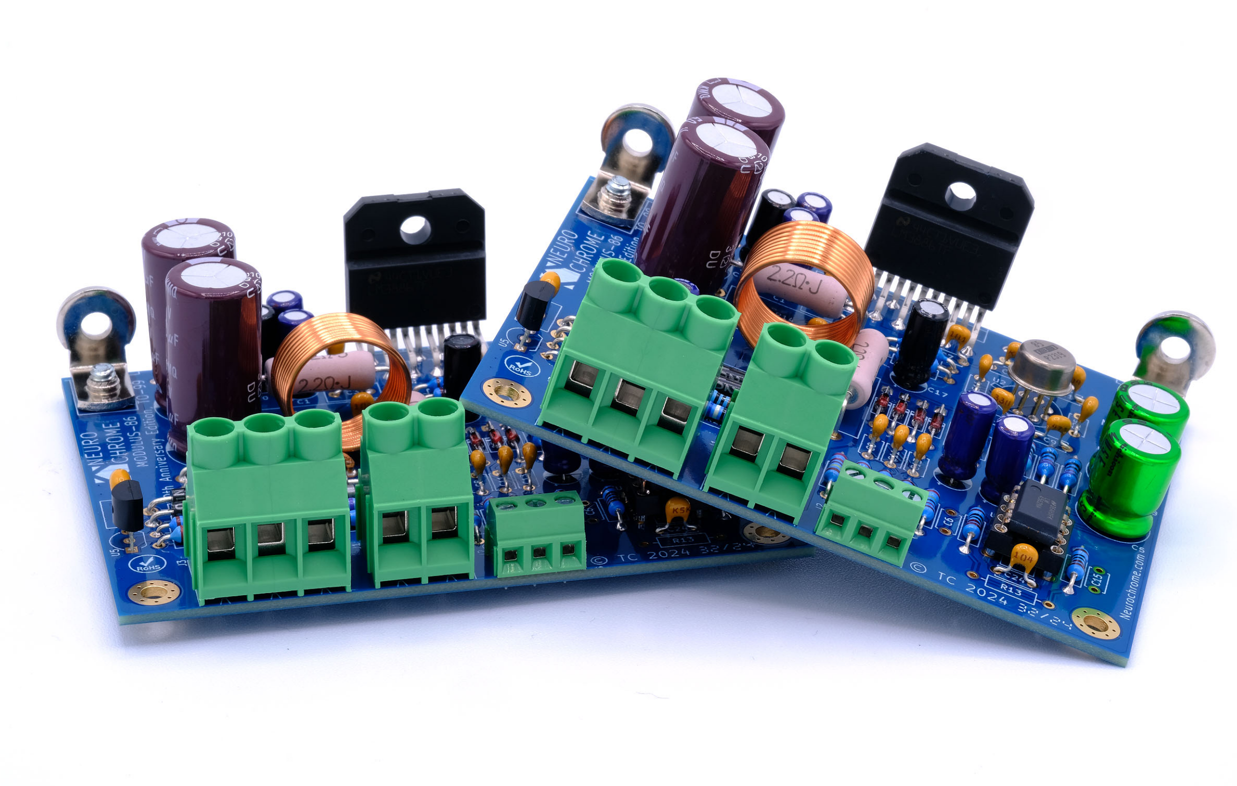
Modulus-86 10th Anniversary Edition
Design Documentation



Contents

Revision History

Modulus-86 10th Anniversary Edition Design Documentation

Revision	Date	Notes
1.0	08 JUL 2024	Document created.

Modulus-86 Circuit Board

Revision	Date	Notes
1.0	20 JUL 2014	First production layout.
1.01	30 SEP 2014	Layout tweak for easier assembly.
2.0	16 FEB 2015	Improvements: Third order DC servo, performance near clipping, ground layout improvement.
2.01	02 MAR 2015	Layout tweak for easier assembly.
2.1	27 MAR 2016	Changed U3 (LME49710) to TO-99 footprint.
2.2	09 JUL 2017	Changed U3 to DIP-08 footprint. DC servo tweaks. Added Neurochrome logo and blue solder mask.
2.3	09 MAR 2018	Changed U3 to LM4562. Improved EMI/RFI filter. Reduced L1 to 1.1 µH.
2.4	16 MAY 2019	CM cap connections to U1. Made in Canada.
3.0	03 SEP 2021	Eliminated THAT1200 and DC servo. Differential output stage. Noise reduced 7.4 dB.
10th AE	20 JUL 2024	Redesigned to use OPA627 in the composite amp. Redesigned and further optimized PCB layout for higher signal integrity.

Disclaimer

The Modulus-86 is a circuit intended for Do-It-Yourself (DIY) assembly and use. While the circuit has been thoroughly tested and found to work exceptionally well, mistakes in assembly do happen. By using the circuit board, the builder assumes all responsibility for the performance of the assembled board and assumes all risk associated with the assembly and use of the board.

WARNING!

SUPPLY VOLTAGE

The absolute maximum power supply voltage for the Modulus-86 is ±42 V. Do not exceed this value under any circumstances! The recommended power supply voltage range is ±20 V to ±30 V for 4–8 Ω load. If only 8 Ω loads are used, the supply voltage may be increased to ±36 V.

