C10, which is used to power some operational amplifiers as well as circuitry internal to the MAX9736. LED1 and R2 act as an optional power indicator. L1 reduces the amount of RF switching noise the MAX9736 IC generates from its 5V supply that enters the external operational amplifiers.

The prefilter section consists of two identical input channels (one in mono mode) which apply a high-pass and low-pass filter (R10,C17,C18 and R13,C21,C22) to remove any DC offset or RF noise respectively from the source. C20,C23,C24,C25,C18,C22 act as low-pass filters that reduce the level of capacitively coupled interference to the relatively sensitive input from the "noisy" switching output. There is also a potentiometer connection to allow for adjusting the volume (typically a logarithmic potentiometer is used). In constant voltage mode the potentiometer is replaced with a potentiometer-equivalent — a solder bridge (JP8 and JP10) and a resistor (R11 and R15) — effectively acting as a potentiometer at maximum gain.

The core of Cheapamp consists of the MAX9736 circuit along with passive components. The input signal is first amplified with the use of the internal operational amplifier and R1/R2,R3/R4, leading to a voltage gain of 10. As the MAX9736 amplifies this signal internally with a voltage gain of approximately 7 the minimum input signal amplitude to achieve full power output becomes approximately

$$V_{sig,min} = \frac{2 \cdot V_{supply}}{70} \approx \underbrace{0.5\mathrm{V_{pp}}}_{V_{supply}=20\mathrm{V}}$$

which is less than the typical line-level amplitude of $1\mathrm{V_{pp}}$. Other components consist primarily of decoupling capacitors, output filtering ferrite beads and capacitors, as well as a start-up click-reduction filter consisting of R8 and C14, which powers down the amplifier for approximately $R_8C_{14} \approx 100\mathrm{ms}$ during startup to ensure that all other voltages have stabilized. Keep in mind that should $\overline{SHDN}$ be driven from an external source that it presents a very capacitive load (assuming C14 is mounted).

[3] Depending on the level of overvoltage; low levels are triggered by the power dissipation in D2 conducting to F2 and F3 while high levels through ohmic resistance in the fuses.

