AA-10A-1 25 Watt Audio Amplifier

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A simple self contained audio amplifier capable of 25 Watt (true rms) output. Line input for mono or stereo program source such as computer sound card, audio players or other devices compatible with -10 dBv, 10 k Ohm line levels. High impedance microphone input compatible with -51 dBv levels.

Applications

- Designed specifically for Public Address system using the SP-10A-1 speaker.
- Line and microphone inputs support general audio amplifier applications
- Supports music and speech amplification for driving 4 to 16 Ohm speakers

Features

- Compact and self contained audio amplifier with line and microphone inputs
- Operates from 105 to 125 Vac
- Low distortion 25 Watt (rms) audio output
- Excellent frequency response 10 Hz to 100 kHz (line input)
- Built in microphone preamplifier
- 60 Hz rejection on microphone input
- Line input combines stereo program content from media players or computers
- Class AB complementary symmetry output with class A drivers providing low distortion down to zero output

Characteristics

Size	8” wide by 4” deep by 3” high
Finish	Textured multi-color paint and laminated panels
Controls	Power on/off, Level, Input selector and LED power indicator
Inputs/outputs	Line (combines stereo inputs), Microphone and Speaker

Specifications

Parameter	Conditions	Value	Notes
Input Voltage	60 Hz line 0 to 20 W output at 1 kHz	105 to 125 VAC	
Input power		<36 VA nominal	
Microphone Input Level	For full rated output	2.8 mV nominal (-51 dBv)	
Microphone Input Freq Response	From 500 Hz to 15 kHz	< 3.0 dB	
Microphone Input 60 Hz rejection	Referenced to 1 kHz level	> 30 dB	
Total noise + hum	Open jack	< -50 dB	Referenced to 20W output
	Terminated jack	< -60 dB	
Microphone Input Impedance	1 kHz	> 450 kΩ	
Microphone Input connector	1/4” standard phone jack, single circuit		
Line input level	For full rated output single line	300 mV	-10 dBv
	Two low impedance line inputs per line	530 mV	-5 dBv
Line Input Freq Response	Single line, referenced to 1 kHz 10 Hz to 50 kHz	< 3 dB	
Total noise + hum	Level control minimum	< -90 dB	Open jack referenced to 20W output
	Level control maximum	< - 87 dB	
Line Input Impedance	Referenced to 1 kHz for all combinations of single and two line inputs	> 40 kΩ nominal > 15 kΩ minimum	
Line Input connector	3.5 mm (1/8”) two circuit (stereo)		
Level control	1 kHz, single line input referenced to full output	0 to -90 dB	Nominal
Output impedance	1 kHz into 8 Ω resistive load	< 0.20 Ω	
Output Load	Functional for all other specifications	4 to 16 Ω	
Output power	1 kHz into 8 Ω resistive load	20 W	Nominal
	1 kHz into 4 Ω resistive load	25 W	
Output protection	Shorted load acceptable down to (Open load acceptable)	0.10 Ω	
Load protection	DC and overdrive	2 A GMA	Fast acting
Output connector	1/4” standard phone jack, single circuit		

Circuit description

This simple, general purpose audio amplifier is based on an RCA design published in the 1969 edition of their "Transistor, Thyristor, & Diode Manual©". It appeared in a quasi-complementary symmetry form, I suspect because it was difficult at the time to make PNP bipolar transistors equivalent to their NPN counterparts. Today good complementary transistors allow the circuit to be implemented in a true complementary symmetry form, as I did in this updated design.

The basic design uses negative feedback for bias stabilization, very low distortion, and low output impedance (high damping factor). This suits most applications, but some audiophiles prefer the small distortion products of non-feedback amplifiers (primarily vacuum tube) with associated low damping factors. Obviously this design does not pretend to address their interests; but for a good, clean, single channel amplifier it is quite good.

I never dealt with audio amplifier designs (at least not power type) in my design work at Rockwell/Collins, but I remember talk about issues with cross-over distortion vs quiescent bias in the output stage being a major challenge. So I started the design update with the output stage. The trade-off of cross-over distortion to bias seems to require precise control of the output stage voltage/current levels including over temperature.

However, after a little analysis I found that low level output (that is near cross-over) requires small signal currents which can be provided by the driver stage. This allows for judicious selection of the driver stage bias current so as to operate class A, that is always with current flow. See Figure 1 for the following circuit description.