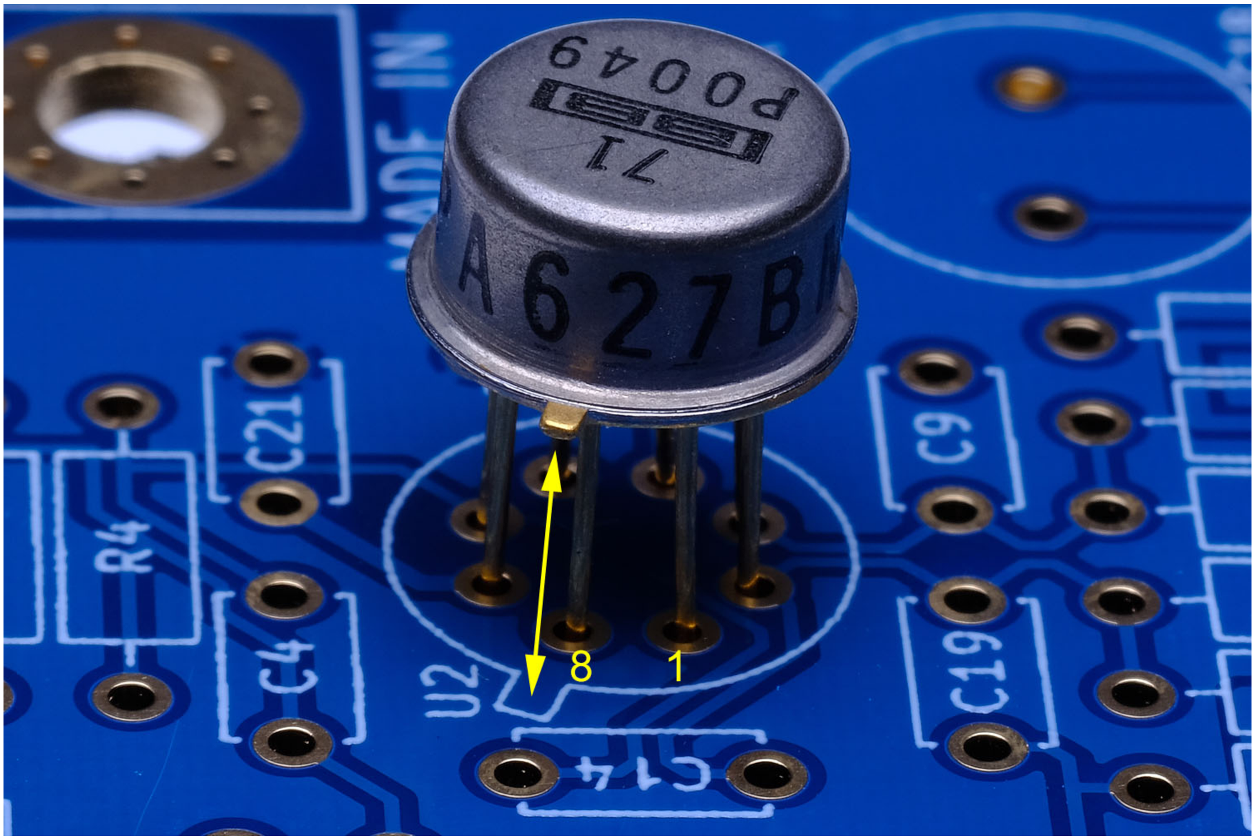
HEAT SINKING

The Modulus-86 must be fitted with a sizeable heat sink to prevent overheating. A heat sink with a thermal resistance in the range of 1.4–1.5 K/W or better (lower) is appropriate for most builds.

The free, online heat sink calculator provided by Heatscape can be useful for evaluating whether a particular heat sink is suitable for use with the Modulus-86. You can find the calculator here: https://heatscapecal.com/natural

OPA627 POLARITY

Builders who use the TO-99 version of the OPA627 need to be extra careful when populating that IC. The TO-99 (metal can) version of the OPA627 has pin 8 marked with a metal tab. Ensure that this lines up with the corresponding mark on the PCB footprint as shown below. Failure to align the chip properly will destroy the OPA627 when power is applied. The DIP version has pin 1 marked.



Connections

The power supply to the Modulus-86 is connected at J3, a 3-pin terminal block, that supports wire sizes up to AWG10 (5 mm^2). The pinout of the power connector is as follows:

J3	Function
Pin 1	V–
Pin 2	Ground
Pin 3	V+

The recommended power supply voltage range is ±20 V to ±30 V. The power supply needs to be capable of supplying 5–7 A peak to support 4 Ω operation. If only 8 Ω loads are used, the supply voltage may be increased to ±36 V (5 A, peak).

Note that due to the increase in drop-out voltage of the LM3886 vs supply voltage, there is no advantage of using supply voltages beyond ±36 V with 8 Ω loads or beyond ±30 V with 4 Ω loads. In fact, increasing the supply voltage beyond ±30 V with 4 Ω loads will result in lower maximum output power due to the increased thermal dissipation in the LM3886 and earlier engagement of the SPiKe protection circuit within the LM3886.

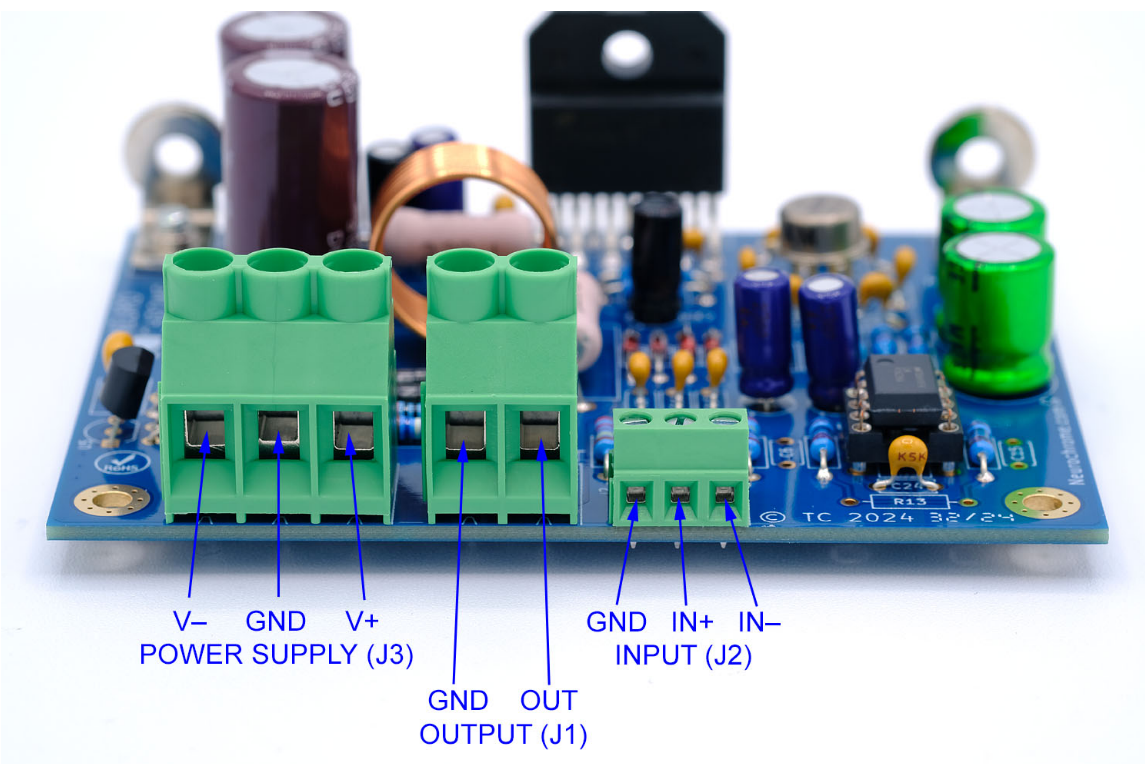
The speaker output is provided on J1, a 2-pin terminal block capable of handling wires up to AWG10 (5 mm²). The pinout is tabulated below.

J1	Function
Pin 1	Speaker (–)
Pin 2	Speaker (+)

J2 is the input to the Modulus-86 and is a 3-pin terminal block. The pinout is below.

J2	XLR pin (differential)	RCA pin (single-ended)	Function
Pin 1	Pin 1	Shield	Shield / Ground
Pin 2	Pin 2	Center Pin	IN (+)
Pin 3	Pin 3	Shield	IN (–)

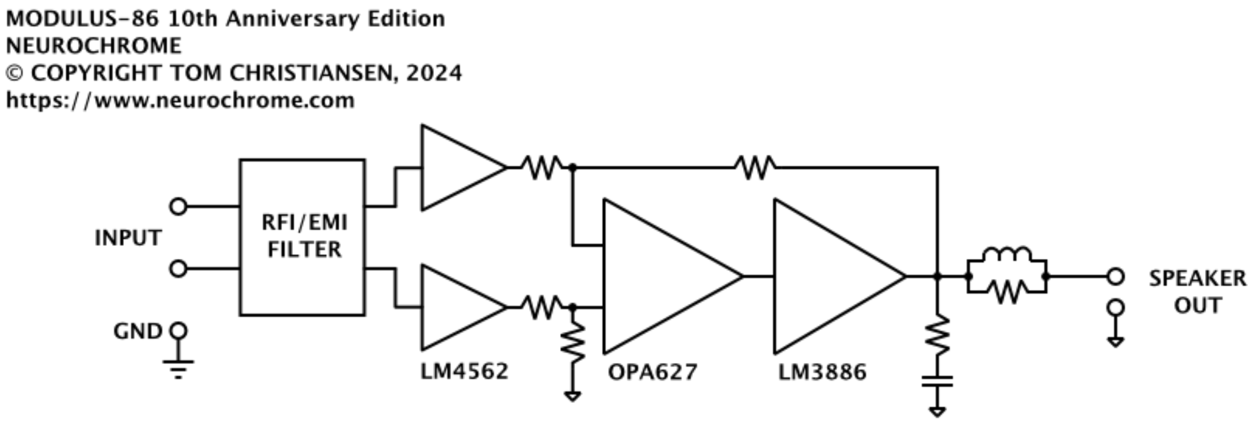
The three connectors and their connections are illustrated below.



