Modulus-286 R3.0

Design Documentation

Contents

Revision History

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Revision	Date	Notes
1.0	29 SEP 2024	Document created.
1.01	15 AUG 2025	Corrected front page image.

Modulus-286 Circuit Module

Revision	Date	Notes
2.0	10 SEP 2018	First prototype layout.
2.01	19 OCT 2018	Cleaned up silk screen. First production layout.
3.0	03 AUG 2024	Redesigned PCB for better signal integrity. Optimized feedback networks for lower THD.

Observant readers may notice that Rev. 1.0 is missing from the revision history. Rev. 2.0 represents a complete redesign of the Modulus-286, hence, I found the inclusion of Rev. 1.0 in the revision history to be somewhat misleading. The only commonalities between the two are the ICs used as well as the Modulus-286 name. Revision 3.0 represents a major improvement on Rev. 2.0 resulting mainly from changes in the PCB layout and layer stack-up.

Disclaimer

The Modulus-286 is a circuit intended for use by original equipment manufacturers (OEMs) and do-it-yourself (DIY) enthusiasts. While the circuit has been thoroughly tested and found to work exceptionally well, mistakes in assembly do happen. By using the amplifier module, the builder assumes all responsibility and risk associated with the use of the amplifier module.

WARNING!

POWER SUPPLY POLARITY

Please observe correct polarity of the power supply. Reversing the polarity of the power supply will destroy the Modulus-286 module.

SUPPLY VOLTAGE

The absolute maximum power supply voltage for the Modulus-286 is ±42 V. Do not exceed this value under any circumstances! The recommended power supply voltage range is ±20 V to ±36 V for 4–8 Ω load.