The value of R28 and R29 are selected to provide sufficient voltage drop for reasonable bias stabilization while providing sufficient output current to eliminate cross-over distortion. The quiescent bias and R28/R29 values must also be selected such that the output transistors do NOT conduct during zero signal (or very low signal) conditions.

D2 and D3 provide reasonable temperature compensation for Q6 and Q7 V_{BE} but do NOT need to be in contact with the output transistors (as some older designs required). If anything, they should be in contact with Q6 and Q7. However, the 100 Ω emitter resistors prevent the need for exact temperature tracking. R24 establishes the differential bias for Q6 and Q7. Its' voltage drop appears across R28 + R29 and Q6/Q7 emitter current will therefore be established. DC feedback through R20 forces the voltage sum at the R28/R29 junction to zero (or as close as the input offset allows). Q6 and Q7 emitter voltages then adjust themselves accordingly.

The design objective is 2.5 mA quiescent emitter current in Q6 and Q7. While this provides sufficient current to eliminate cross-over distortion it does not bias Q8 or Q9 on. When larger output current is required, due to larger signal levels, the increased voltage drop across R28 and R29 bias on Q8 and Q9. As this occurs Q6/Q8 and Q7/Q9 behave as Darlington pairs capable of providing several amps of signal current.

Once this is understood, the rest of the design is rather simple. C13 and C14, along with the associated resistors provide bootstrap (regenerative feedback with less than unity gain) from the output to the base drive of Q6 and Q7. The peak base voltage must be a couple of volts higher than the desired output peak voltage to ensure the transistors are biased on.

Q5 must swing its' collector voltage over the entire peak-to-peak range of the output plus this drive margin. In order to do so its' collector load, R23, D2, R24, D3 and R25, connects to the positive bootstrap of C13 and R22. Q5's emitter connects to the negative bootstrap of C14, R26 and R27.

Q5 is a current amplifier. Its base voltage is riding the bootstrap feedback and appears at Q3's collector. However, the real story is Q3's collector current provides Q5's base current from the signal half of a differential pair. Q4 is the feedback half and the two transistors share a quasi-constant current from R17. D1 and C10 reduce the effects of load current swings on the supply voltage and the emitter voltage of Q3/Q4 stays very close to 0.65 volts, therefore almost constant voltage across a fixed resistance provides a near constant current source.

Q4 is DC coupled to the output via R20 for unity voltage gain. The output DC offset voltage is almost zero and can be minimized using the appropriate value and location of R16, which is test selected for < ± 5 mV output offset voltage. R20 also sets the amplifier's signal gain, in conjunction with R19 and C12, the values of which are selected for a 2 Hz corner frequency. The signal gain is approximately (R20/R19 + 1) over the operational frequency range. This negative feedback ensures the amplifier has very low output impedance and low distortion.

L1/R32 and C18/R33 are selected to stabilize the amplifier for reactive loads and higher frequencies. C9 provides RFI reduction as well as assisting in high frequency stability. These stabilization networks require testing above about 50 kHz be done at no more than 1 Watt output power. Higher power levels above 50 kHz can excessively stress these components.

Q1 and Q2 form a DC coupled amplifier with negative voltage feedback. The closed loop gain is approximately 38 dB and is shaped for voice band operation. Low frequencies (and 60 Hz) are intentionally rolled off with C2 and C5 value selection. C4 rolls off frequencies above the voice band for stability. The input impedance is approximately 450 kΩ with R1 and C1 providing RFI reduction.

The line inputs are via a 3.5 mm, two wire jack. Stereo program content is combined by R2 and R3 into a single line.

The power supply uses a transformer with dual 18V windings feeding a bridge rectifier to produce positive and negative 25 VDC. Oversized filter capacitors are used to provide some extended surge capability for large peak signals.

Construction details

Figure 1 shows details of the construction. Note the printed circuit board is a permanent part of the chassis. Service is simple because both top and bottom sides of the board have open access. The output transistors, Q8 and Q9 are mounted to the left-hand cover screw plate with mica insulators and thermal compound.

The rear panel is mounted to the chassis by four #4 screws and the front panel is attached by the control shafts and hardware. The microphone jack is insulated from the chassis and its' sleeve connected to R6 ground end. Even with the significant isolation of the power supply components, the peak ripple current introduces significant circulating ground currents into the chassis and printed circuit board ground plane. The mic input must be totally isolated from the chassis to avoid these currents.