Circuit Description

Block Diagram

The figure below shows the block diagram of the Modulus-86 10th Anniversary Edition.



The Modulus-86 consists of a differential buffer based on an LM4562 with EMI/RFI filter and ESD protection circuits added. This buffer can be configured for gain if desired. Should you wish to use a different opamp for the differential buffer you are free to do so. The circuit board includes footprints for the compensation capacitors needed for use with the Sparkos SS3602. An OPA627 provides error correction for the LM3886 power amplifier IC and also provides a differential input. A low DC offset of less than ±140 µV is guaranteed by design.

Differential input, EMI filter, and ESD protection

The Modulus-86 is equipped with a differential input. There are two reasons for this:

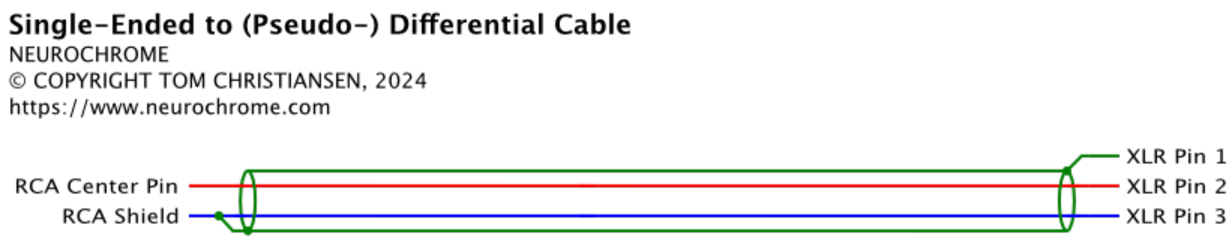
1. Differential signalling sounds better.
2. Differential signalling measures better.

The differential input of the Modulus-86 offers a common-mode rejection ratio approaching 80 dB at mains frequencies for a typical build. This means that any mains-related noise injected on the input cables is rejected by a factor of about 10000. The result is complete silence during quiet parts of the music, good separation between instruments, and a wider and deeper sound stage. Hence, the optimal connection to the Modulus-86 is a differential connection.

While differential connections are standard on professional audio equipment, many consumer and prosumer sources do not offer a differential output. In those cases it is possible to connect a single-ended source to the Modulus-86. If a single-ended source is used, there are three possibilities for its connection to the Modulus-86:

1. Pseudo-differential interconnect to the source output.
2. Pseudo-differential connection at the amplifier input, either by using an XLR-RCA adapter (e.g. Neutrik NA2MPMF) or by fitting the amplifier with an RCA connector.
3. Add a differential driver, such as the Neurochrome Universal Buffer to the source.

If adding a differential driver to the source is not desired, the best solution is to use a pseudo-differential cable to the single-ended source output. Such a cable can be constructed by following the diagram below.



These types of cables are also available commercially. The conventional configuration is to use a male RCA connector and a male XLR connector on the interconnect cable.

If a custom interconnect is not desired, the single-ended to pseudo-differential connection can be moved inside the amplifier chassis and made at the input RCA connector. If using RCA connectors, the RCA shield must be electrically isolated from the chassis. The NF2D-series of RCA connectors from Neutrik is excellent for this.

It is recommended to use a shielded cable, such as a microphone cable, between the input XLR or RCA connector and the input connector on the Modulus-86 circuit board.

The electromagnetic interference (EMI) filter prevents any RF pickup from interfering with the amplifier. This filter ensures that RF energy present from cell phone signals, WiFi, motor control switch transients, etc. as well as interference sources within the chassis, such as micro controllers, will not interfere with the music reproduction. Two pairs of small-signal diodes form an electrostatic discharge (ESD) protection circuit.

This protects the amplifier from the ESD events that commonly occur when a cable is plugged into the amplifier.

Error Correction

The Neurochrome Modulus composite amplifier topology uses a precision amplifier to perform error correction on a less precise power amplifier. The Modulus-86 10th Anniversary Edition uses an OPA627 to perform error correction on an LM3886 power amplifier. This results in an amplifier which has the precision of the OPA627 and the power of an LM3886. This error correction is the central point of the Neurochrome Modulus composite architecture. The composite design will correct for many types of error, including distortion and power supply induced errors.

The error correction circuit in the Modulus-86 has its own regulated power supply. Consequently, the power supply for the error correction circuit is clean and free of ripple, even if there is some ripple voltage on the power supply to the amplifier. In addition, the error correction circuit (OPA627 and associated components) has its own power supply rejection (the PSRR of the OPA627 due to its design and architecture). Therefore, the error correction circuit will correct for any distortion and supply-induced errors in the LM3886 without introducing any errors of its own, within the performance limitations of the OPA627. The end result is a power amplifier that is practically free of distortion.

As mentioned, the error correction circuit also corrects for power supply induced errors in the power amplifier. This makes the Modulus-86 indifferent to the type of power supply used. When operated at levels below clipping, the Modulus-86 performs as well on a well-regulated switching supply as it does on an unregulated power supply.

Gain Options

The default gain of the Modulus-86 is 20 dB (10×) resulting in an input sensitivity of 1.8 V RMS. I.e., applying 1.8 V RMS will result in 40 W output into 8 Ω.

The gain can be increased by adding a resistor (R13). The resistor values for common gains are tabulated below.

Gain (lin)	Gain (dB)	R13
14 V/V	23 dB	4.87 kΩ
20 V/V	26 dB	2.00 kΩ
28 V/V	29 dB	1.10 kΩ
40 V/V	32 dB	665 Ω

Should you desire a different gain than the ones listed, you can calculate R13 from the equations below.

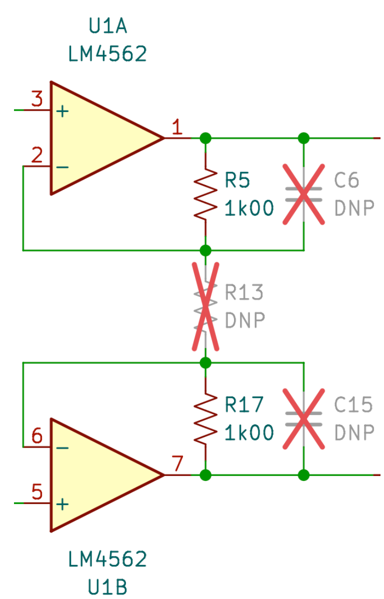
$$G_{lin} = 10 \cdot \left(1 + \frac{2000}{R13}\right)$$

$$R13 = \frac{2000}{\frac{G_{lin}}{10} - 1}$$

Other Modifications

A sizeable part of the DIY community enjoys tweaking circuits. Note, however, that arbitrary modifications of the Modulus-86 are much more likely to degrade its performance than to improve it. In addition, arbitrary modifications and tweaks are very likely to cause instability. Thus, it is not recommended to modify the Modulus-86 circuit. That said, should you wish to try a different opamp in the input buffer, most unity gain stable audio opamps will work for U1.

Footprints C6 and C15 are provided should your opamp of choice need an external compensation capacitor. The connections for C6 and C15 are shown on the right.



