ECC83 (12AX7) Microphone Preamplifier

studio quality with valves

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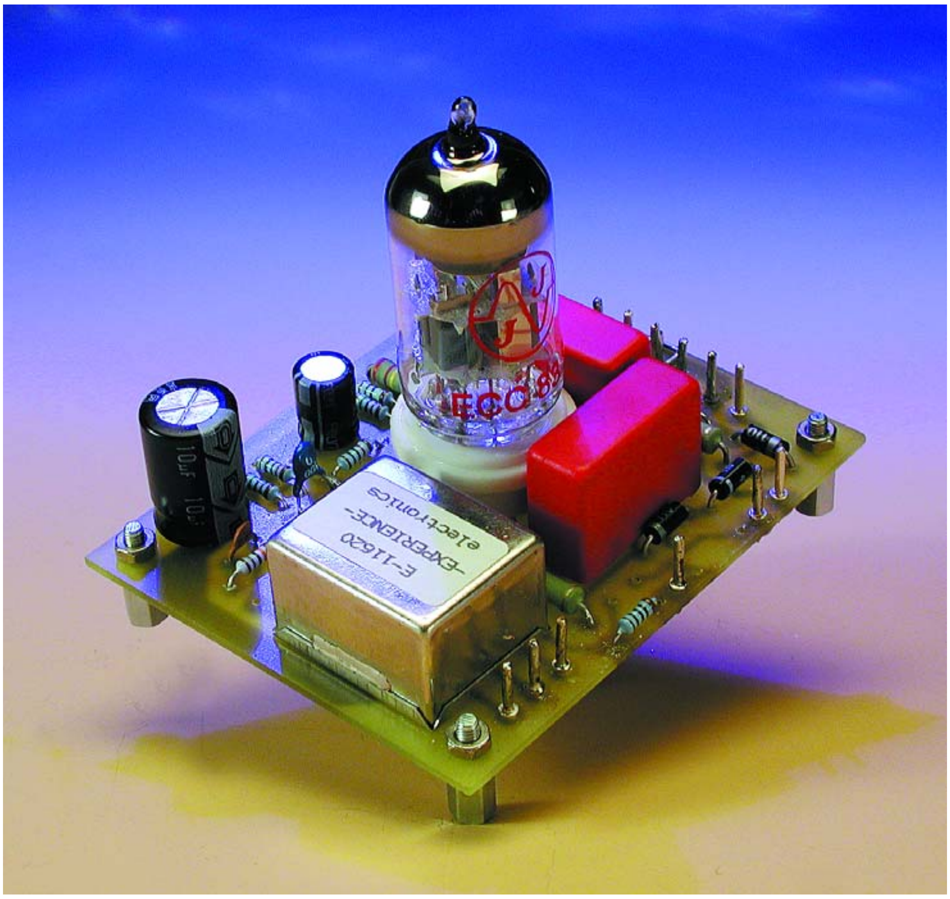
In this semiconductor age, we find valves being used increasingly often for hi-fi and guitar amplifiers, top-end condenser microphones and studio equipment. This article presents an excellent microphone amplifier with a uniquely attractive sound.



Microphone amplifiers must amplify extremely small signals to much higher levels while introducing the least possible amount of additional noise. In principle, it does not matter whether a transistor, operational amplifier or valve us used as the gain element.

A signal can be amplified by any desired amount, but the limit is set by the signal-to-noise ratio. If the magnitude of the noise signal is equal to or greater than that of the desired signal, any amplification is pointless. Consequently, microphone amplifiers must be designed to have the lowest possible levels of hum, noise and distortion, since every corruption of the signal originating in the microphone amplifier will be magnified by the following amplifier. Particular attention must therefore be given to the design of the input stage.

A low-noise transistor or low-noise valve will not by itself automatically yield a low-noise amplifier.

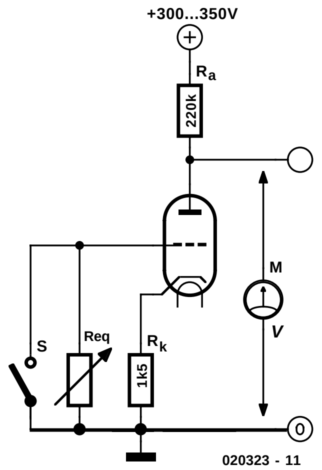


Figure 1. Basic noise measurement circuit

$U_{ntot} = \sqrt{(U_V^2 + U_{Req}^2)}$
$U_{V2} = U_{Req}^2$
$U_{ntot} = UV \cdot \sqrt{2}$
U_{ntot} = total noise voltage
U_V = valve noise voltage
U_{Req} = noise voltage of resistor
R_{eq} = equivalent noise resistance