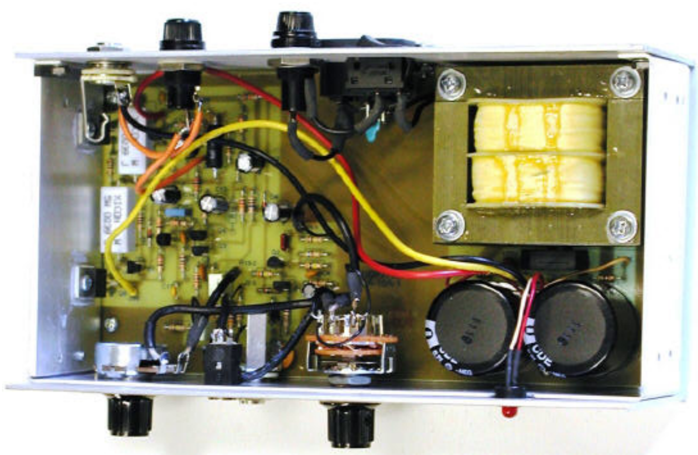

Figure 1. Inside view showing the printed circuit board and chassis wiring.

Figure 2 shows the rear panel and associated connectors, jacks and switch. Power transformer, T1, is mounted to the printed circuit board with #6-32 threaded hex spacers 0.500" long. T1 terminals solder to the board, but the spacers are used for additional mechanical support.

The plus and minus 25 VDC connections are wired to the power amplifier via the red and yellow wire. During initial assembly these are connected to the amplifier end of the board, but not to the rectifier end. Initial testing can then be performed using (current limited) bench power supplies. Once functional test confirms the integrity of the assembly, the wires are connected to the rectifier outputs labeled +25V and -25V as appropriate.

The AC line connections are heat-shrink covered to avoid exposed line voltages. A 0.010" FR-4 sheet is attached with adhesive to the rear panel along the terminals of T1. C21 and C22 are wired directly to the terminals of J4 with C21 inside the heat-shrink tubing. J4 ground pin is wired to a solder lug mounted under one of J4's mounting screws. A #16 wire is used to ensure chassis ground return capable of handling line fault conditions.

Cover screws are #6-32 and install into threaded holes in the two 0.125" cover screw plates. The bottom cover has rubber feet attached, but otherwise is identical to the top cover. Both are primed and painted with a textured, multi-color finish.

Figure 2. Rear view showing the connectors, fuses and switch.

Figure 3 is the printed circuit board component locator. The etched, drilled and solder platted board, with legend, is available from Far Circuits as PWB AA10A120 for about $16. Specify Rev A to have the reworks mentioned in the “Engineering Prototype Results” included. The board is 3.97” x 7.85” 0.063” FR-4 with #4 mounting holes to attach to the chassis frame.

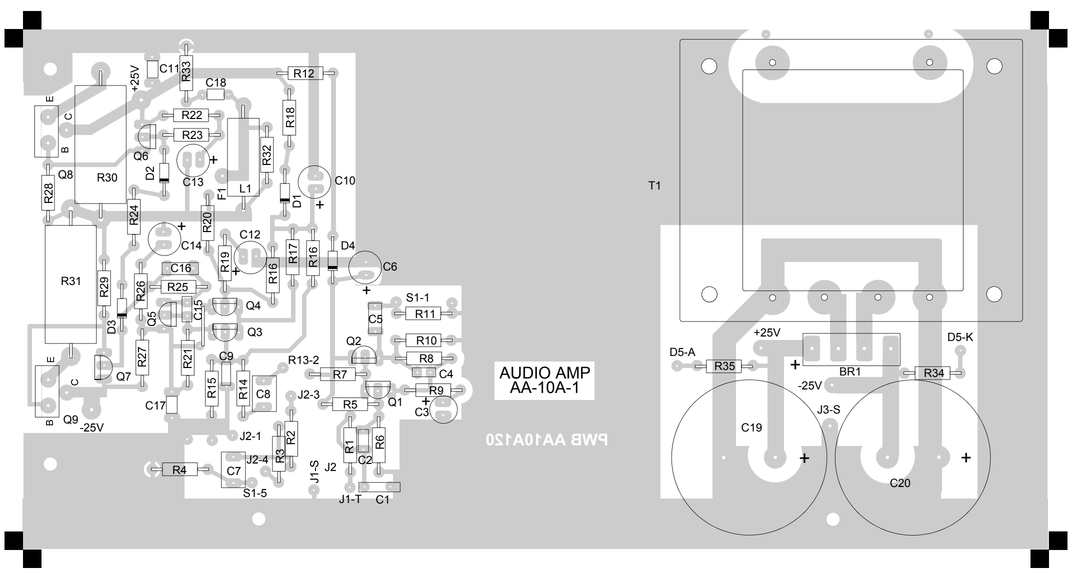

Figure 3. Printed wiring board component locator.