Power Supply & Heat Sinking

The supply voltage determines the maximum output power of the amplifier, however, it also determines the size of the heat sink. A very common mistake of DIY amplifier builders is to underestimate the size of the heat sink needed. Hence, they end up with amplifiers that perform poorly at higher output powers.

In any Class AB amplifier the maximum power is dissipated when the amplifier delivers a clean sine wave at half the maximum output power. Hence if the amplifier is to perform in this operating condition without overheating, the heat sink must be designed for this operating point. The highest power draw from the power supply occurs when the amplifier delivers a sine wave at levels just below clipping. Hence, for sine wave operation, the power supply should be designed for this operating point. Both of these operating points will result in a power supply and heat sink that are very large, expensive, and rather over-engineered for the typical application of music reproduction.

For music reproduction, it is possible to reduce the size and cost of the heat sink and power supply by relaxing the design criteria a bit. This is done by accounting for the crest factor of music.

The crest factor is the ratio of peak power to RMS power. For most kinds of music the crest factor is considerably higher than that of a sine wave, i.e., the peak power of the music is considerably higher than the average power. This means that in an amplifier intended for music reproduction, the power supply and heat sink can be sized smaller than they would be in an amplifier designed for continuous sine wave operation. The recommended heat sink and power transformer sizes for the Modulus-86 are tabulated below for various supply voltages and load impedances for both sine wave and music reproduction. The recommended operating points are highlighted in green.

Supply Voltage	Load Impedance	Program Material	Maximum Output Power	Heat Sink θ_{SA}	Power Transformer
±20 V	8 Ω	Sine Wave	19 W	3.63 K/W	45 VA
±20 V	8 Ω	Music	19 W	5.24 K/W	15 VA
±24 V	8 Ω	Sine Wave	28 W	2.59 K/W	66 VA
±24 V	8 Ω	Music	28 W	3.75 K/W	21 VA

Supply Voltage	Load Impedance	Program Material	Maximum Output Power	Heat Sink θ_{SA}	Power Transformer
±30 V	8 Ω	Sine Wave	44 W	1.71 K/W	103 VA
±30 V	8 Ω	Music	44 W	2.49 K/W	32 VA
±36 V	8 Ω	Sine Wave	62 W	1.21 K/W	148 VA
±36 V	8 Ω	Music	62 W	1.76 K/W	46 VA

The data for 4 Ω operation are tabulated below.

Supply Voltage	Load Impedance	Program Material	Maximum Output Power	Heat Sink θ_{SA}	Power Transformer
±20 V	4 Ω	Sine Wave	33 W	1.98 K/W	84 VA
±20 V	4 Ω	Music	33 W	3.06 K/W	26 VA
±24 V	4 Ω	Sine Wave	48 W	1.40 K/W	122 VA
±24 V	4 Ω	Music	48 W	2.16 K/W	37 VA
±30 V	4 Ω	Sine Wave	70 W	0.91 K/W	191 VA
±30 V	4 Ω	Music	70 W	1.41 K/W	57 VA
> ±30 V	4 Ω	Not Recommended			

Above heat sink thermal resistances were calculated assuming an ambient temperature of 25 °C and a maximum heat sink temperature of 60 °C which is appropriate for an external heat sink. Also note that the maximum output power was calculated from the data sheet figures and may be slightly lower in practice.

Music varies in crest factor. For example, the crest factor of well-recorded classical music often exceeds 20 dB, whereas some heavily compressed heavy metal tracks are closer to 6–7 dB. In an analysis of 4500 tracks of various genres, Sound on Sound Magazine found a mean crest factor of 14 dB, hence I used this value as a representative value for music signals in the calculations of the heat sink and power transformer sizes.

Above numbers are per Modulus-86 board. Hence, if operating multiple boards on the same power supply, multiply the transformer VA rating in the table by the number of boards. For operating multiple Modulus-86 boards on the same heat sink, divide the thermal resistance in the tables above with the number of Modulus-86 boards on the heat sink to find the needed thermal resistance.

Further detail on heat sink dimensioning can be found on the Taming the LM3886 - Thermal Design page.

A heat sink with a thermal resistance of 1.4–1.5 K/W per Modulus-86 board will be a good fit in most builds. The heat sinks included in the 2U Dissipante series from ModuShop (distributed in the US by DIY Audio Store) are well suited for use with the Modulus-86, assuming a maximum of two Modulus-86 boards per heat sink. Those who wish to use a smaller heat sink than those listed above should seriously consider using a lower power supply voltage (e.g. ±24 V) or, at the very least, fit the heat sink with a thermal cut-off switch, which turns the amplifier off once the heat sink temperature reaches 60–65 °C.

Many speakers have impedance dips below their nominal impedance. These dips typically occur in relatively narrow frequency bands and are not problematic for the Modulus-86 to drive. I suggest sizing the power supply and heat sink for the nominal speaker impedance.

Power Supply

The Modulus-86 amplifier has very high power supply rejection. Hence, the Modulus-86 performs as well on an unregulated supply as it does on a regulated supply. This is one of the benefits of the Neurochrome Modulus amplifier topology. The only advantage of using a regulated supply with the Modulus-86 is that the peak output power will be a few watt higher, as the regulated supply will experience less voltage droop when the load current increases.

For an unregulated power supply, a power transformer with a secondary voltage of 2 × 22 V RMS, rated at 60–100 VA per channel, would be a good choice, though many builders choose higher powered transformers. The Neurochrome MOD-XFMR (0-22-25 VAC, 300 VA) is a strong candidate. In the US, Antek Inc. provides very cost effective toroidal transformers. The Antek AN-1222 would be a good fit for a mono amp. For a stereo build, an AS-2222 is recommended. The Hammond brand of transformers may be easier to source outside of North America. The Hammond 1182L22 (2 × 22 VAC, 80 VA) would be a suitable choice for a mono build. A stereo build can be powered by the 1182N22 (2 × 22 VAC, 160 VA). Mouser Electronics and Digi-Key carry the Hammond line of transformers. For additional transformer options, please see Appendix A-3. For suitable switch-mode power supply options, please see Appendix A-4. For further information on transformer sizing, please consult the Neurochrome website: Taming the LM3886 - Power Supply Design.

Power-86

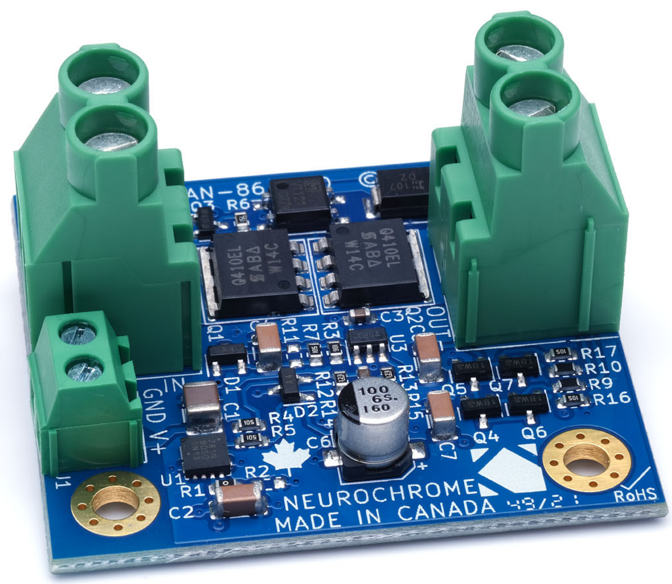
While it is possible to assemble the power supply using point-to-point wiring, a more elegant solution is to use a PCB. The Power-86 power supply board shown below is the companion board to the Modulus-86.