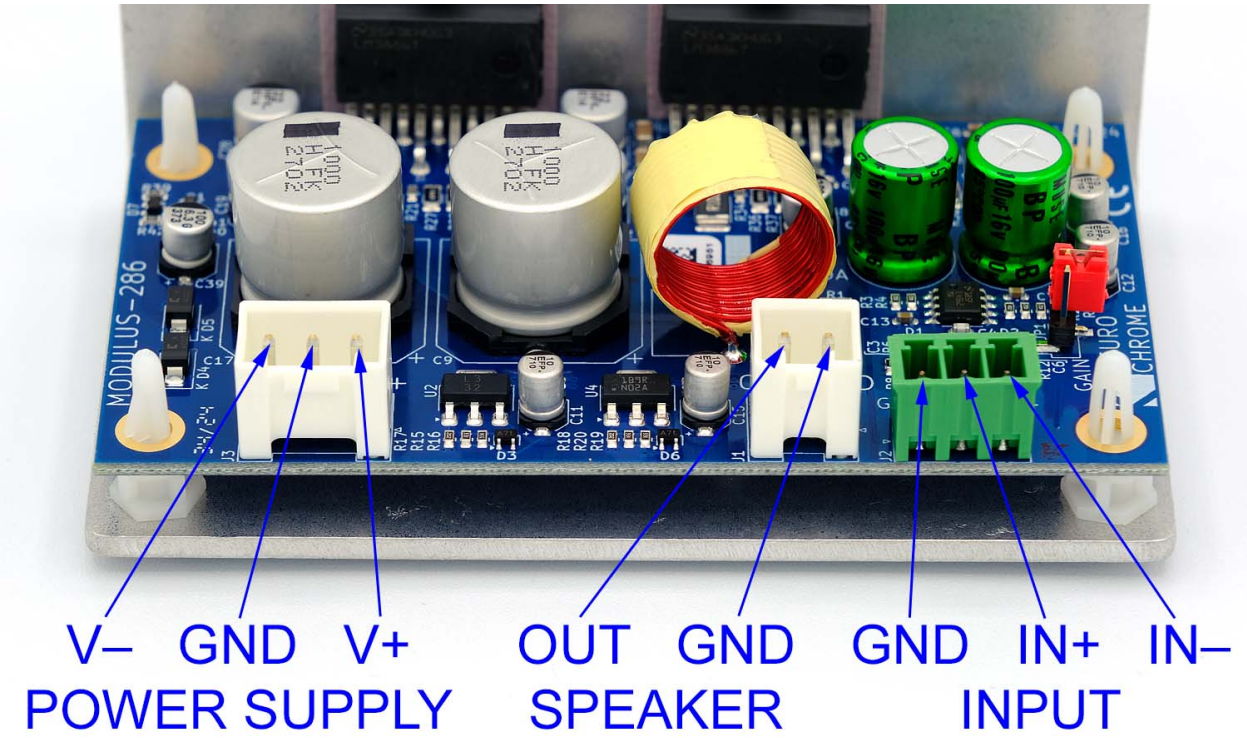
HEAT SINKING

The Modulus-286 must be fitted with a sizeable heat sink to prevent overheating. A heat sink with a thermal resistance in the range of 0.7–0.9 K/W per channel 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-286. You can find the calculator here: https://heatscapecal.com/natural

Connections

The connections to the Modulus-286 are illustrated below.



The power supply to the Modulus-286 is connected at J3. 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 ±36 V. The power supply needs to be capable of supplying 5–9 A peak, per channel, to support 4 Ω operation.
A power transformer providing 2×25 VAC @ 100-160 VA per channel is well-suited for a traditional transformer-based power supply. This will result in a quality build capable of reproducing music into both 4 Ω and 8 Ω loads.

The speaker output is provided on J1. Its pinout is tabulated below.

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

The Modulus-286 module includes the necessary wiring harnesses for the power and speaker connectors. Should you need to build your own harness, the mating connector housings, crimp terminals, and pre-crimped wire leads for use with the power connector and speaker connector are tabulated below.

Description	Manufacturer	Manufacturer P/N
Connector housing (J1)	JST	VHR-2N
Connector housing (J3)	JST	VHR-3N
Crimp terminal	JST	SVH-41T-P1.1
Pre-crimped lead, 30 cm	JST	ASVHSVH16K305

Digikey carries a full line of JST products.

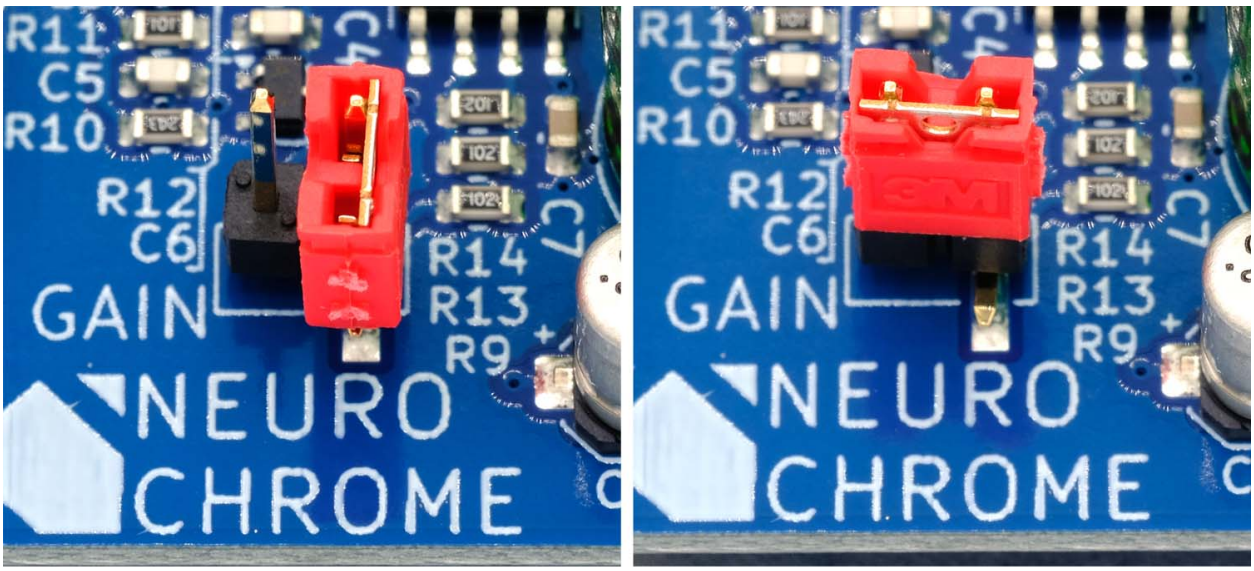
J2 is the input to the Modulus-286 and is a 3-pin pluggable terminal block. The pinout of the input connector is shown below.

