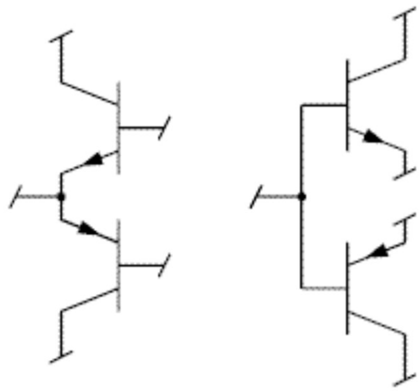
HEAD AMPS FOR MOVING-COIL CARTRIDGES



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Prologue

For all practical purposes, the disk phonograph has been replaced by the compact disk player. However, there are still many devotees to the long playing (LP) record. Back in 1978, I published an article in Audio Magazine describing a pre preamplifier or head amp for use with moving coil phono cartridges. From the feedback I received, the circuit was popular. I had titled my article "Build a Head Amp for Moving Coil Cartridges." However, Gene Pitts, then editor of Audio, changed the title to "Build a Pre Preamp for Moving Coil Cartridges." He told me that James Bongiorno, designer of the Ampzilla, had originated the term "head amp" for a product and Gene felt we should not use that term for my article. In the following, I have used "head amp" and "pre preamp" interchangeably.

In the first version of the circuit, I used 2N5210 and 2N5087 transistors. These were listed in the Motorola transistor handbook as being low-noise audio frequency transistors. When I sent the prototype to Gene at Audio, he had it evaluated by one of his reviewers. The reviewer contacted me and suggested that I change the transistors to 2N4401 and 2N4403. He said that these were secrets of audio designers for low-noise applications. The Motorola handbook listed them as general purpose switching transistors. When I replaced the original transistors with them, the noise was reduced by 4 dB, a significant reduction in low-noise design. The reason the 2N4401 and 2N4403 transistors have lower noise is because they have a lower base spreading resistance. This is a parameter that is seldom specified for transistors.

A company copied the design without my permission and marketed it. The company name was Markof. When I first heard of this, I asked Gene Pitts if he knew anything about the company. By coincidence, he had just received a Markof head amp for test. He mailed it to me. I opened it up and found the circuit to be the same as mine with one exception. 300 ohm resistors had been added in series with the emitters of the two transistors for bias stabilization.

In 2003, a second company has copied the design. The name of the company is LC Audio Technology. They called it a "current-to-voltage" transformer. To power the preamp, they used photo cells illuminated with an incandescent bulb . They refered to the circuit as "a clone of the famous 1970's step up, that transforms the currents from the cartridge coil,..."

The circuit was also published in the "Handbook for Sound Engineers: The New Audio Cyclopedia." There the circuit was incorrectly credited to "Marshall Electronics." To my knowledge, there was never a Marshall Electronics that made claim of the circuit design.

The addition of emitter resistors eliminate the need to hand select one of the resistors to obtain the proper bias current in the transistors. Although the resistors added thermal noise, I decided to add them to my circuit to make it simpler for others to construct. My modified circuit also had two additional transistors which operated as current mirrors in the bias circuit. I called it a current-mirror pre preamp.

A particular high end manufacturer of planar loudspeakers ordered several circuit boards of the original head amp for use in demonstrations. They told my partner in selling the circuit boards that they liked it. When they tried the new current mirror version with the emitter resistors, they told him that they did not like it as well as the original one. I never knew what their objection was, but I suspect that it was noise. Both circuits are described here.

I have received email from a number of people asking for information on the circuit. This web page is based on the original article. It describes the original circuit: a common-base amplifier, the current-mirror version of the common-base amplifier, and a third circuit - a common-emitter amplifier. All are complementary circuits which are dc coupled to the cartridge. The common-emitter version has not been published previously. The major difference between the common-base and common-emitter circuits is the input resistance. It is 100 ohms for the two common-base circuits and 1000 ohms for the common emitter circuit.

Introduction

Moving coil phono cartridges have probably been regarded with mystic by audiophiles who have never used them. Not only are they expensive when compared to a standard magnetic cartridge, but they require either an impedance matching transformer or a head amp which must be inserted into the reproducing chain between the cartridge and the RIAA preamplifier. Either of these necessary items can cost as much or more than the cartridge itself.

