Before attempting to design a transistor amplifier circuit, it is necessary to acquaint ourselves with some very important design equations. The most commonly used design equations are listed to the right to help us with our effort. The first few equations are derived from ohms law and you should already be familiar with them. The bottom two equations deal with transistor gain and are equally important to our work. The formula for $h_{fe}$ refers to the ratio of collector current ($I_c$) to base current ($I_b$). For most modern transistors it is typically in the 50 to 100 range. To insure a circuit will always work properly, it is safe to assume a value of 50 for modern transistors.

\[
\begin{align*}
I_c &= \frac{E}{R} \\
E &= IR \\
R &= \frac{E}{I} \\
P &= EI \\
h_{fe} &= \frac{I_c}{I_b} \\
I_b &= \frac{I_c}{h_{fe}}
\end{align*}
\]

At this time, we need to make some decisions about our audio preamplifier circuit. For this design example we will choose the following:

- $V_{cc} = 12$ V
- $I_c = 5$ ma
- $h_{fe} = 50$
- $Q1 = 2N3904$

With all those big decisions made, we can now begin our design.

Using the one of the $h_{fe}$ formulas, we will now calculate the base current as follows:

\[I_b = \frac{I_c}{h_{fe}}\]

\[I_b = \frac{0.005}{50} = 0.0001 \text{ ma}\]

Let's calculate $R_1$, the collector load resistor, as follows:

\[R_1 = \frac{1}{2V_{cc}} = 0.005\]

\[R_1 = 6 / 0.005 = 1200\]

Notice above that we assumed 1/2 of the supply voltage to be dropped across $R_1$. This is necessary to insure that the amplifier remains in the linear operating range of the transistor.

We need to determine how much voltage is to appear across the emitter resistor, $R_2$, before we calculate its value. A good value is anywhere between 5 to 10 percent of $V_{cc}$. For this circuit we will use 1 volt which is about 8 percent of $V_{cc}$. Resistor $R_2$ is now calculated as follows:

\[R_2 = \frac{1}{I_b + I_c} \]

\[R_2 = \frac{1}{0.005 + 0.0001} = 196\]
Because the voltage across the base to emitter of a silicon transistor is always .7 volts, the voltage from the base to ground is .7 plus the 1 volt drop across R2 for a total of 1.7 volts. This 1.7 volts happens to be the voltage drop across resistor R4. In order to provide a stiff base voltage, resistor R4 should have a current of about 5 to 10 times the base current. For this example, we will assume 9 times the base current for a total of .9 ma. Resistor R4 can now be calculated as follows:

\[ R4 = \frac{1.7 \text{ volts}}{.0009} = 1889 \]

If the voltage drop across R4 is 1.7 volts then the voltage drop across R3 must be 12 - 1.7 for a total of 10.3 volts. The current through R3 is the total of the current through R4 (.9ma) and the base current (.1ma) for a total of 1 ma. R3 can now be calculated as follows:

\[ R3 = \frac{10.3 \text{ volts}}{.001} = 10300 \]

Now that we have calculated all our resistor values, we will select the nearest standard values as indicated below:

\[ \begin{align*}
R1 &= 1.2K \\
R2 &= 180 \\
R3 &= 10K \\
R4 &= 1.8K \\
\end{align*} \]

The circuit at right is the result of our design efforts. 4.7\( \mu F \) capacitors were use for input and output coupling and slightly larger or small values could be used satisfactorily. Notice the optional 4.7\( \mu F \) capacitor across the emitter resistor R2. This capacitor increases the current gain to the hfe of the particular transistor used. This emitter bypass capacitor should only be used when the maximum amount of gain is desired without regard to a predictable level of gain.

Remember, hfe will vary from transistor to transistor even though they have the same part number and even if they were produced by the same manufacturer. It is always better to assume an hfe that is at least 20% less than that specified by the manufacturer.