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

Mating connector: Amphenol P/N: TJ0331530000G.

Gain Settings

The Modulus-286 offers two gain settings: 20 dB (10×) and 26 dB (20×), which is the THX standard gain. It ships with the 20 dB (10×) gain setting selected. To change the gain, move the gain selection jumper as shown below.



20 dB GAIN (DEFAULT)

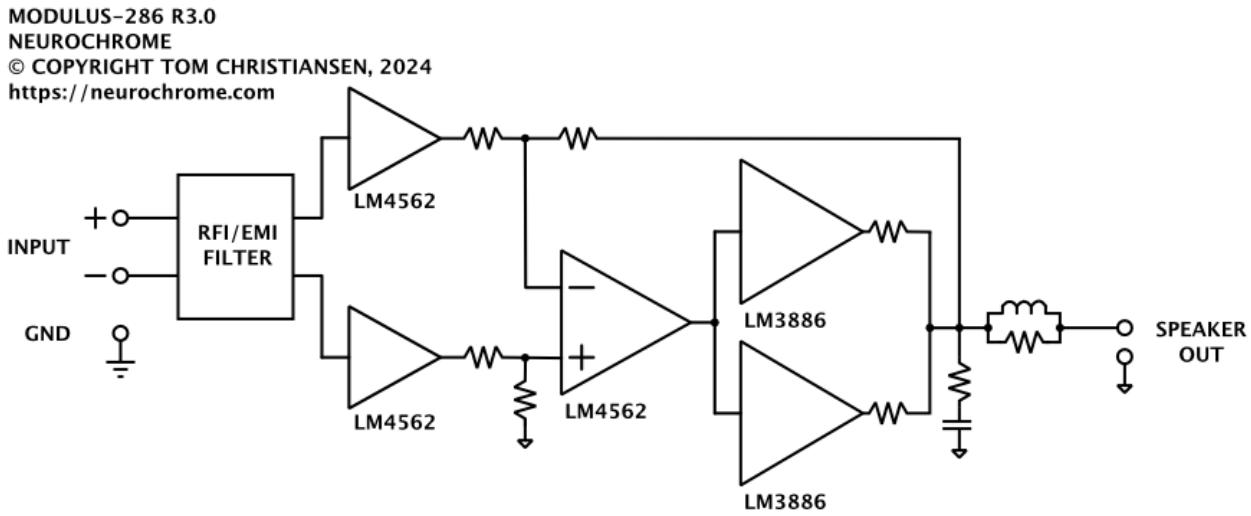
26 dB GAIN

With the default gain of 20 dB, the input sensitivity is 2.3 V RMS. Applying 2.3 V RMS will result in 65 W output into 8 Ω. Increasing the gain to 26 dB decreases the input sensitivity to 1.15 V RMS, i.e., 1.15 V RMS applied to the input will result in 65 W (8 Ω) output.

Circuit Description

Error Correction

The Neurochrome Modulus composite amplifier topology uses a precision amplifier to perform error correction on a less precise power amplifier. This architecture illustrated in the block diagram below.



The Modulus-286 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. An LM4562 provides error correction for the LM3886 power amplifier IC and also provides a differential input. A low DC offset of less than ±2 mV is guaranteed by design. The DC offset is typically below ±320 µV.

Differential input, EMI filter, and ESD protection

The Modulus-286 is equipped with a differential input. There are two reasons for this:

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

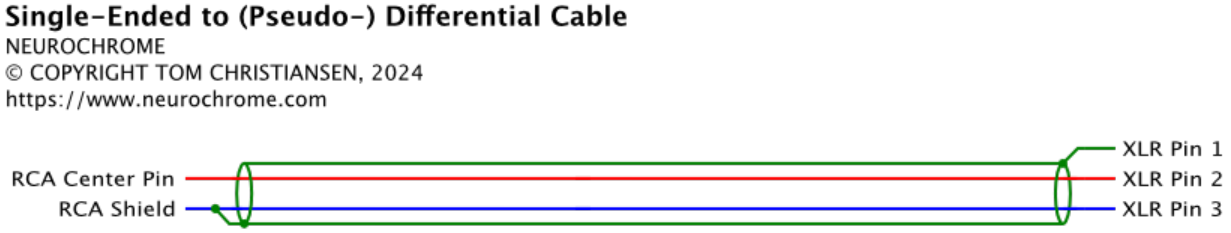
The differential input of the Modulus-286 offers a common-mode rejection ratio approaching 80 dB at mains frequencies for a typical build. This means that any mains-related noise injected on the input cables is rejected by a factor of about 10000. The result is complete silence during quiet parts of the music, good separation between

instruments, and a wider and deeper sound stage. Hence, the optimal connection to the Modulus-286 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-286. If a single-ended source is used, there are three possibilities for its connection to the Modulus-286:

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-286 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-286 uses an LM4562 to perform error correction on a power amplifier with two LM3886 ICs in parallel. This results in an amplifier which has the precision of the LM4562 and the power of the LM3886es. 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-286 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 (LM4562 and associated components) has its own power supply rejection (the PSRR of the LM4562 due to its design and architecture). Therefore, the error correction circuit will correct for any distortion and supply-induced errors in the LM3886es without introducing any errors of its own, within the performance limitations of the LM4562. 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-286 indifferent to the type of power supply used. When operated at levels below clipping, the Modulus-286 performs as well on a well-regulated switching supply as it does on an unregulated power supply.

Other Modifications

A sizeable part of the DIY community enjoys tweaking circuits. Note, however, that arbitrary modifications of the Modulus-286 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-286.

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-286 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	Heat Sink θ_{SA}	Power Transformer
±20 V	8 Ω	Sine Wave	3.11 K/W	36 VA

Supply Voltage	Load Impedance	Program Material	Heat Sink θ_{SA}	Power Transformer
±20 V	8 Ω	Music	4.26 K/W	18 VA
±24 V	8 Ω	Sine Wave	2.27 K/W	51 VA
±24 V	8 Ω	Music	3.12 K/W	25 VA
±30 V	8 Ω	Sine Wave	1.53 K/W	79 VA
±30 V	8 Ω	Music	2.12 K/W	37 VA
±36 V	8 Ω	Sine Wave	1.10 K/W	113 VA
±36 V	8 Ω	Music	1.53 K/W	51 VA

The data for 4 Ω operation are tabulated below.

Supply Voltage	Load Impedance	Program Material	Heat Sink θ_{SA}	Power Transformer
±20 V	4 Ω	Sine Wave	1.81 K/W	65 VA
±20 V	4 Ω	Music	2.64 K/W	30 VA
±24 V	4 Ω	Sine Wave	1.29 K/W	95 VA
±24 V	4 Ω	Music	1.88 K/W	42 VA
±30 V	4 Ω	Sine Wave	0.85 K/W	149 VA
±30 V	4 Ω	Music	1.24 K/W	65 VA
±36 V	4 Ω	Sine Wave	0.60 K/W	215 VA
±36 V	4 Ω	Music	0.88 K/W	92 VA

Above heat sink thermal resistances were calculated assuming an ambient temperature of 25 °C and a maximum heat sink temperature of 60 °C, appropriate for an external heat sink.

Music varies in crest factor. For example, the crest factor of well-recorded classical music approaches or 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-286 module. If operating multiple modules on the same power supply, multiply the transformer VA rating in the table by the number of modules. For operating multiple Modulus-286 modules on the same heat sink, divide the thermal resistance in the table above by the number of Modulus-286 modules on the heat sink to find the needed thermal resistance.

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

A heat sink with a thermal resistance of 0.7–0.9 K/W per Modulus-286 module 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-286, assuming a maximum of one Modulus-286 module 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. ±30 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.

Power Supply

The Modulus-286 amplifier has very high power supply rejection. Hence, the Modulus-286 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-286 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 × 25 V RMS, rated at 100–160 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 for a stereo amplifier. For additional transformer options, please see Appendix A-1. For suitable switch-mode power supply options, please see Appendix A-2. For further information on transformer sizing, please consult the Neurochrome website: Taming the LM3886 - Power Supply Design.