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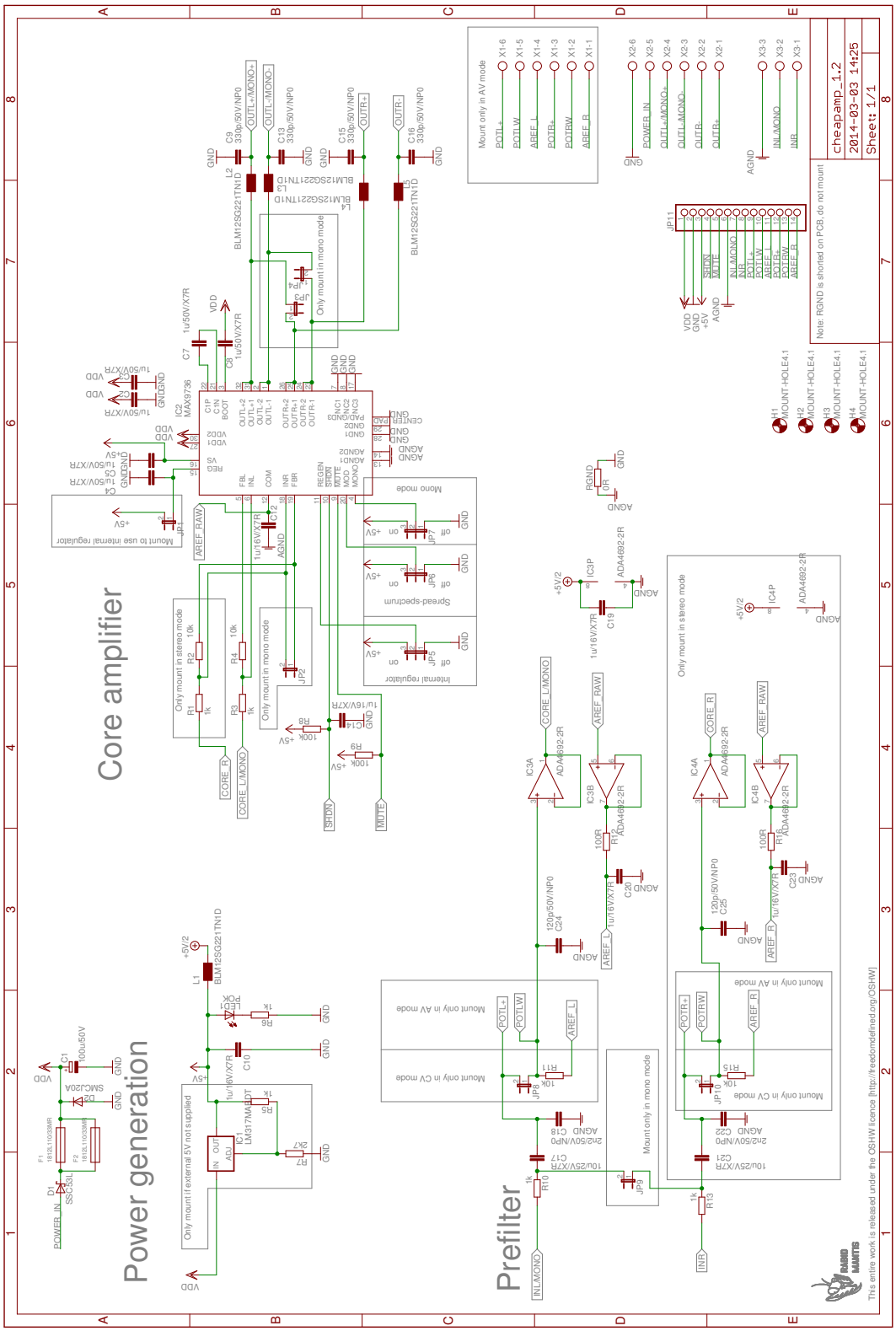
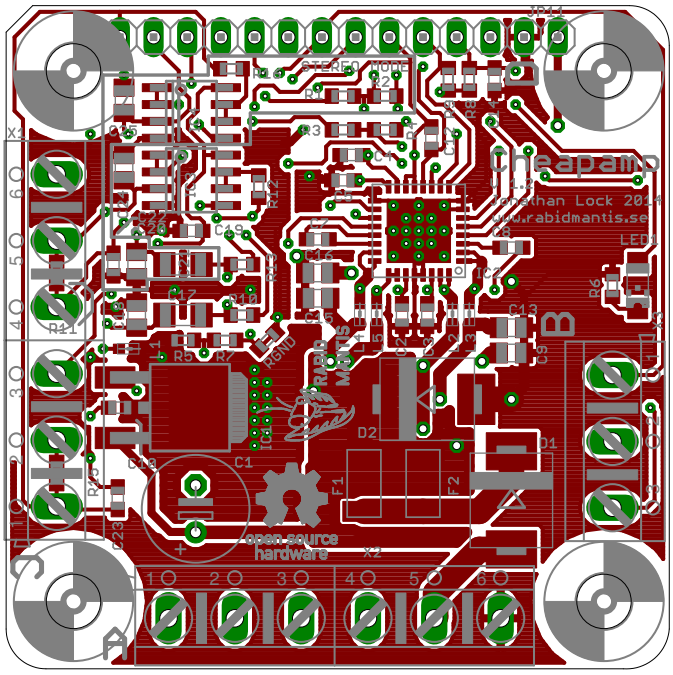
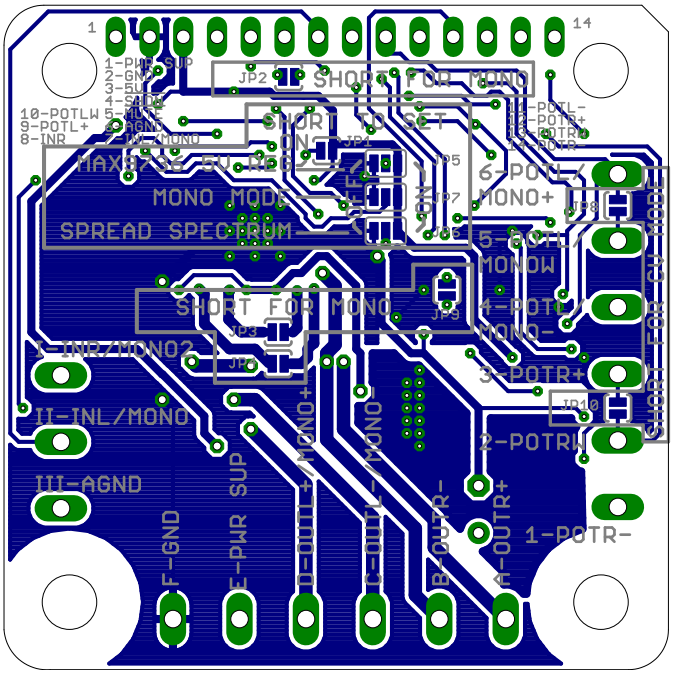