The operation of the moving coil cartridge is based on the same laws of physics that all magnetic cartridges operate. That is, a mechanical force which is proportional to the groove modulation on a phonograph record is used to change the magnetic flux linkage in a coil of wire. A corresponding voltage is induced in the coil which is equal to the number of turns in the coil multiplied by the time rate of change of the magnetic flux linkage through the coil. This voltage is then applied to the phono input of a preamplifier which performs three basic functions:

- It must have adequate gain to boost the input voltage to a level that is sufficient to drive a power amplifier.
- It must correct for the time derivative response of the magnetic cartridge.
- It must equalize for the RIAA recording characteristic used by the record industry.

The principal difference between a moving coil cartridge and a conventional magnetic cartridge is the mechanical mechanism which is used to vary the flux linkage in the coil. In a conventional cartridge, the coil is stationary and some element of the magnetic circuit is attached to the phono stylus. The motion of this element changes the flux linkage through the coil and generates a phono signal. Thus we have moving magnet, variable reluctance, etc., cartridges. In contrast, a moving coil cartridge has the coil attached to the phono stylus. The motion of the coil changes the flux linkage and generates the phono signal. However, there is one major exception. The output voltage from a moving coil cartridge is 20 to 30 dB lower than that from a conventional magnetic cartridge.

The output impedance of conventional magnetic cartridges is typically 2 kohm to 3 kohm resistance in series with 500 to 1000 mH inductance. This very large inductance causes the output impedance at high frequencies to become large. The input impedance to preamplifiers has a capacitive component at high frequencies. In combination with the inductive output impedance of the cartrige, this can cause a loss of high frequencies. Depending on the damping of the circuit, a resonant peak can exist in the high frequencies just below the rolloff frequency. This is one of the reasons that different cartridge and preamplifier combinations can sound so different.

One of the methods of minimizing cartridge preamplifier impedance interactions is to use use a cartridge with a very low output impedance. Such a cartridge is able to drive a capacitive load with no impedance interactions. A moving coil cartridge has this characteristic. Unfortunately, the output voltage is too low to drive a phono preamplifier directly.

There are two approaches to interfacing a moving coil cartridge to a preamplifier. The first is to use a step up transformer which steps up the voltage to a level sufficient to drive the preamplifier. But there are two problems with transformers. First, the transformer is very susceptable to hum pickup. Second, the output impedance characteristic of the transformer can be as bad or worse than that of a conventional cartridge.

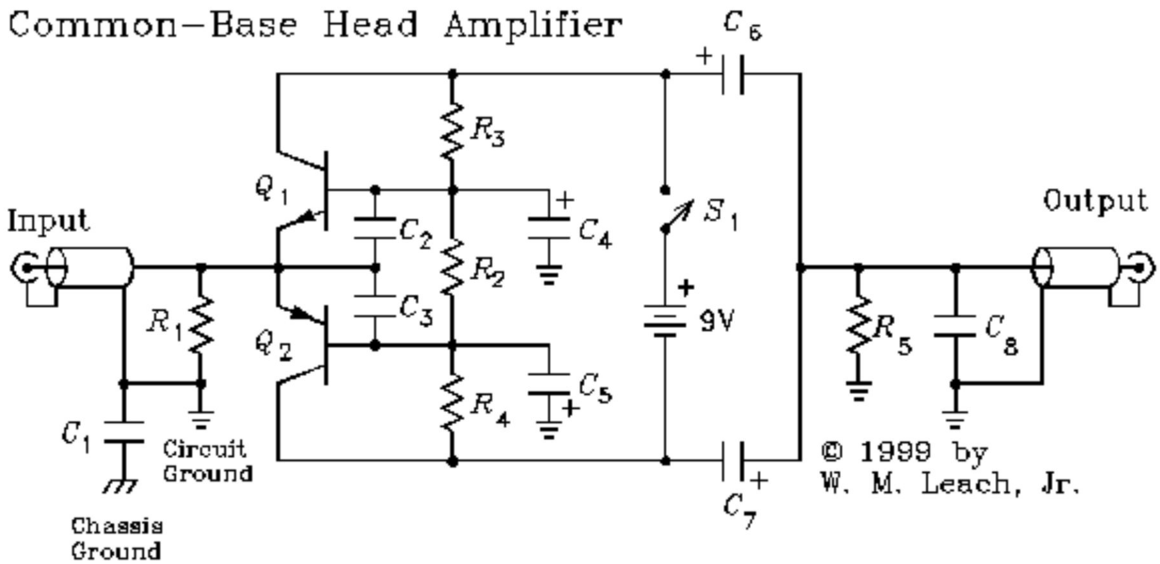
Enter the head amp. This is an active circuit which boosts the output voltage from the coil by 20 to 30 dB while exhibiting a purely resistive output impedance in the range of the output resistances of conventional cartridges. Thus impedance interactions are eliminated, and the hum problem can be virtually eliminated.