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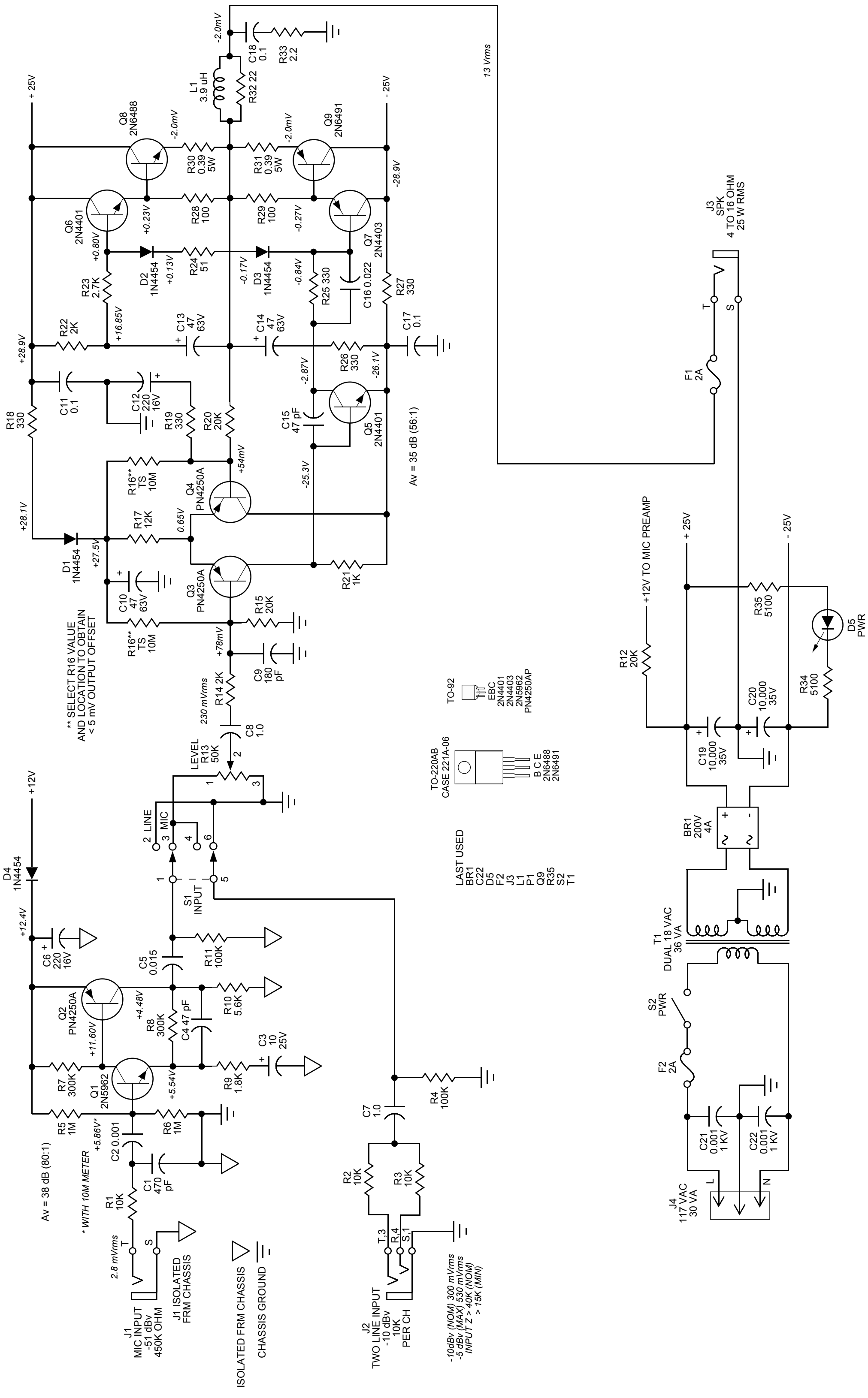

Figure 4. Schematic diagram of the AA-10A-1.