The Power-86 board has been fully optimized to ensure the best performance. Copper planes and pours are used to ensure the lowest possible output impedance of the power supply. The Power-86 board is designed to feed the two Modulus-86 amplifier boards of a stereo amplifier.

Guardian-86 Speaker Protection

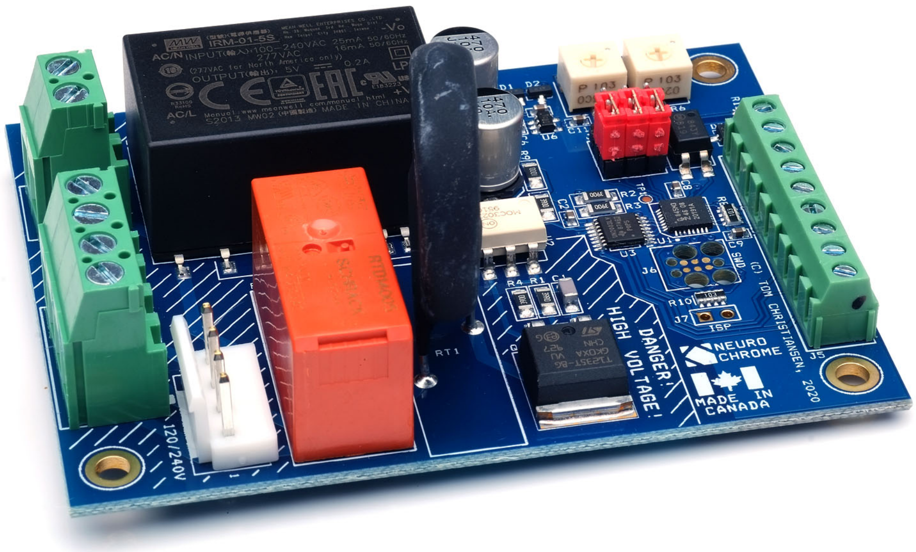
The LM3886 amplifier IC used in the Modulus-86 is a very rugged chip with many built-in protection features. That said, no amplifier is immune to failure and a catastrophic amplifier failure can make the amplifier provide the full power supply voltage at the speaker terminals which is likely to destroy the speaker.

I consider speaker protection to be optional in DIY builds and mandatory in commercial builds. Thus, I fit all my fully built amplifiers with speaker protection. I offer the Guardian-86 Speaker Protector for those who wish to add speaker protection to their builds. The Guardian-86 is available as a fully assembled module as shown below.



Soft Start

Traditional transformer-based power supplies draw significant inrush current on startup, which stresses the transformer and the mains fuse. This is especially true for toroidal transformers. Thus, builders who use toroidal transformers larger than 150-200 VA should consider using a soft start circuit, such as the Neurochrome Intelligent Soft Start (ISS), shown below. Even if the soft start feature is not strictly necessary in your build, other features of the ISS, such as the ability to use a low-voltage momentary power switch, the LED dimmers, and the 12 V trigger input will likely be attractive.



Assembly

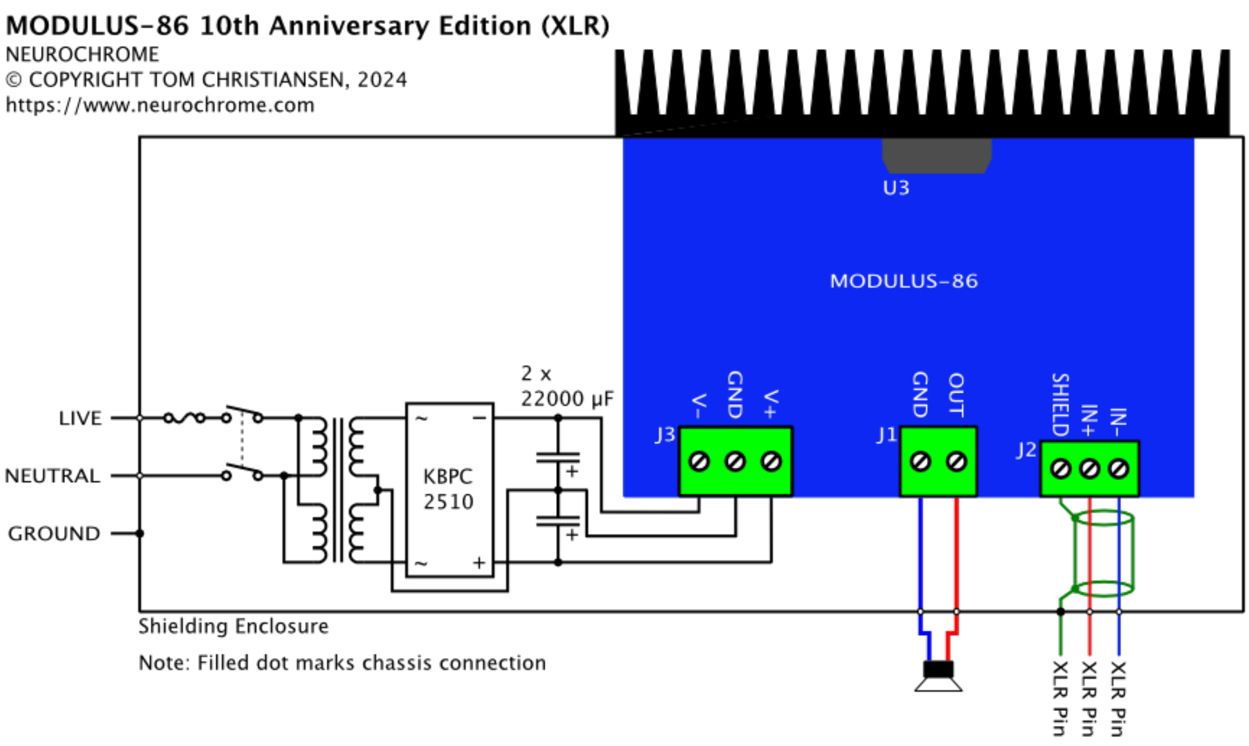
The easiest way to populate the circuit board is to work from the smaller components to the larger. I suggest the following sequence:

1. 1/4 W resistors: R1–R7, R9–R12, R13 (if higher gain is desired), and R15-R25.
2. Optional: IC sockets for U1 and U2 (DIP-8 version) or socket for U1 (TO-99 version).
3. Ceramic capacitors: C3, C4, C7–C14, C19–C21, C23–C25, and C31.
4. 1N4148 diodes: D1–D4.
5. 1N4007 diodes: D5–D10.
6. Electrolytic capacitors: C1, C2, C5, C16–C18, C22, and C26–C30.
7. Power resistors: R8 and R14. Mount these elevated 2-3 mm above the circuit board to allow for better airflow around them.
8. Terminal blocks: J1, J2, and J3.
9. Inductor: L1.
10. Voltage regulator ICs: U4 and U5.
11. Optional: Test the voltage regulators by applying ±20 V to ±36 V at J3. Then measure these voltages at the socket for U1: Pin 4 (–16 V ±1 V); Pin 8 (+16 V ±1 V). Turn the power off and disconnect the power supply before continuing with Step 12.

12. Verify all solder joints and ensure that the board is clean of wire clippings and excess flux.
13. Populate ICs U1–U3 and the two angle brackets. I recommend mounting the circuit board to the heat sink before soldering the LM3886.