This page describes the design of three push pull head amps which are inexpensive and simple to build. Each has a gain of 26 dB and a resistive output impedance of 2 kohms. Because no negative feedback is used, the circuits cannot oscillate or exhibit transient or dynamic distortions caused by frequency dependent overload. To minimize hum, they are battery operated and draw only 125 microamps of current. Each is dc coupled to the cartridge for reproduction of the lowest bass frequencies. An unusual feature of the circuits is the isolation of all dc bias current and voltage from the cartridge, even though the cartridge is dc coupled to the circuit.

The Common-Base Circuit

The original head amplifier that I published in Audio Magazine is shown in the following figure. The circuit is a complementary common base amplifier. The input signal is connected to the emitters of the two transistors and the output signal is taken from the collectors. The bases are connected to signal ground through capacitors C4 and C5. The transistors are biased at 0.125 mA. At this bias current, the ac resistance seen looking into the emitter of each transistor is 200 ohms. The two emitters are in parallel, so that the input resistance is 100 ohms. Resistor

R1 has a value that is large enough so that it is effectively an open circuit compared to the 100 ohms.



The power supply is a 9 V battery. Because the battery is floating, it is impossible for battery current to flow through the cartridge. Thus no coupling capacitors are required at the input. When switch S1 is closed, a current flows through the base bias resistors R2 through R4 to slowly charge capacitors C4 and C5, thus turning transistors Q1 and Q2 on.

Resistor R5 is the collector load resistor which sets the gain and output resistance. It is ac coupled to the circuit through electrolytic capacitors C6 and C7. These are large enough so that they are effectively ac short circuits for frequencies above 0.4 Hz. Each of these capacitors has a dc polarizing voltage of 4.5 V across it. Because this is much larger than the ac signal voltage, the problems associated with using electrolytic capacitors with a low polarizing voltage as coupling capacitors are eliminated.

The only connection between circuit ground and chassis ground is through capacitor C1 at the input jack. Capacitors C2, C3, and C8 are for rf suppression. These capacitors are essentially open circuits at audio frequencies. They can be omitted without affecting the operation of the circuit. With the element values given below, the circuit has a voltage gain of 20 (26 dB), an input resistance of 100 ohms, and an output resistance of 2000 ohms.

The need to adjust resistor R2 to obtain the 0.125 mA bias current can be eliminated if small value resistors are added in series with the emitters of the transistors. The Marcof version of the pre preamp had these resistors. However, the thermal noise generated by the added resistors decreases the signal to noise ratio.

Parts List for the Common-Base Head Amplifier
R1 - 100 kohm
R2 - Select for a battery current of 0.125 mA, typically 330 kohm
R3, R4 - 1 Megohm
R5 - 2 kohm
C1 - 0.1 ufd
C2, C3, C8 - 100 pF
C4, C5, C6, C7 - 100 ufd

Q1 - 2N4401
Q2 - 2N4403

The 2N4401 and 2N4403 transistors are specified to be general purpose switching and small signal amplifier transistors. Although they are not specified for low noise applications, they have a low base spreading resistance which makes the suitable for low noise amplifiers. An engineer once told me that some audio designers consider the noise performance of the 2N4401/2N4403 pair to be a design secret. Hence they sometimes remove the numbers to keep others from knowing what transistors they use. The original transistors which I developed the circuit with were the 2N5210 and 2N5087. The Motorola data book specifies these as low noise transistors. When I replaced them with the 2N4401 and 2N4403 transistors, the signal to noise ratio was improved by about 4 dB.