Figure 2: Cheapamp schematic..

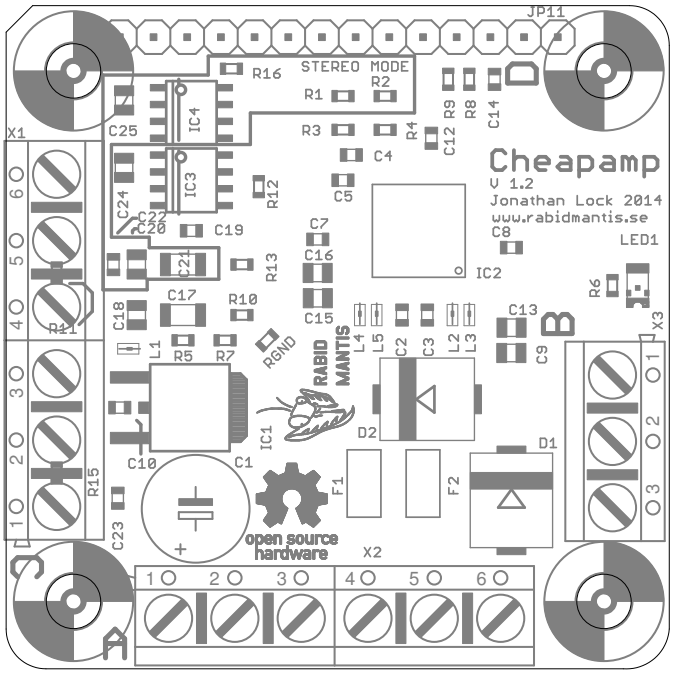


(a) Complete top layer as seen from above.

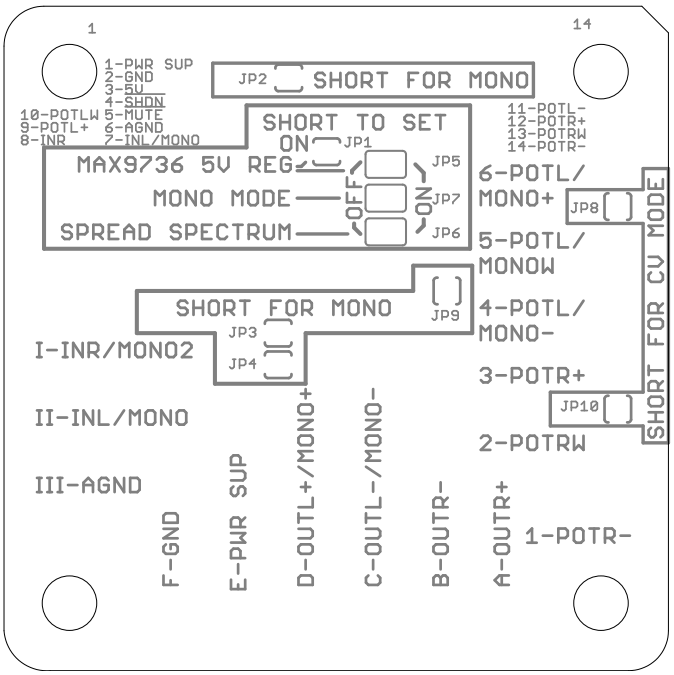


(b) Complete bottom layer as seen from below.

Figure 3: Cheapamp PCB details.



(a) Top layer component outline as seen from above.



(b) Bottom layer component outline as seen from below.

Figure 4: Cheapamp component placement details.