Note that the circuit board is *not* intended to dangle by the LM3886. Please attach the board to the heat sink using the two angle brackets provided in the kit. Attach the board to the chassis with the two mounting holes by the connectors using machine screws and appropriately sized standoffs or spacers. The locations of the mounting holes are indicated on the mechanical drawing in Appendix A-2. The LM3886 protrudes 0.019" from the circuit board edge to ensure room for thermal expansion. Thus, the mounting holes closest to the heat sink are located 0.293" + 0.019" = 0.312" (7.92 mm) from the heat sink.

The top level wiring schematic for the Modulus-86 is shown below. For information regarding how to connect an RCA connector to the Modulus-86, see Appendix A-5.



Note that the mains ground *must* connect to the metal chassis. It is also recommended that pin 1 of the XLR input connector connects to the chassis right at the XLR connector.

It is recommended to use shielded cable between the input connectors and the Modulus-86 board.

The mains voltage input must be fused. The safest approach is to use one of the many IEC power entry modules with a built-in fuse holder. The fuse should be a slow-blow (time-delay) type as toroidal transformers draw significant inrush current. A fuse rated for 5.0 to 6.3 A would be appropriate in countries with 120 V mains voltage. For countries with 230 V mains voltage, 2.5 to 3.15 A would be a good choice.

Due to the significant inrush of high-VA toroidal power transformers, it may be necessary to increase the ampacity of the fuse significantly or, for a safer solution, use a soft start circuit, such as the ISS mentioned earlier.

Final Check

I suggest performing the checks below before putting the finished amplifier into service.

1. Verify all connections to the board.
2. Apply ±20 V to ±36 V to the power connector (J3), preferably using a current-limited power supply.
3. Measure the DC offset on the output of the amp (J1) by connecting a DC voltmeter (or better yet, milli-voltmeter) across the output of the amp. The DC offset should be well below ±1 mV within a few seconds of power-up. The DC offset should be measured with the input to the amplifier shorted (connect pins 1, 2, and 3 together on the XLR connector).
4. Apply a 400 Hz test signal with an amplitude of 1.0 V RMS to the input of the amplifier. Measure the output voltage of the amplifier with an AC voltmeter. The amplifier output should be 10 V RMS. If you do not have a function generator handy, a test tone can be created at www.wavtones.com. Create a 400 Hz sine wave test tone of 5 second duration, -6 dBFS in amplitude. Download the file and play it on repeat using your media player. Adjust the volume control for 1.0 V on the amplifier input.

After the final test, the amplifier is ready for use. Enjoy the music. Congratulations on a state-of-the-art build.

Appendices

A-1: Modulus-86 10th Anniversary Edition Bill of Materials

The bill of materials for the *DIP-08 version* of the Modulus-86 10th Anniversary Edition is tabulated below.

Modulus-86 10th Anniversary Edition - Bill of Materials - DIP-08

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Reference	Value	Qty	Manufacturer	Manufacturer P/N	Markings
ELECTROLYTIC CAPACITORS					
C1,C16,C26,C27,C28,C29	22uF	12	Panasonic	ECA-1JM220I	22 µF, 63 V
C2,C17	100uF	4	Panasonic	EEU-EB1A101SH	100 µF, 10 V
C5,C18	100uF NP	4	Nichicon	UES1C101MPM1TD	100 µF, 16 V, MUSE BP
C22,C30	1000uF	4	Chemicon	EKMQ500ELL102MK25S	1000 µF, 50 V
CERAMIC CAPACITORS					
C10,C20,C21,C24,C25	100nF	10	KEMET	C322C104K5R5TA7301	104
C3,C12,C23,C31	1uF	8	KEMET	C333C105K5R5TA7301	105
C8,C9,C11,C13	470pF	8	KEMET	C317C471J1G5TA7301	471
C4,C7,C14	180pF	6	KEMET	C317C181J1G5TATR	181
C19	33pF	2	KEMET	C317C330J1G5TA7301	330
RESISTORS					
R6,R10,R11,R20,R21	10k0	10	Yageo	MFP-25BRD52-10K	Brown-Black-Black-Red-Violet
R2,R19,R23,R24	2k00	8	TE	YR1B2K0CC	Red-Black-Black-Brown-Violet
R4,R5,R16,R17	1k00	8	Yageo	MFR-25FTE52-1K	Brown-Black-Black-Brown-Brown
R1,R7,R15	24k	6	Yageo	MFR-25FTE52-24K	Red-Yellow-Black-Red-Brown
R22,R25	169R	4	Yageo	MF0207FTE52-169R	Brown-Blue-White-Black-Brown
R3,R18	100R	4	Yageo	MF0207FRE52-100R	Brown-Black-Black-Black-Brown
R8,R14	2R2	4	KOA Speer	MOSX3CT631R2R2J	2.2 Ω
R9	332R	2	Yageo	MF0207FTE52-332R	Orange-Orange-Red-Black-Brown
R12	2M21	2	Yageo	MFR-25FRF52-2M21	Red-Red-Brown-Yellow-Brown
SEMICONDUCTORS					
D5,D6,D7,D8,D9,D10	1N4007	12	Diodes Inc.	1N4007-T	1N4007
D1,D2,D3,D4	1N4148	8	On Semi	1N4148TA	1N4148
U1	LM4562	2	TI	LM4562NA/NOPB	LM4562
U2	OPA627	2	TI	OPA627BP	OPA627BP
U3	LM3886	2	TI	LM3886TF/NOPB	LM3886TF
U4	LM317L_TO92	2	TI	LM317LZ/NOPB	LM317LC
U5	LM337L_TO92	2	TI	LM337LZ/NOPB	LM337LZ
MISCELLANEOUS					
BR1,BR2	4332	4	Keystone	4332	
BR1,BR2	#6-32 x 1/4	4	Keystone	9307	
U1,U2	Socket	4	Mill-Max	110-47-308-41-001000	
J1	OUT	2	Phoenix	1714955	
J2	IN	2	Amphenol	20020327-D031B01LF	
J3	PWR	2	Phoenix	1714968	
L1	1.1uH	2	Neurochrome	OUT_IND	
N/A	PCB	2	Neurochrome	MOD86_10AE	

The table below shows the bill of materials for the *TO-99 version* of the Modulus-86 10th Anniversary Edition.