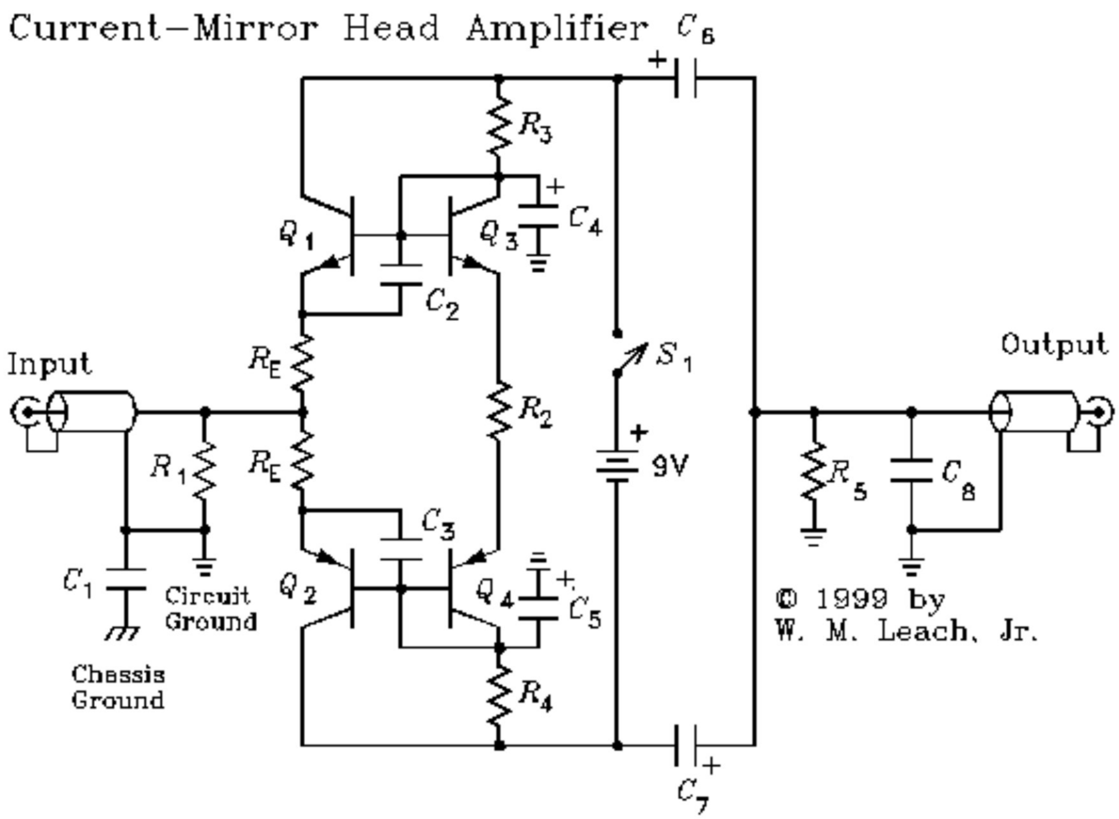
Resistor R1 is a 100 kohm resistor in parallel with the input. It generates thermal noise, but this is in parallel with the output resistance of the moving-coil cartridge. Because its output resistance is so low, the thermal noise generated by R1 is effectively shorted out. The only purpose R1 serves is to provide a ground reference for the input.

The Current-Mirror Common-Base Circuit

The figure below shows the current-mirror version of the common-base amplifier. It differs from the version above with the addition of transistors Q3 and Q4 which act as current mirrors to set the bias currents in Q1 and Q2. In addition, the output resistance is 2.9 kohm. The element values are the same as for the common-base amplifier with the following exceptions: R1 - 330 ohms, RE - 100 ohms, R2 - 200 ohms, R3 and R4 - 30 kohms, R5 - 3.6 kohms, Q3 - 2N4401, and Q4 - 2N4403. The current drawn by this circuit is 0.250 mA.

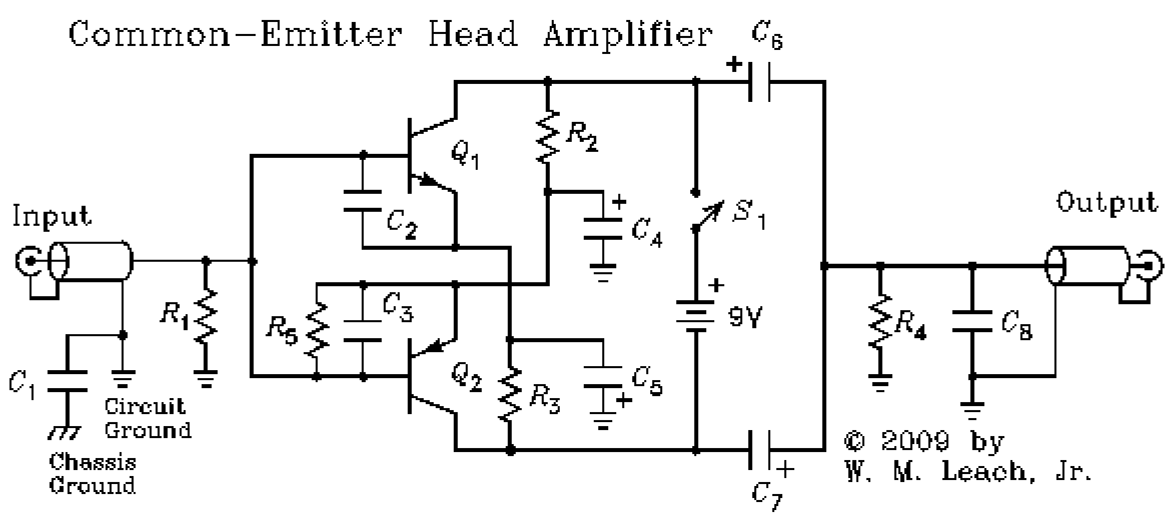
Because the emitter resistors RE are in series with the signal, they add thermal noise. This decreases the signal-to-noise ratio of the circuit compared to the common-base version. If short circuits are used for the REs and R2, the noise would be lower. In this case, the bias currents would depend on the matching of the transistors. I have not tried this, but I would expect that the currents would be close to the design values.