Specifications

Supply voltages			350 V at approx. 4 mA			
	for ECC83S		12.6 V/0.15 A			
	for ECC808		6.3 V/0.34 A			
Frequency response	a_u = 40 dB		28 Hz - 24 kHz (–1 dB)			
Input impedance	1 kHz		approx. 900 Ω			
Unweighted noise voltage	20 Hz - 20 kHz		–72.5 dBm			
Noise voltage			–81.0 dBm(A)			
	CCIR-468		–67.8 dBm			
Input referenced noise voltage	CCIR-468, a_u = 50 dB		–117.8 dBm			

Harmonic distorsion	dtot	d2	d3	d4	d5	
–40 dBm, a_u = 30 dB	0.342%	0.020%	0.287%	0.018%	0.041%	at 80 Hz
	0.023%	0%	0.001%	0%	0%	at 1 kHz
–40 dBm, a_u = 40 dB	0.353%	0.030%	0.294%	0.018%	0.040%	at 80 Hz
	0.025%	0.006%	0.001%	0%	0%	at 1 kHz
–40 dBm, a_u = 50 dB	0.350%	0.023%	0.293%	0.018%	0.040%	at 80 Hz
	0.046%	0.036%	0.003%	0%	0%	at 1 kHz

Noise arises from the motion of electrons in any type of electrical conductor. The fundamental noise level of a given component is set by its construction and the materials used. The noise generated by an input stage is determined by the valve noise (or semiconductor noise) and the internal resistance of the signal source (resistance noise).

Noise measurements

Figure 1 shows a measurement circuit that can be used to determine the equivalent noise resistance (R_{eq}) of the valve used here (ECC83). The values of Ra and Rk are typical for this type of valve, but they anyhow do not have any effect on the measurement. First, the noise voltage of the valve (U_V) is measured at the anode with switch S closed, using a millivolt meter. The switch is then opened, and the value of R_{eq} is adjusted until the measured value is a factor of √2 greater. The value of R_{eq} is then recorded; this is the equivalent noise resistance of the valve. From the formulas, it can be concluded that if R_{eq} is smaller than R_V, valve noise predominates, while if R_{eq} is greater than R_V, resistance noise predominates.

If a pentode is used instead of a triode, there is an additional noise source in the form of partition noise. In a pentode, the number of electrons leaving the cathode is larger than the number arriving at the anode. As more electrons leave via the screen grid, the noise level increases. This is why we often see an EF86 pentode, which has low noise and microphonics, wired as a triode. The larger gain that can be achieved with the pentode configuration has been foregone in favour of better noise performance. A pentode in the triode configuration, or just a triode, is often used in such cases. Triodes also have a structural advantage over pentodes, in that they tend to produce second-harmonic distortion. This is

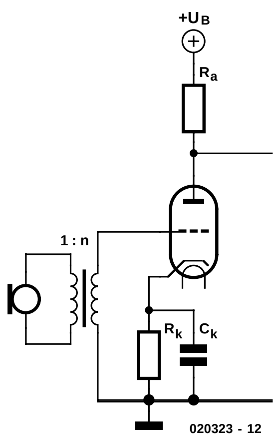


Figure 2. Microphone impedance matching using an input transformer.

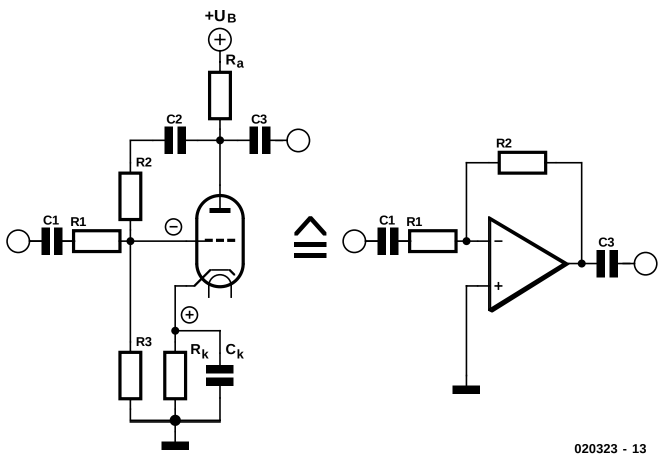


Figure 3. An inverting operational amplifier using a valve.

more pleasant to the ear than the 'scratchy' third-harmonic distortion produced by pentodes due to variations in the division of the cathode current between two electrodes, the anode and the screen grid, which depends on the drive level.

Transformer matching

In traditional circuits, such as that shown in **Figure 2**, an input transformer is used to match the microphone impedance to that of the valve. This transformer typically has a turns ratio of 1:10 to 1:30. With an input transformer, it is possible to boost the input signal level with practically no noise. However, stray circuit capacitances in combination with transformer capacitances limit the upper corner frequency and linearity of this arrangement, especially at large turns ratios. This problem can only be mastered using an elaborate transformer construction and sophisticated circuit design. The valve in Figure 2 works without feedback, so the amplification factor depends only on the turns ratio of the input transformer and the transconductance (g_m) of the valve. If the valve is replaced, the gain may also change.