Modulus-86 10th Anniversary Edition - Bill of Materials - TO-99

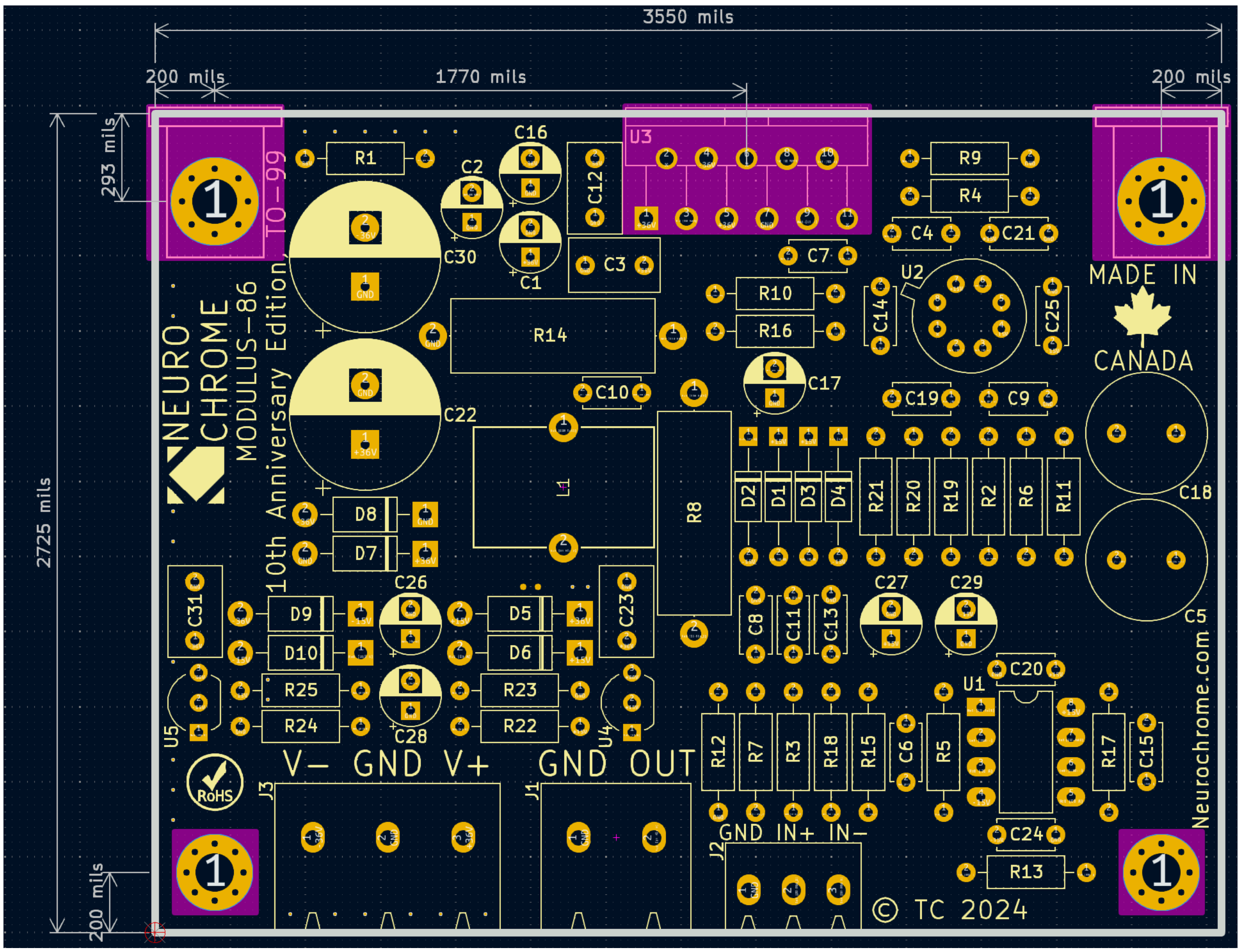
© Tom Christiansen, Neurochrome, 2024

Reference	Value	Qty	Manufacturer	Manufacturer P/N	Markings
ELECTROLYTIC CAPACITORS					
C1,C16,C26,C27,C28,C29	22uF	12	Panasonic	ECA-1JM220I	22 µF, 63 V
C2,C17	100uF	4	Panasonic	EEU-EB1A101SH	100 µF, 10 V
C5,C18	100uF NP	4	Nichicon	UES1C101MPM1TD	100 µF, 16 V, MUSE BP
C22,C30	1000uF	4	Chemicon	EKMQ500ELL102MK25S	1000 µF, 50 V
CERAMIC CAPACITORS					
C10,C20,C21,C24,C25	100nF	10	KEMET	C322C104K5R5TA7301	104
C3,C12,C23,C31	1uF	8	KEMET	C333C105K5R5TA7301	105
C8,C9,C11,C13	470pF	8	KEMET	C317C471J1G5TA7301	471
C4,C7,C14	180pF	6	KEMET	C317C181J1G5TATR	181
C19	33pF	2	KEMET	C317C330J1G5TA7301	330
RESISTORS					
R6,R10,R11,R20,R21	10k0	10	Yageo	MFP-25BRD52-10K	Brown-Black-Black-Red-Violet
R2,R19,R23,R24	2k00	8	TE	YR1B2K0CC	Red-Black-Black-Brown-Violet
R4,R5,R16,R17	1k00	8	Yageo	MFR-25FTE52-1K	Brown-Black-Black-Brown-Brown
R1,R7,R15	24k	6	Yageo	MFR-25FTE52-24K	Red-Yellow-Black-Red-Brown
R22,R25	169R	4	Yageo	MF0207FTE52-169R	Brown-Blue-White-Black-Brown
R3,R18	100R	4	Yageo	MF0207FRE52-100R	Brown-Black-Black-Black-Brown
R8,R14	2R2	4	KOA Speer	MOSX3CT631R2R2J	2.2 Ω
R9	332R	2	Yageo	MF0207FTE52-332R	Orange-Orange-Red-Black-Brown
R12	2M21	2	Yageo	MFR-25FRF52-2M21	Red-Red-Brown-Yellow-Brown
SEMICONDUCTORS					
D5,D6,D7,D8,D9,D10	1N4007	12	Diodes Inc.	1N4007-T	1N4007
D1,D2,D3,D4	1N4148	8	On Semi	1N4148TA	1N4148
U1	LM4562	2	TI	LM4562NA/NOPB	LM4562
U2	OPA627	2	TI	OPA627BM	OPA627BM
U3	LM3886	2	TI	LM3886TF/NOPB	LM3886TF
U4	LM317L_TO92	2	TI	LM317LZ/NOPB	LM317LC
U5	LM337L_TO92	2	TI	LM337LZ/NOPB	LM337LZ
MISCELLANEOUS					
BR1,BR2	4332	4	Keystone	4332	
BR1,BR2	#6-32 x 1/4	4	Keystone	9307	
J1	OUT	2	Phoenix	1714955	
J2	IN	2	Amphenol	20020327-D031B01LF	
J3	PWR	2	Phoenix	1714968	
L1	1.1uH	2	Neurochrome	OUT_IND	
U1	Socket	2	Mill-Max	110-47-308-41-001000	
N/A	PCB	2	Neurochrome	MOD86_10AE	

The two options differ in the OPA627 package option and in the number of 8-pin IC sockets provided. The TO-99 version only contains two sockets as the TO-99 version of the OPA627 is soldered directly into the circuit board.

A-2: Mechanical Dimensions

The dimensions of the Modulus-86 10th Anniversary Edition board are shown below. The dimensions are in mil. 1.0 mil = 0.001 inches. The board measures 3.550 × 2.725 inches. The two mounting holes by the connectors are 3.2 mm in diameter and are intended for use with M3 or US #4 machine screws. The two mounting holes by the LM3886 are 3.8 mm in diameter and are intended for the US #6 machine screws and mounting brackets provided with the Kit. The LM3886 overhangs the edge of the board by 0.019” to allow for thermal expansion and contraction.



A-3: Power Transformers

The following is not by any means an exhaustive list of available power transformers. I identified these transformers as suitable candidates for a stereo Modulus-86 build based on their data sheets. These transformers should result in a supply voltage in the range of ±30–±32 V at idle and approximately ±28–±30 V under load.

All the transformers listed have primary windings which can be configured for worldwide mains voltages.

Manufacturer/Vendor	Part Number	Secondary Voltage, VA	Primary Voltage
Neurochrome	MOD-XFMR	2 × 22 VAC @ 300 VA 2 × 25 VAC @ 300 VA	115/230 VAC
Antek Inc.	AN-2222	2 × 22 VAC @ 200 VA	115/230 VAC
Antek Inc.	AS-2222	2 × 22 VAC @ 200 VA	115/230 VAC
Antek Inc.	AS-3222	2 × 22 VAC @ 300 VA	115/230 VAC
Hammond Mfg.	1182N22	2 × 22 VAC @ 160 VA	117/234 VAC
Hammond Mfg.	1182P22	2 × 22 VAC @ 225 VA	117/234 VAC

Hammond products are available from Mouser and DigiKey.