Capacitors C2, C3, and C8 are added to the circuit to minimize the chance of rf interference. They are small enough so that they should not affect the frequency response of the circuit. They can be omitted without affecting the operation of the circuit.



The Common Emitter Circuit

The following figure shows a modification to the original circuit which converts the transistors to common emitter amplifiers. The input signal is applied to the bases of the transistors and the output signal is taken from the collectors. Because the ac input resistance looking into the base is high, this circuit has a higher input resistance than the common base circuit. This makes the gain of the circuit less dependent on the output resistance of the cartridge. Resistor R1 must be chosen to set the input resistance. It is specified to be 1 kohm in the parts list. Other values may be used. As with the common emitter circuit, the floating battery makes it possible to dc couple the cartridge to the input.



When the switch is closed, current flows through the emitter bias resistors R2 and R3. This charges emitter bypass capacitors C4 and C5 to turn on transistors Q1 and Q2. The bias current is set at 0.125 mA. Resistor R4 sets the voltage gain and output resistance. With the element values given, the voltage gain is 20 (26 dB), the input resistance is 1 kohm, and the output resistance is 2 kohm.

Parts List for the Common Emitter Head Amplifier
R1 - 1 kohm
R2, R3 - 30 kohm
R4 - 2.4 kohm
R5 - Selected (typically 500 kohm to 1 Megohm)
C1 - 0.1 ufd
C2, C3, C8 - 100 pF
C4, C5 - 470 ufd
C6, C7 - 100 ufd
Q1 - 2N4401
Q2 - 2N4403

The input resistance is set by R1. I have heard people say, "Don't load the coil!" Therefore, I have specified 1 kohm for R1. This is very large compared to the output resistance of typical moving-coil cartridges to minimize loading effects. If a manufacturer specifies a particular cartridge load resistance, that value should should be used for R1. Although R1 generates thermal noise, it is in parallel with the output resistance of the cartridge. Because the cartridge output resistance is so low, the thermal noise generated by the resistor is effectively shorted out. The value specified for R4 gives a gain of approximately 26 dB. This resistor can be varied to adjust the gain.

Capacitors C2, C3, and C8 are added to the circuit to minimize the chance of rf interference. They are small enough so that they should not affect the frequency response of the circuit. They can be omitted without affecting the operation of the circuit.

The CE amplifier is much more sensitive to beta mismatches between the two transistors than the CB amplifier is. Beta mismatches lead to unbalanced dc voltages (measured with respect to ground) at the collectors of the two transistors. Preferably, the two voltages should be plus and minus 4.5 volts. However, the circuit will work if the voltages are not equal, but I would like to see them differ by 1 volt or less. The collector voltages can be tweaked by adding R5 in parallel with the base-emitter junction of the BJT that has the higher beta. This is usually the PNP transistor as shown in the figure. The exact value depends on the betas of the two transistors. The typical value should be in the 500 kohm to 1 Megohm range. Thanks to John Traugut for suggesting the addition of this resistor.

Here is an LTSpice file for the CE Head Amp if anyone wishes to play with it. The betas in the model statements for the two transistors are different, leading to unbalanced voltages without the addition of R5. The value 750 kohm is used for the simulation. Because the parameters in the SPICE model statement are only typical, it is doubtful that the value of the resistor would be the same in a real circuit. It must be hand selected.

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