Opamp circuits

A valve can also be wired as an operational amplifier, as shown in **Figure 3**. The plus and minus signs next to the valve electrodes identify the corresponding inputs of the valve opamp. Capacitors C1–C3 serve only to separate dc and ac voltages; in principle, they have no further effect. The grid-leak resistor R3 is needed by the valve, but its resistance is so large that it has no significant effect on the overall circuit. The cathode of the valve corresponds to the non-inverting input of the opamp. Since Rk is needed to set the dc operating point of the valve, it must be bypassed for ac signals by Ck to connect this input to signal ground. Now we have an inverting opamp whose gain is set by the resistance ratio R2:R1, independent of the amplifying component. Of course, the open-loop gain of this component must be significantly greater than the value of R2:R1. The input resistance of the circuit is equal to that of R1. As the value of R2 cannot be made arbitrarily large, since the value of grid-leak resistor R3 also cannot be made arbitrarily large, the value of R1 will be relatively small for large amplification factors. This imposes a significant load on the signal source. The internal resistance of the signal source forms a voltage divider in combination with R1. The control grid, just like the inverting input of an opamp, represents a virtual ground.

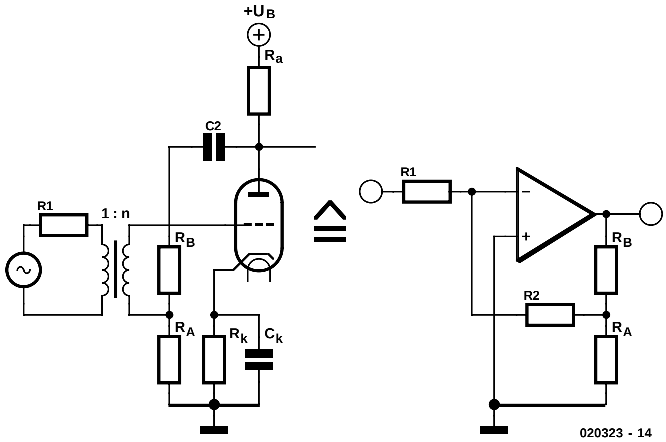


Figure 4. A non-inverting operational amplifier using a valve.

If the opamp circuit is modified as shown in **Figure 4**, the gain is essentially determined by the ratio R_B:R_A. This gives us considerably more freedom in selecting the values of R1 and R2. If R1 and R2 are now replaced by an impedance-matching transformer, R1 becomes the source impedance of the signal source and R2 becomes R1 × n^2. An equivalent circuit using a triode guarantees high gain with low noise. However, this arrangement has the disadvantage of having a limited amount of fundamental gain.

This situation can be improved using the circuit shown in **Figure 5**, which includes an additional valve. V2 acts as an impedance converter, since the feedback signal is taken from the cathode resistor. This yields the same considerations for R_A and R_B as in Figure 4, but since the cathode resistor of V1 is not bypassed, the fundamental gain is less. This has a beneficial effect on the distortion characteristic and long-term stability of the circuit, due to the use of negative feedback. The emissivity of valve cathodes decreases with age. If a lower level of system gain is used from the start, the useful life of the valves is extended. Valve V2 makes up for the missing gain. Here again, the cathode resistor is not bypassed with a capacitor, since the ac voltage on the cathode is needed for the negative feedback. Overall negative feedback is also provided via R_{FB}, in order to constrain the characteristics of the overall system without requiring selected valves to be used.

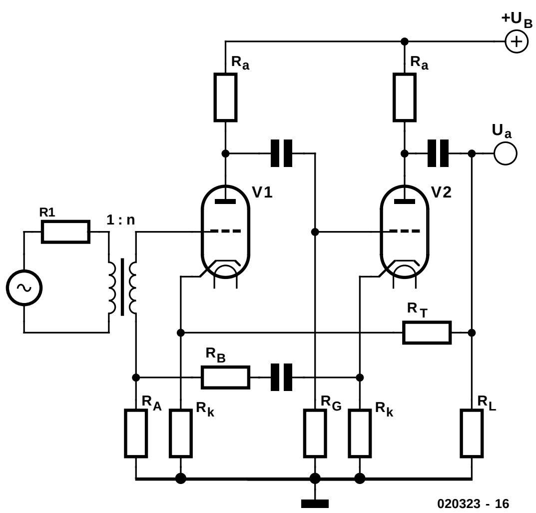


Figure 5. Amplifier with impedance converter.