Material List - AA-10A-1

Qty	Designator	Value/Type	Description	Part Number**	Supplier
1	BR1	400V, 4A	Bridge rectifier	512-KBL04	Mouser
1	C1	470 pF, 50V	Disk ceramic	140-50S5-471J-RC	
1	C2	0.001 µF, 50V	Poly film	667-ECQ-E6102KF	
1	C3	10 µF, 25V	Aluminum Electrolytic	647-UVR1E100MDD	
2	C4, C15	47 pF, 50V	Disk ceramic	140-50S2-470J-RC	
1	C5	0.015 µF, 50V	Poly film	667-ECQ-V1H153JL	
2	C7, C8	1.0 µF, 63V	Poly film	80-R82DC4100DQ60J	
2	C6, C12	220 µF, 16V	Aluminum Electrolytic	647-UVR1C221MED	
1	C9	180 pF, 50V	Disk ceramic	140-50S5-181J-RC	
3	C10, C13, C14	47 µF, 63V	Aluminum Electrolytic	647-UVR1J470MED	
3	C11, C17, C18	0.1 µF, 50V	MLC ceramic	80-C317C104M5U-TR	
1	C16	0.022 µF, 63V	Poly film	871-B32529C223K189	
2	C19, C20	10,000 µF,35V	Aluminum Electrolytic	598-SLPX103M035E3P3	
2	C21, C22	0.001 µF, 1kV	Disk ceramic	81-DEBB33A102KA2B	
4	D1, D2, D3, D4	1N4454	Silicon signal diode	512-1N4454	
1	D5	LED	Green panel mount	604-WP7113SGD	
1	F1, F2	2 Amp, GMA Fast acting	5mm x 20mm	504-GMA-2	
2	J1, J3	Mono	¼” Phone jack	568-NYS229	
1	J2	Stereo	3.5 mm Phone jack	161-0352-EX	
1	J4	IEC 320-C14	AC power inlet	562-703W-00/03	
1	L1	3.9 µH	High current axial lead inductor	542-5800-3R9-RC	
1	P1	NEMA 5-15P, IEC 320-C13	3x18AWG Cord set	562-212004-01	
1	Q1	2N5962	Hi gain small signal NPN	512-2N5962	
3	Q2, Q3, Q4	PN4250A	Hi gain small signal PNP	512-PN4250A	
2	Q5, Q6	2N4401	Medium power NPN TO-92	512-2N4401TA	
1	Q7	2N4403	Medium power PNP TO-92	512-2N4403TA	
1	Q8	2N6488G	75 W, NPN, TO-220	863-2N6488G	
1	Q9	2N6491G	75W, PNP, TO-220	863-2N6491G	
3	R1, R2, R3	10 kΩ, 0.25 W, 5%	CF	291-10K-RC	
2	R4, R11	100 kΩ, 0.25 W, 5%	CF	291-100K-RC	
2	R5, R6	1 MΩ, 0.25 W, 5%	CF	291-1M-RC	
2	R7, R8	300 kΩ, 0.25 W, 5%	CF	291-300K-RC	
1	R9	1.8 kΩ, 0.25 W, 5%	CF	291-1.8K-RC	
1	R10	5.6 kΩ, 0.25 W, 5%	CF	291-5.6K-RC	
3	R12, R15, R20	20 kΩ, 0.25 W, 5%	CF	291-20K-RC	
1	R13	50 kΩ Audio taper	Panel mount variable	31VJ405-F	
2	R14, R22	2 kΩ, 0.25 W, 5%	CF	291-2K-RC	
1	R16*	10 MΩ, 0.25 W, 5%	CF	291-10M-RC	
1	R17	12 kΩ, 0.25 W, 5%	CF	291-12K-RC	
5	R18, R19, R25, R26, R27	330Ω, 0.25 W, 5%	CF	291-330-RC	
1	R21	1 kΩ, 0.25 W, 5%	CF	291-1K-RC	
1	R23	2.7 kΩ, 0.25 W, 5%	CF	291-2.7K-RC	
1	R24	51 Ω, 0.25 W, 5%	CF	291-51-RC	
2	R28, R29	100Ω, 0.25 W, 5%	CF	291-100-RC	
2	R30, R31	0.39 Ω, 5 W, 5%	WW ceramic filled	280-CR5-0.39-RC	
1	R32	22 Ω, 0.25 W, 5%	CF	291-22-RC	
1	R33	2.2 Ω, 0.25 W, 5%	CF	291-2.2-RC	
2	R34, R35	5.1 kΩ, 0.25 W, 5%	CF	291-5.1K-RC	
1	S1	2 position six pole	Rotary panel mtg switch	105-SR2511F-62RN	
1	S2	SPST	Snap in rocker switch	642-FMC12A220	
1	T1	Dual 18 VAC, 36 VA	Split bobbin 117 VAC primary	595-1193-ND	DigiKey
2	XF1, XF2	5mm x 20 mm Fuse holder	Panel mount	441-R3-12-GRX	
2		Knobs	0.25” shaft	506-PKA50B1/4	
1		Enclosure	including heat sink & fab parts	Shop built	BWC
1			PWB	AA10A120	Far Circuits

* Test select for offset null
** Mouser unless otherwise specified

Engineering Prototype Test Results

See Figure 5 for measured frequency response.