One common error that designers make is that they forget to calculate the actual power that each resistor will dissipate in a circuit. Failure to perform these calculations can sometimes result in a resistor exceeding its maximum power level and cause premature resistor failure. This is particularly important for circuits which have collector currents exceeding 40 milliamps. Fortunately, power ratings for each of our resistors in this circuit can be easily calculated as follows:

\[ \begin{align*}
R1 &= 6 \text{ Volts} \times .005 \text{ Amps} = .03 \text{ Watts} \\
R2 &= 1 \text{ Volt} \times .0051 \text{ Amps} = .0051 \text{ Watts} \\
R3 &= 10.3 \text{ Volts} \times .001 \text{ Amps} = .0103 \text{ Watts} \\
R4 &= 1.7 \text{ Volts} \times .0009 \text{ Amps} = .00153 \text{ Watts} \\
\end{align*} \]

The preceding calculations indicate that 1/4 watt, 5\% resistors are adequate for this design.

Although our preceding circuit does have substantial gain, lets design a second stage to the previous circuit to further increase gain. Before we can begin our design we must make those all important design decisions again as indicated below:

\[ \begin{align*}
Q1 &= 2N3904 \\
Vcc &= 12V \\
Ic &= 10ma \\
hfe &= 50 \\
\end{align*} \]
Vr2 = 1V (8% of Vcc)
Ir4 = 9 times Ib

Now we're ready to calculate our resistor values as follows:

\[
R1 = \frac{6}{.010} = 600
\]
\[
Ib = \frac{.01}{50} = .0002
\]
\[
R2 = \frac{1}{(Ic + Ib)} = \frac{1}{(.01 + .0002)} = 98
\]
\[
Ir4 = 9 \times .0002 = .0018
\]
\[
R4 = \frac{(1 + .7)}{.0018} = 944
\]
\[
R3 = \frac{(12 - 1 - .7)}{(.0018 + .0002)} = 10.3 / .002 = 5150
\]

We will select standard resistor values as follows:

R1 = 560
R2 = 100
R3 = 5.1K
R4 = 1K

The circuit at right is the result of our design efforts. 10uF capacitors were used for output coupling and optional emitter bypass. Slightly larger or smaller capacitor values could also be used satisfactorily. As always, the emitter bypass capacitor should only be used when the maximum amount of gain is desired without regard to a predictable level of gain.

Now let's add the two transistor stages together to get the resulting circuit below.

Because of the large amount of gain obtained with this circuit, we added a 10K variable resistor at the output as a gain control. This circuit will provide good results for almost any microphone pre-amplifier application. Incidentally, we can substitute a 2N2222A, 2N4401 or any general purpose NPN with a minimum hfe of 50 for the 2N3904 transistor used in this design example. There are many general purpose NPN transistors that can be easily used in this circuit with good results.

Perhaps a good exercise for the designer is to recalculate all of the above resistor values using a Vcc
of 9 volts which will allow the use of a 9 volt battery.

Now that we got our hands wet designing these circuits, let’s summarize what we’ve learned below:

\[ \begin{align*}
V_{cc} & = \text{Supply Voltage} \\
hfe & = \text{Absolute minimum current gain for the selected transistor} \\
I_c & = \text{Selected collector current} \\
I_b & = \frac{I_c}{hfe} \text{ (base current)} \\
V_{r1} & = \frac{1}{2} V_{cc} \\
V_{r2} & = 5 \text{ to } 10\% \text{ of } V_{cc} \\
V_{r3} & = V_{cc} - .7 - V_{r2} \\
V_{r4} & = .7 + V_{r2} \\
I_{r4} & = 5 \text{ to } 10 \text{ times } I_b \\
R_1 & = \frac{1}{2} V_{cc} / I_c \\
R_2 & = \frac{V_{r2}}{(I_c + I_b)} \\
R_3 & = \frac{(V_{cc} - .7 - V_{r2})}{(I_{r4} + I_b)} \\
R_4 & = \frac{(.7 + V_{r2})}{I_{r4}}
\end{align*} \]

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