Power-86

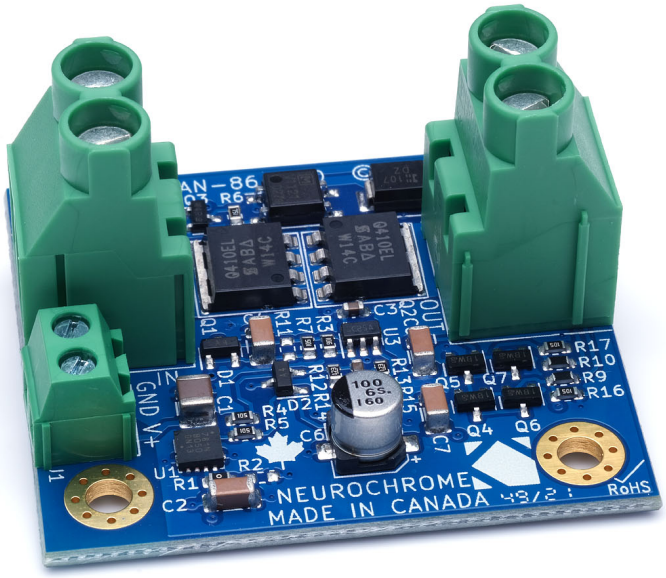
While it is possible to assemble the power supply using point-to-point wiring, a more elegant solution is to use a PCB. The Power-86 power supply board shown below is the companion board to the Modulus-286.

The Power-86 board has been fully optimized to ensure the best performance. 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-286 amplifier modules of a stereo amplifier. The Power-86 features two JST connectors to facilitate this.
Many builders choose to oversize the power supply. Builders inclined to do so may be interested in the Power-686, which offers twice the reservoir capacitance of the Power-86 and also individual rectifier diodes.

Guardian-86 Speaker Protection

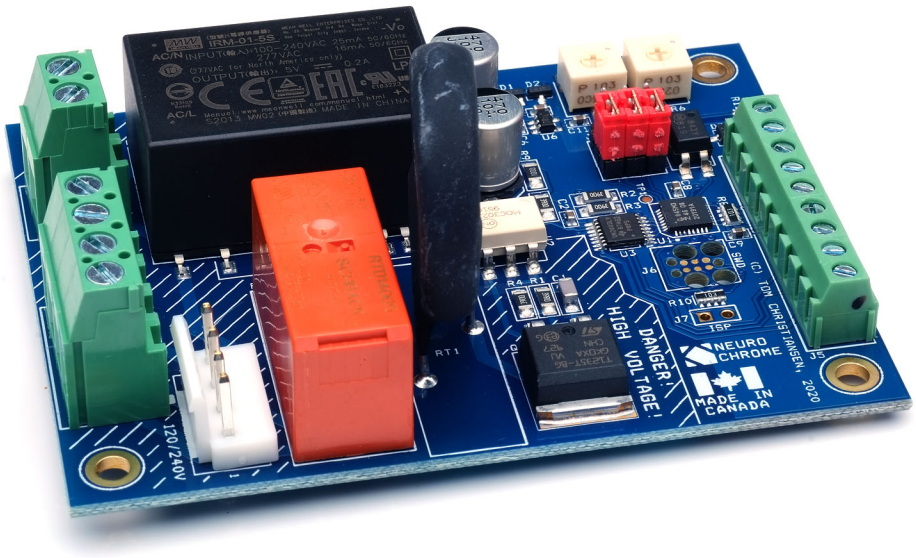
The LM3886 amplifier ICs used in the Modulus-286 are very rugged chips with many built-in protection features. That said, no amplifier is immune to failure and a catastrophic amplifier failure can make the amplifier provide the full power supply voltage at the speaker terminals which is likely to destroy 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.



Completing the Build

Note that the mains ground *must* connect to the metal chassis. I also recommend to connect pin 1 of the XLR input connector to the chassis right at the XLR connector. Conveniently most chassis-mount XLR connectors, such as the Neutrik NC3FD-series, have a metal tab intended for this exact purpose. Further, I recommend to use shielded cable between the input connectors and the Modulus-286 module.

If RCA connectors are used, I recommend using a connector type that has the shell of the RCA connector isolated from the chassis, such as the Neutrik NF2D-series.

The amplifier module should be given a light coat of thermal compound on the side of the backplate that faces the heat sink. I recommend using a good quality compound, such as the Wakefield 120, which is available from Mouser, Digikey, and other distributors of electronic components. Alternatively, compounds intended for use in computer systems, such as Arctic Silver, will work well.