Microphone preamplifier

Figure 6 shows the complete schematic diagram of the preamplifier, with all component values. The input transformer (type E-11620), which is one of the most important components for this application, is wound with a turns ratio of 1:8+8. Here it is wired for a 1:16 ratio. This provides a good compromise between signal level boosting and the noise performance of the circuit. Furthermore, this transformer can also be used for other purposes, so its price can be kept within reasonable limits by virtue of a relatively large production volume.

The input transformer can be used with an input level of around 800 mV_{eff} at 40 Hz, but that does not mean that the amplifier circuit should be fed such a strong input signal. The maximum input level depends on the maximum output level of the complete installation. The transformer is fully encased in mu-metal, since otherwise even minute amounts of coupled-in noise would be amplified to high levels by subsequent amplifier stages.

The component values have been chosen to allow a gain of around 25 to 60 dB to be used with high sound quality. The gain is essentially determined by the values of R6 and R15. A gain of 25 dB is provided by the signal level boost of the input transformer alone. A fixed minimum gain can be thus set using R6. R15 can also be replaced by a wire bridge, a selector switch with fixed dB settings, or a trimpot. Of course, only premium-quality components should be used for this purpose. The selector switch must have gold-plated contacts and make-before-break switching, since otherwise it will produce crackling noises and switching clicks.

Coupling capacitors C4 and C5 are specially marked in the schematic diagram. The marking indicates the lead connected to the outer foil of the capacitor, which should be connected to the non-critical side of the circuit. Many types of film capacitors are correspondingly marked. The result is that the capacitor screens itself, thereby reducing the susceptibility of the circuit to interference.

The printed circuit board, whose layout is shown in **Figure 7**, allows the input transformer to be used at a ratio of either 1:16 or 1:8 by means of wire bridges. This allows other types of valves with the same basing to be used, such as the ECC81, ECC82 or similar dual triodes. However, if a different type of valve is used, the component values cannot simply be used as is. It is essential to modify them as necessary to match the dc operating point of type of valve used.

Components R3, C1 and C9 attenuate the resonance peak formed by the input transformer in combination with the amplifier circuit, in order to make the frequency response of the amplifier as flat as possible. The indicated component values can be adjusted as necessary according to circumstances. With the indicated values, the overall arrangement has a slight rise in the frequency response (around 0.8 dB) at 17.7 Hz. This could be suppressed even more, but only at the expense of a lower corner frequency at the high-frequency end.

Resistor R1 provides a finite load for the input transformer. The grid of the valve has such a high impedance that the transformer would otherwise operate with practically no load on the secondary. Since this can also result in a non-linear frequency response, a finite load impedance provides a definite benefit.

High-quality power supply

Both the enclosure for the circuit and the power supply must meet demanding require-