Low level hum caused by rectifier peak currents appeared in both the power amplifier and the mic preamp.
Reworks to resolve:

1. C12 negative lead connects to ground at R15/C9 junction.
2. Mic jack, J1, insulated from the chassis with sleeve connected to R6 ground end.
3. C6 and C3 negative leads connect to R6 ground end.

It appears these points are isolated enough from the rectifier/filter caps to not be a problem, but indeed they are not. The low impedance ground plane is not sufficient and these points must be connected as the rework describes to eliminate the artifact.

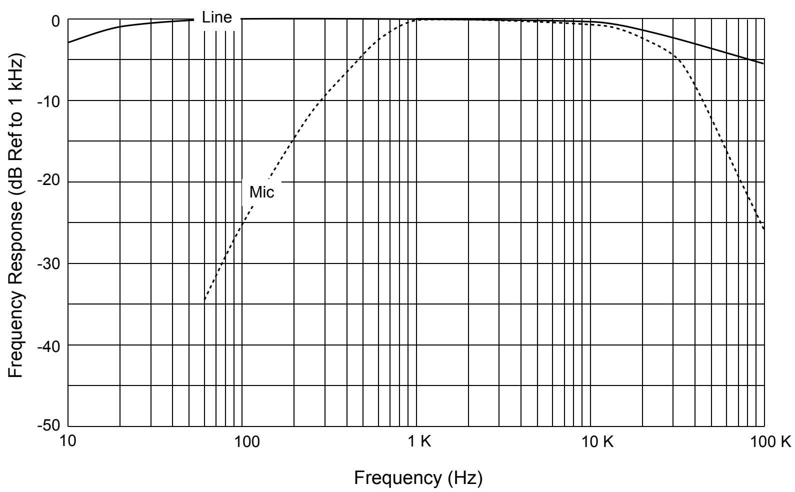

Figure 5. Line and microphone frequency response referenced to 1 kHz as measured on the engineering prototype.

Line Input Frequency Response (Referenced to 1 kHz)	
Frequency (Hz)	Response (dB)
5	-9.5
7	-6.0
11	-3.0
14.5	-2.0
22	-1.0
90	0
1k	0
10k	-0.5
15k	-1.0
25k	-2.0
100k	-5.5

Mic Input Frequency Response (Referenced to 1 kHz)	
Frequency (Hz)	Response (dB)
60	-34.5
100	-25.5
155	-18.0
233	-12.0
270	-10.0
410	-6.0
560	-3.0
650	-2.0
780	-1.0

Mic Input Frequency Response (Referenced to 1 kHz)	
Frequency (kHz)	Response (dB)
1.0	0
10.0	+0.2
13.5	-1.0
16.0	-2.0
18.5	-3.0
25.8	-6.0
40.0	-10.0
74.0	-20.0
100.0	-26.0

Engineering Prototype Test Results (continued)

Output Power (single tone of 1 kHz) RMS

8 Ohm resistive load	19.5 Watts	(12.5 Vrms)
4 Ohm resistive load	23.8 Watts	(9.75 Vrms)

Design analysis indicated 25 Watts might be a problem with the 36 VA transformer and indeed it doesn't quite make it. For music or voice it should be fine, but for a continuous single tone it is 1.2 Watts shy.

AC Line power consumption 120.4 VAC @ 0.40 Amp (48.2 VA)

Level range (1 kHz tone) +25 dB to -65 dB = 90 dB

Line Input Noise + hum

Level min	310 µVrms	(-92.5 dB ref 20 W)
Level max	380 µVrms	(-90.6 dB ref 20 W)

Mic Input

Terminated jack	11.5 mVrms	(-61.0 dB)
Open jack	23.0 mV	(-55.0 dB)

Output Impedance

(1 kHz)	10.0 - 9.8 Vrms (0 to 8 Ω) = 0.16 Ω
(100 kHz)	1.00 - 0.87 Vrms (0 to 8 Ω) = 1.25 Ω