For top-level hook-up diagrams for the Modulus-286 please see Appendix A-3.

Final Check

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

1. Verify all connections to the module.
2. Apply at least ±20 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 below ±2 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 100 mV RMS to the input of the amplifier. Measure the output voltage of the amplifier with an AC voltmeter. The amplifier output should be 2.0 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 100 mV 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: 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-286 build based on their data sheets. These transformers should result in a supply voltage in the range of ±34–±36 V at idle and approximately ±32–±34 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-2225	2 × 25 VAC @ 200 VA	115/230 VAC
Antek Inc.	AS-3225	2 × 25 VAC @ 300 VA	115/230 VAC
Antek Inc.	AS-4225	2 × 25 VAC @ 400 VA	115/230 VAC
Hammond Mfg.	1182S24	2 × 24 VAC @ 500 VA	117/234 VAC
RS Components	422-5332	2 × 25 VAC @ 225 VA	115/230 VAC
RS Components	123-4037	2 × 25 VAC @ 300 VA	115/230 VAC
RS Components	123-4040	2 × 25 VAC @ 500 VA	115/230 VAC

Hammond products are available from Mouser and DigiKey.

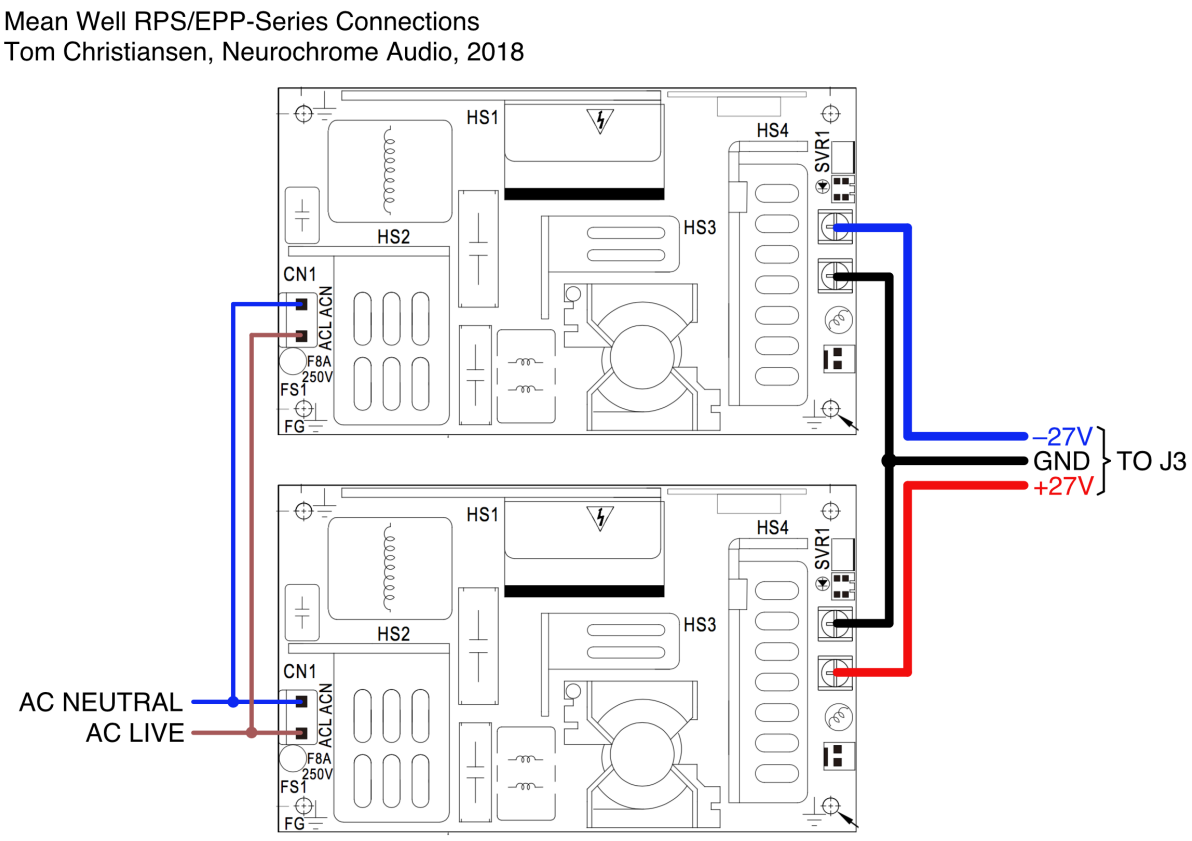
A-2: Switch Mode Power Supply (SMPS) Options

There is an abundance of switching power supplies available on the market. Unfortunately ±36 V ones are rare, though it is often possible to connect two +36 V types in series to the obtain ±36 V needed for the Modulus-286.