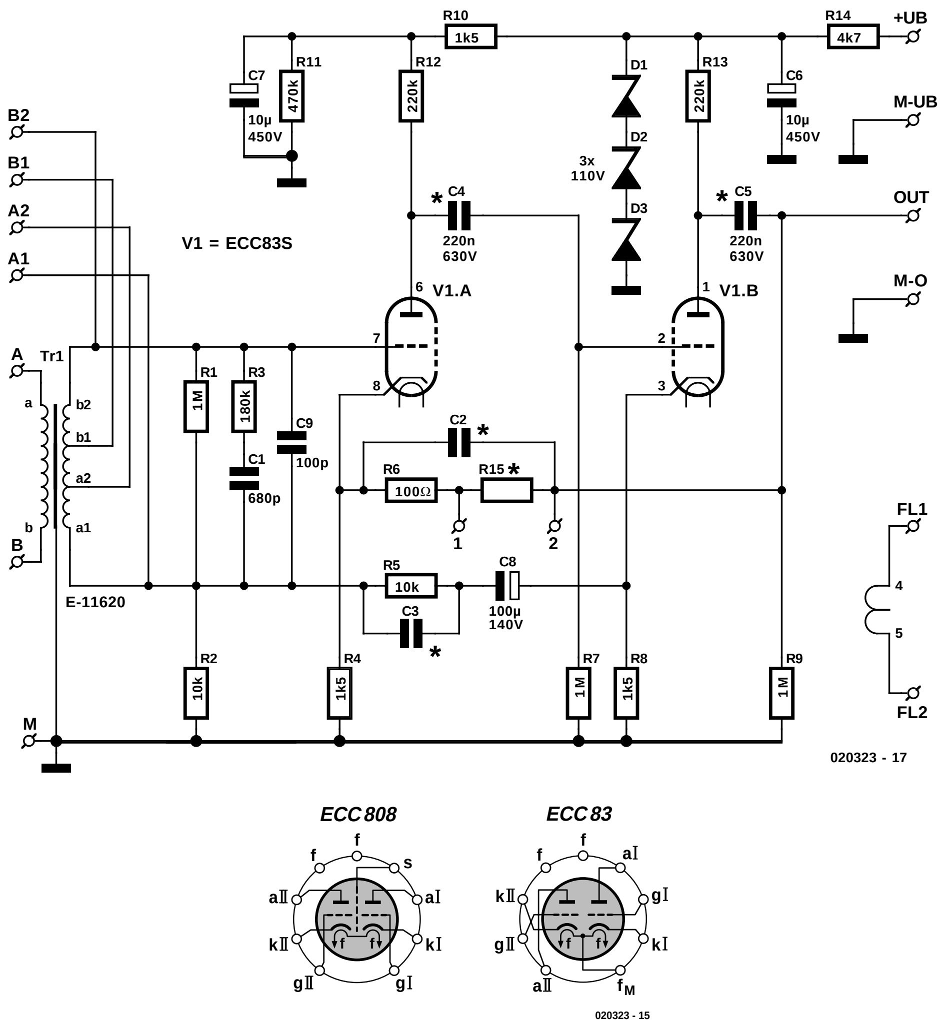


Figure 6. The final circuit of the microphone preamplifier, including the base diagrams for the two types of valves used.

f filament	**aI** anode I	**aII** anode 2
gI grid I	**gII** grid 2	**kI** cathode I
kII cathode 2	**fM** filament tap	**s** screen

(as seen from the bottom viewing the pins)

COMPONENTS LIST

Resistors:

(metal film, 1% tolerance, 0.7 watts, unless otherwise noted)

R1 = 1MΩ
R2 = 10kΩ
R3 = 180kΩ
R4 = 1kΩ5
R5 = 10k
R6 = 100Ω
R7 = 1MΩ
R8 = 1kΩ5
R9 = 1MΩ
R10 = 1kΩ5
R11 = 470kΩ, metal oxide, 2% tolerance, 2W
R12,R13 = 220kΩ, metal oxide, 2% tolerance, 2W
R14 = 4kΩ7
R15 = see text and Table 2

Capacitors:

C1 = 680pF ceramic
C2,C3 = only fitted when oscillation or RF noise is noted (approx. 10-47pF)
C4,C5 = 0.22µF 630V, MKS4, lead pitch 22.5mm
C6,C7 = 10µF 450V, lead pitch 5mm
C8 = 100µF 40V, lead pitch 5mm
C9 = 100pF ceramic

Semiconductors:

D1,D2,D3 = 110V zener diode, 1.3W

Miscellaneous:

R1 (Ü1) = E-11620
V1 (Rö1) = ECC83S, E83CC, 12AX7, ECC808 (see text)
1 valve socket, ceramic, PCB mount

Kits, special parts and PCBs available from

Experience Electronics
Weststrasse 1
D-89542 Herbrechtingen
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Maximum input voltage

(as a function of gain, for 1 percent total harmonic distortion)

a_u	u_i	R15
25 dB	375 mV	0 Ω
30 dB	180 mV	11 kΩ
40 dB	180 mV	62 kΩ
50 dB	85 mV	173 kΩ