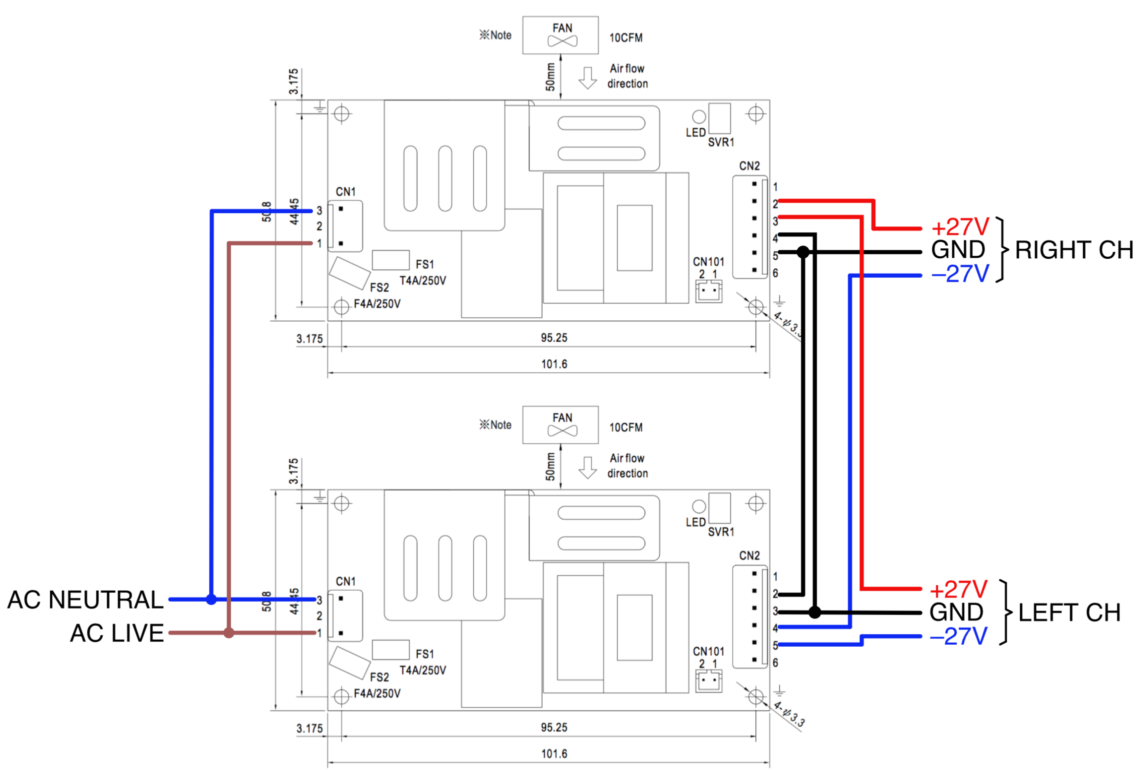
A-4: Mean Well EPP/RPS-Series SMPS

Switch Mode Power Supply (SMPS) Options

There is an abundance of switching power supplies available on the market. Unfortunately many of them are either prohibitively expensive or ill-suited for an audio amplifier. One exception is the RPS-series from Mean Well. Specifically the RPS-200-27-C is of interest to Modulus-86 builders, however, I should note that I have no personal experience with it. I have tested its bigger brother, the RPS-400-27-C, and found it to work very well. Builders who wish to use ±36 V supplies, are unfortunately out of luck as the only 36 V supply in the Mean Well RPS lineup is the RPS-400-36-C. That specific model has a tendency to whine audibly at light load, hence is *not* suitable for an audio amplifier build. The newer LOP-series may be an option.

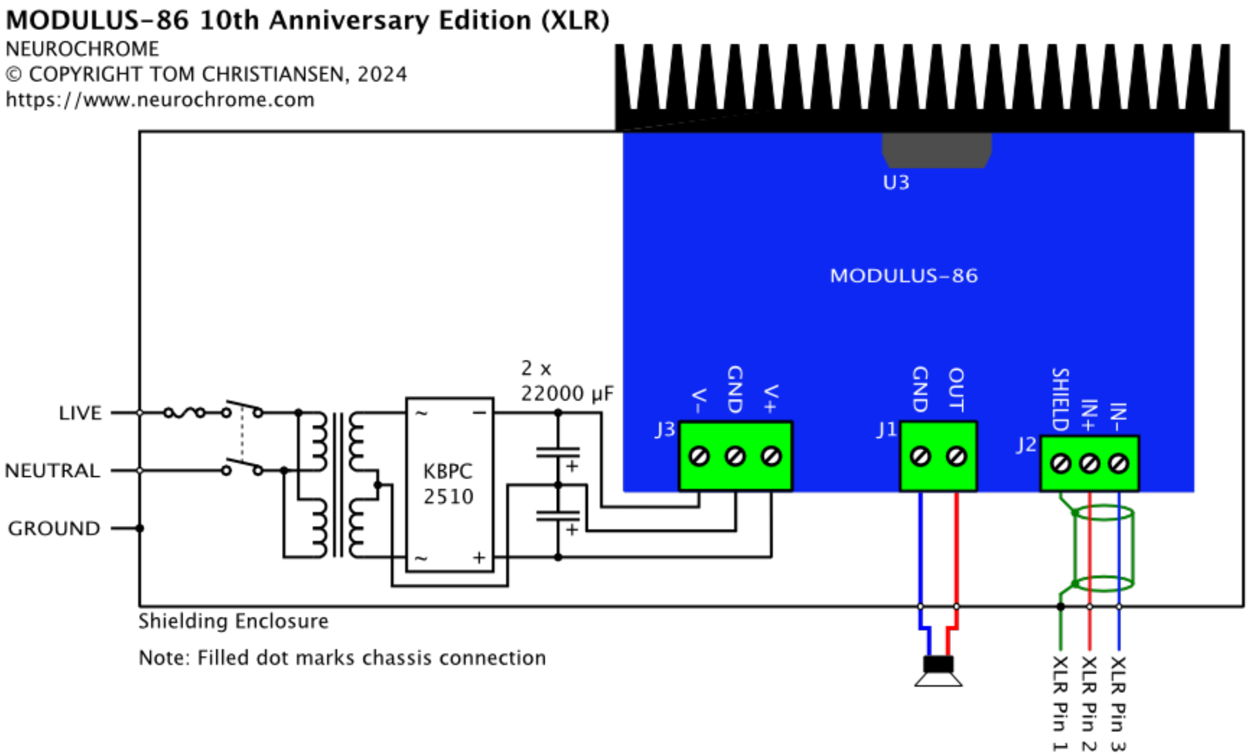
Should you wish to use the Mean Well RPS-200 series power supply in your build, the necessary connections are shown below.

Mean Well RPS/EPP-Series Connections
Tom Christiansen, Neurochrome Audio, 2018



A-5: System Level Connections

The system level connections for the Modulus-86 using differential/balanced (XLR) connections are shown below.



Note that the mains ground and the XLR ground (pin 1) connect to the chassis as indicated by the filled dot on the chassis wall for those connections.

If you prefer to build your Modulus-86 using unbalanced (RCA) inputs, please follow the diagram below.