The Mean Well RPS-400-36 is one such power supply. Unfortunately, some builders have reported issues with that particular model. The newer LOP-400-36 could possibly be a candidate, though I have not yet had the opportunity to test this supply.

The builders who reported issues with the RPS-400-36 reported audible whine from the power supply. In all cases this was resolved by turning the output voltage up until the whine went away.

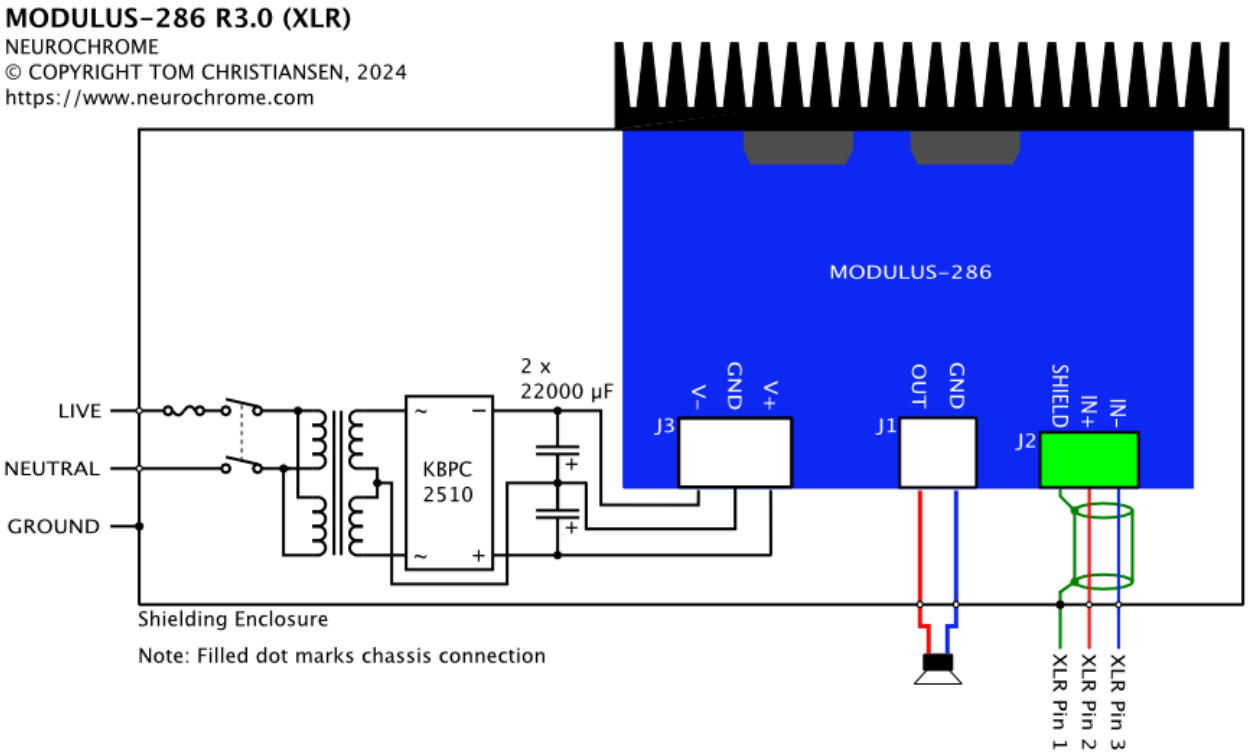
Should you wish to try the Mean Well supplies, please follow the wiring diagram below when connecting them.



The Neurochrome Intelligent Soft Start is a good option for controlling the mains power to the Mean Well power supplies.

Appendix A-3: Top-Level Hook-Up

The top level connections for the Modulus-286 with XLR input are shown below.



Follow the diagram below if you are building the Modulus-286 with an RCA input.