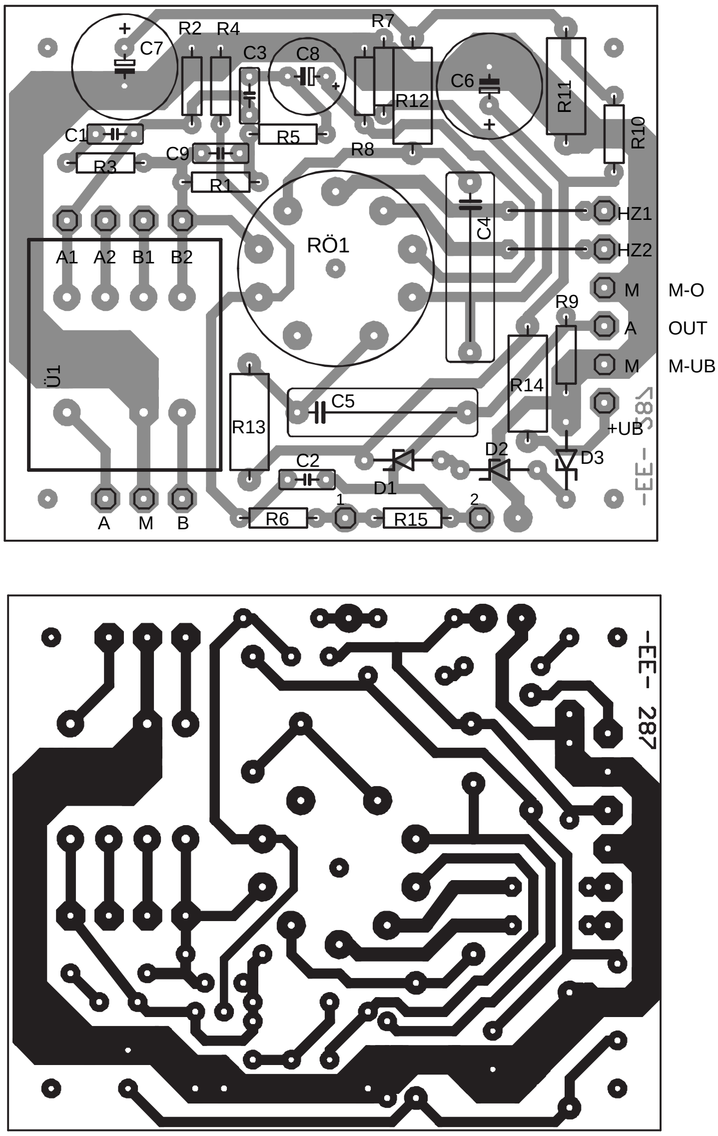
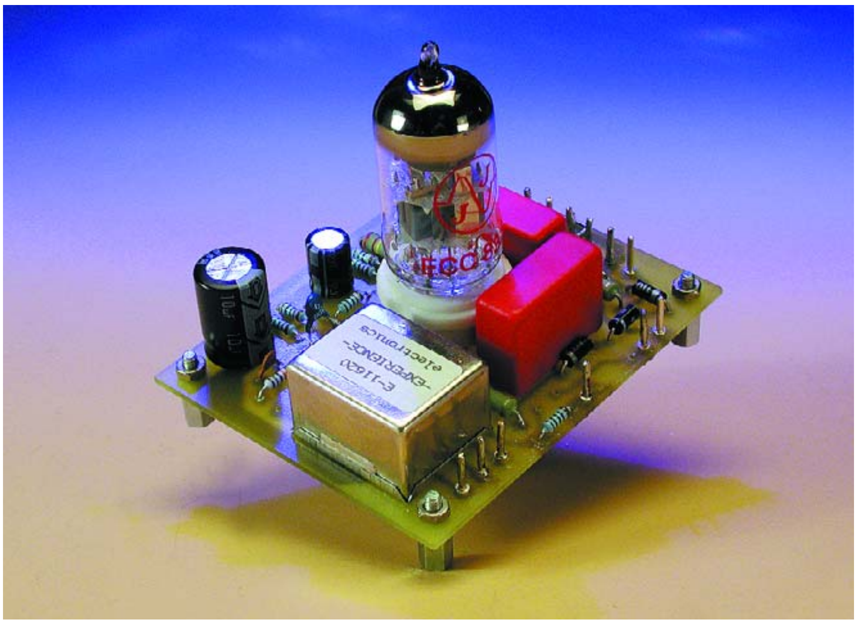


Figure 7. Circuit board layout for ECC83 (board available from Experience Electronics).



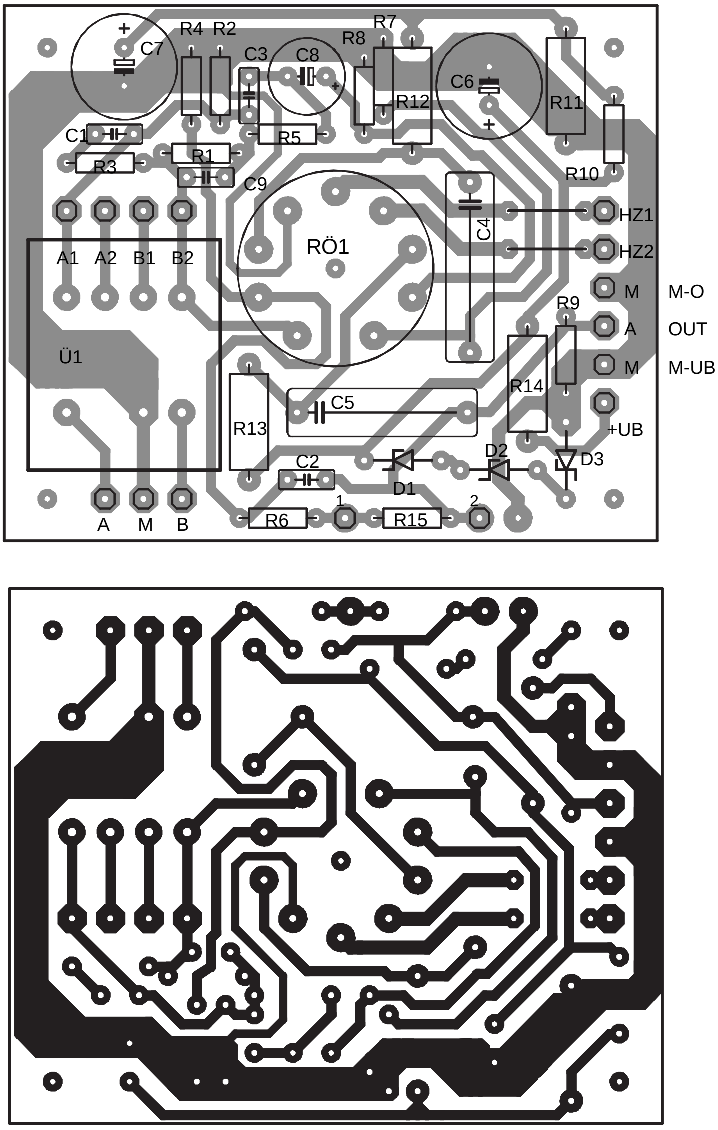


Figure 8. Circuit board layout for ECC808 (board available from Experience Electronics).

