ECC83 (12AX7) Microphone Preamplifier

studio quality with valves

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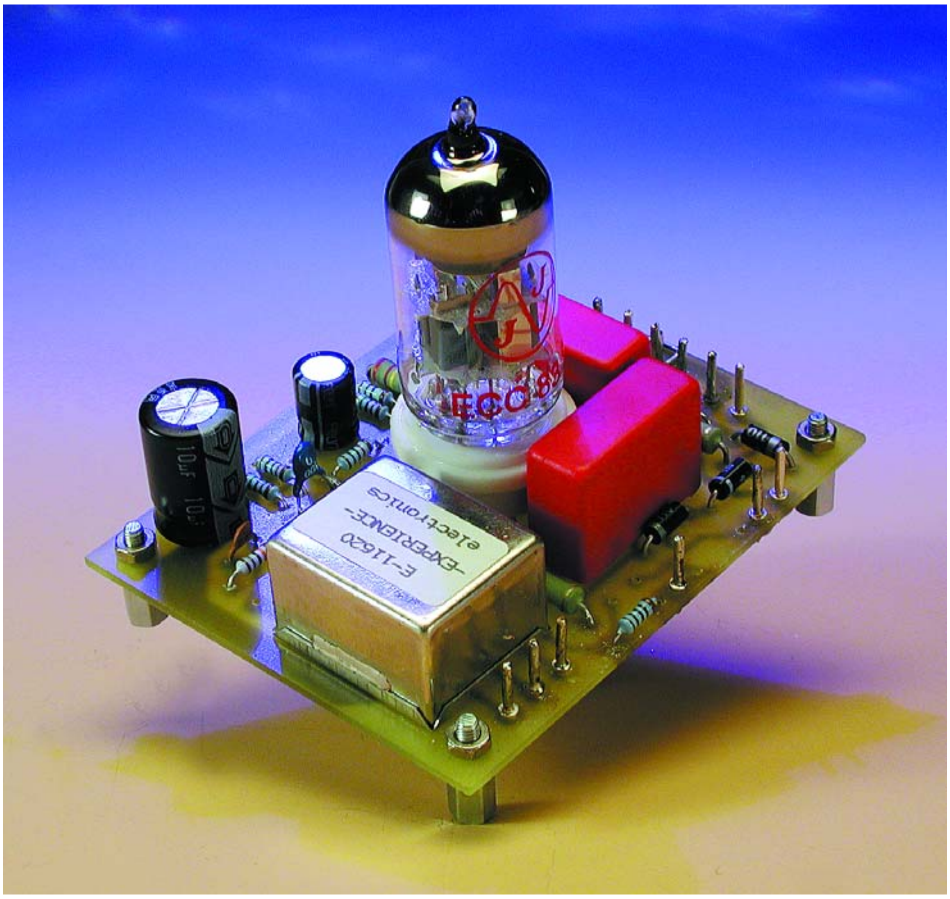
In this semiconductor age, we find valves being used increasingly often for hi-fi and guitar amplifiers, top-end condenser microphones and studio equipment. This article presents an excellent microphone amplifier with a uniquely attractive sound.



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.

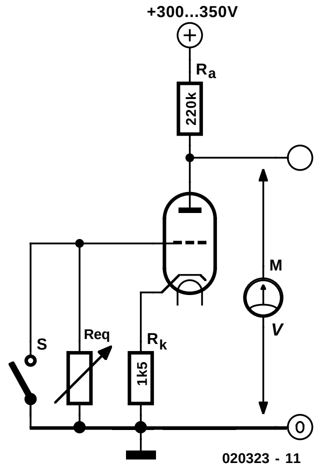


Figure 1. Basic noise measurement circuit

$U_{ntot} = \sqrt{(U_V{}^2 + U_{Req}{}^2)}$
$U_{V2} = U_{Req}{}^2$
$U_{ntot} = UV \cdot \sqrt{2}$
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 distortion	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

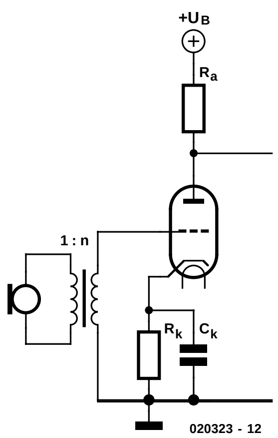


Figure 2. Microphone impedance matching using an input transformer.

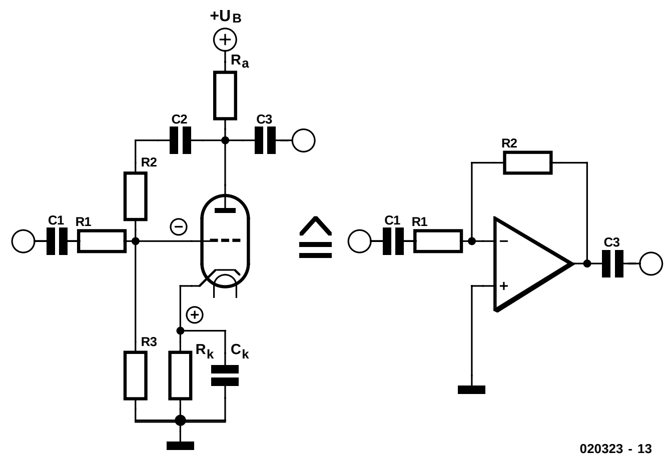


Figure 3. An inverting operational amplifier using a valve.

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.

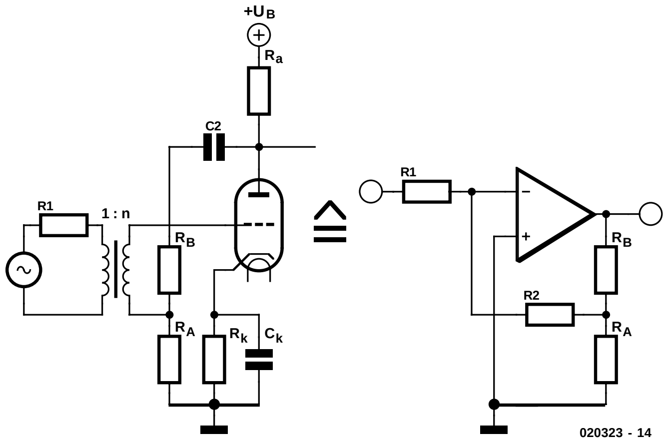


Figure 4. A non-inverting operational amplifier using a valve.

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.

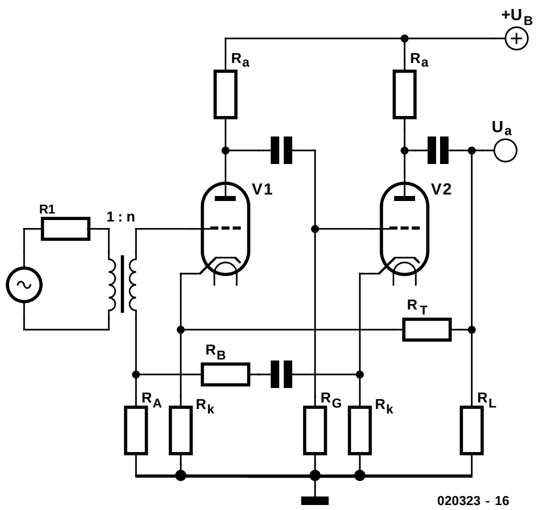


Figure 5. Amplifier with impedance converter.