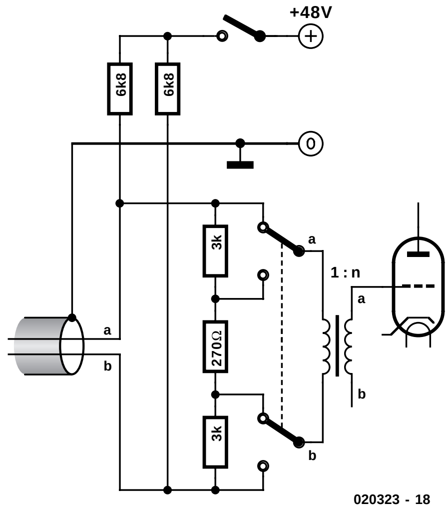
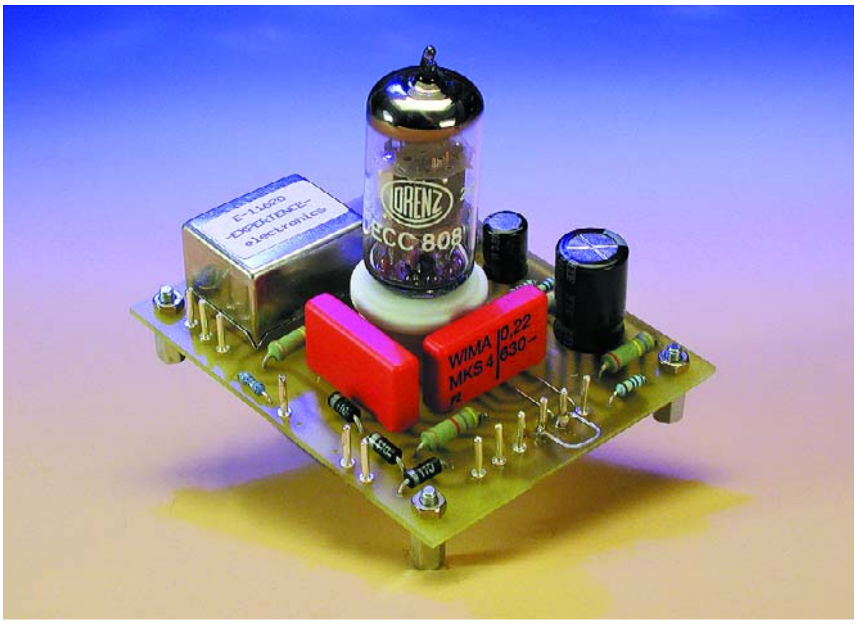


Figure 9. –30 dB input attenuator and connections for a phantom supply.



ments, since the circuit will deliver good results only if it is fitted into a fully screened metallic enclosure. The valves are heated using a 12.6-V dc voltage. The high voltage must be well smoothed. Suitable circuits have already been presented for the Valve Preamplifier (*Elektor Electronics*, June through September 2000 issues). Zener diodes D1–D3 must be used if several preamplifiers are powered from a single supply, or if the power supply has passive RC smoothing. The power supply output voltage must be 350 V.

Using a stabilised supply voltage provides the valves with well-defined operating conditions, which is beneficial since the gain of a triode more or less depends on the value of the supply voltage. An important point is that the negative terminal of the filament voltage must be connected to the negative terminal of the high voltage.

When choosing a valve type, you should pay attention to certain details. The measured performance values were achieved using an ECC83S, which is a cross between the ECC83 and the E83CC (military version). The noise figures of ECC83S valves are significantly better than those of standard ECC83 valves, so the ECC83S is clearly preferable. The ECC83 is also available with a variety of American designations, such as 12AX7, which exactly corresponds to the standard ECC83. The 12AX7A and 12AX7WA are versions with tighter tolerances, lower noise and lower microphonics, while the 7025 is the long-life version. An E83CC, or one of the equivalent American military versions with type numbers such as 6681, 6057 and 5751, can also be used if desired. Although these types are significantly more expensive, they have the advantage of being less microphonic and having longer service lives than the standard type.

The term 'microphonic' refers to the fact that mechanical vibrations, particularly in the control grid, can modulate a valve and lead to unpleasant noises or howling in an amplifier installation. This is thus not the place to cut costs in a good-quality microphone preamplifier.

The preamplifier should not be fitted into the same enclosure as the power supply, since otherwise electromagnetic interference and mechanical humming from the mains transformer can manifest themselves in an unpleasant manner. In some cases, it may be necessary to mount the circuit board elastically, for instance using rubber bushings. The circuit is designed such that it is not necessary to use selected valves.

There is yet another interesting option. The ECC808 valve was developed in response to the shortcomings of the standard ECC83 or its direct equivalent the 12AX7. The ECC83 and ECC808 are identical electrically, but the noise characteristics of the ECC808 are better by a factor of three, it is less sensitive to hum and it is significantly less microphonic. Its noise characteristics roughly match those of the ECC83S. In addition, it has a screen between the two triodes, which is of secondary importance in this application. The base arrangement is also different, with the control grid pins being located well away from the anode and heater pins. Consequently, and ECC808 cannot be used as a direct replacement for an ECC83. For this reason, we have also developed a second circuit board layout, as shown in **Figure 8**. The component values remain exactly the same, with the only difference being that the ECC808 requires a filament supply of 6.3 V dc at 0.34 A, instead of the 12.6 V at 0.15 A used for the ECC83. Unfortunately, the ECC808 is not exactly cheap, since it has become scarce. However, it represents an interesting alternative, and its price can be justified in a high-quality microphone preamplifier stage.

Interpreting the measured values

The measured values for the amplifier, which are shown in **Table 1**, require a little bit of interpretation. The open-loop gain, which is the gain when R15 is not fitted, is around 68 dB. If we want to allow a maximum gain of 60 dB, this leaves only 8 dB for negative feedback, which is not very much. Valves do not have high open-loop gains, unlike modern opamps. Consequently, it is recommended to select a gain in the range of 30 to 50 dB, since the best results with regard to harmonic distortion and frequency response will be obtained in this range.

The harmonic distortion measurements were made at 1 kHz and 80 Hz. As can be seen, the harmonic distortion increases at low frequencies, particularly odd harmonics. The influence of the input transformer can be seen here, since matching transformers generate predominantly this type of harmonic distortion components. The even harmonics can be attributed to the valves. The second-harmonic component has a pleasant sound that is typical of a good 'valve sound'. An increase in harmonic distortion at low frequencies is not especially serious, since the ear is relatively insensitive in this range. Another thing that can be seen from the harmonic distortion values is that the total harmonic distortion at 1 kHz is greater than the average value of the individual harmonic distortion values. At this frequency, amplifier noise predominates. In this case, the measurement equipment cannot distinguish between harmonic distortion and noise, since it makes broadband measurements at frequencies above 1 kHz.

The noise values are to be understood as absolute voltage levels at the output of the amplifier. The input-referenced noise values are obtained by assuming a noise-free amplifier with a noise source at a certain level connected to its input. Three noise values are given: 20 Hz – 20 kHz, A-weighted and CCIR-486. The CCIR-486 filter is used with studio equipment. With this filter, instead of measuring the effective noise value, the rectified peak value is measured using a filter characteristic similar to that of an A-weighted filter, but with the noise components between 1 kHz and 12 kHz being significantly more heavily weighted. That is why it gives the worst noise value.

In order to correctly evaluate the amplifier, it is necessary to correctly interpret the measurements. If a 200-ohm metal-film resistor is connected to the inputs of the instrument, a level of around –118 dBm is measured using the CCIR-486 filter. A dynamic microphone with a source impedance of 200 Ω generates a noise voltage of –118 dBm. If we assume our amplifier to be noise-free and subtract its gain from the noise level measured at its output, we arrive at a value of –117.9 dBm (weighted using the CCIR-468 filter). This means that the amplifier is only 0.2 dB away from what is physically achievable (0 dBm = 775 mV, the standard studio level).

There is another important point to consider, namely the maximum input voltage. It must be borne in mind that the input transformer boosts the input level by a factor of 16. Thus, if a level of 10 mV is present at the transformer input, the voltage on the grid of the first valve is already 160 mV. Since the grid voltage is only around –1.2 V, the knee of the characteristic curve is reached fairly quickly. The maximum input level for 1 percent harmonic distortion depends on the gain. Several typical values are listed in Table 2. A value of 85 mV for a gain of 50 dB may not appear particularly high. However, a dynamic microphone has a nominal level of 2 mV. If the amplifier can handle 85 mV, there is still 18 dB of headroom.

If you want to use this amplifier with a relatively high input signal level, an input attenuator should be used as shown in **Figure 9**. With the indicated component values, the attenuation is approximately 30 dB. If you want to have an exact value, or if you want to modify the attenuation, you can adjust the value of the 270-Ω resistor. Figure 9 also shows how a 48-V phantom supply can be implemented.

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