PHYS341 Design Experiment
AM Radio

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Abstract

The design task was to build an AM radio out of discrete components. This task was divided into five sections. In order, these are the emitter follower, common base, rectifier circuit, Op-amp circuit and power amplifier. The emitter follower acts as a current buffer with it's high input and low output impedance. This is then connected to a common base amplifier, giving a total voltage gain of approximately 1000. This is then connected to a rectifier and low-apss filter which separates the carrier and the data signals. The sound waves are then passed through a op amp, which amplifies the signal so it able to be heard. The final stage of the circuit is a power amp that gives enough power to drive the speaker.

I have tested each section of the circuit individually when constructing the radio, making sure that each works the way it should. However, when putting the circuit together as a whole, no sound is heard. This could be a wide range of things, which is detailed in the Problems section.

Introduction

The radio was built in five sections, each performing one task to enable to whole system to function. The demodulator, or 'tuning circuit' was given to us as plug-in. This consisted of an inductor and a variable resistor that actually tuned in to the radio frequencies. The antenna was attached to this. This then connected to the emitter follower (or common collector). This boosts the current of the input signal, while giving no voltage gain. This sets the impedance of the circuit, as the impedances between the components must match, otherwise each section forms a voltage divider. Therefore, the output impedance of the emitter follower must be the same as the input impedance of the common base amplifier. The common base amplifier has a voltage gain of about 1000. Now with both the current and voltage increased, the signal was passed through a rectifier and low-pass filter circuit. This separated the actual data signal, from the carrier signal. This consisted of a capacitor and resistor in series. The values of these were chosen so as to make the time constant between the period of the AM radio signal and the spoken voice. The voice signal is then amplified by an op amp with a gain of about 10. This gives the signal enough amplification so it can be hard out of the speaker. The last stage is a Power amp, which increases the current, so the speakers can be driven.

Description of Design Task

The overall block diagram of the radio is shown below. All the parts were constructed and tested individually before incorporating it into the rest of the circuit.

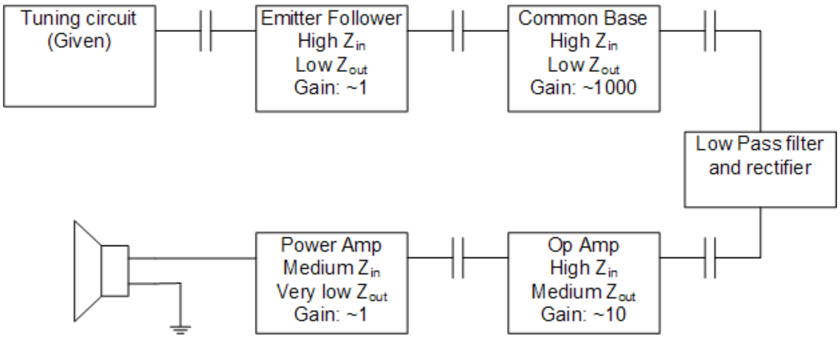

Figure 1: Block Diagram of the radio

The emitter follower (or common collector) was designed so as to have an input impedance of about $100k\Omega$ and an output impedance of less than $1k\Omega$ and a bandwidth of 500kHz to 1.6MHz. The advantage of an emitter follower is that it has a low output resistance and high input resistance, which means that it has a large current gain. Once the current is increased, the voltage can next be increased in the next stage. The larger input signal is neded beause the rectification and low-pass filter stage attenuate the signal. For the details of how the emitter follower was biased, see the appendices. The next stage was the common base, which acted as an RF amplifier. As the current was now at a suitable level, the voltage could not be amplified. The desired gain was about 1000, without the transistor going into saturation. The main characteristics of the common base are a very low input resistance, relatively high input resistance and a large gain. The circuit diagram of the emitter follower and common base are shown below.

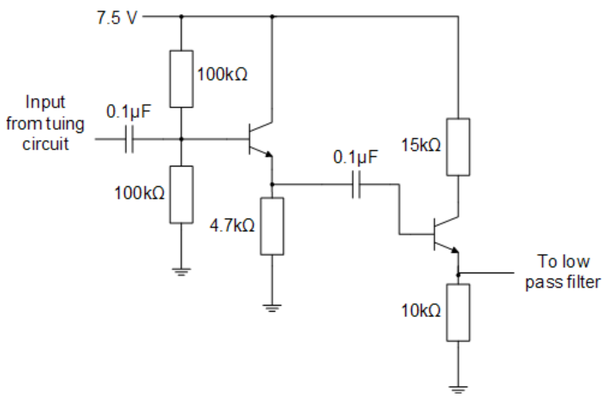

Figure 2: Emitter Follower and Common Base Configuration

The signal then went through a rectifier and a low-pass filter. The rectifier blocked the negative part of the incoming sinusoidal wave, and the low-pass filter separated the signal from the carrier wave, only allowing the voice signal to pass through. The values of the resistor and capacitor had to be chosen carefully to ensure they allowed the AM band (500kHz to 1.6MHz) was not passed through, but the voice (20Hz to 20kHz) was. The components formed a RC circuit with a time constant τ = RC. See the appendices for details. The configuration is shown below.

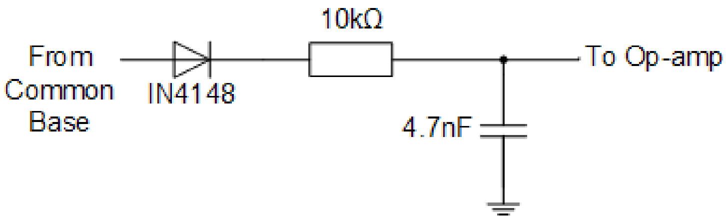

Figure 3: Rectifier and Low-Pass Filter Configuration

The voice signal was then amplified by an Op amp. This was to have a gain of about 10, a high input imepdance and a medium output impedance. The op-amp was biased in such a way to try to achieve all these. It is a very simple configuration that is very similar to one used in the lab experiments. Even though the 741 is an inferior product it was used because it is cheap and the application it is needed for is not 'mission-critical'. The last resistor (that goes to ground) can be replaced with a variable resistor. This will affect the amount of gain of the Op-amp and thus can be used as a volume control.
The configuration is shown below.

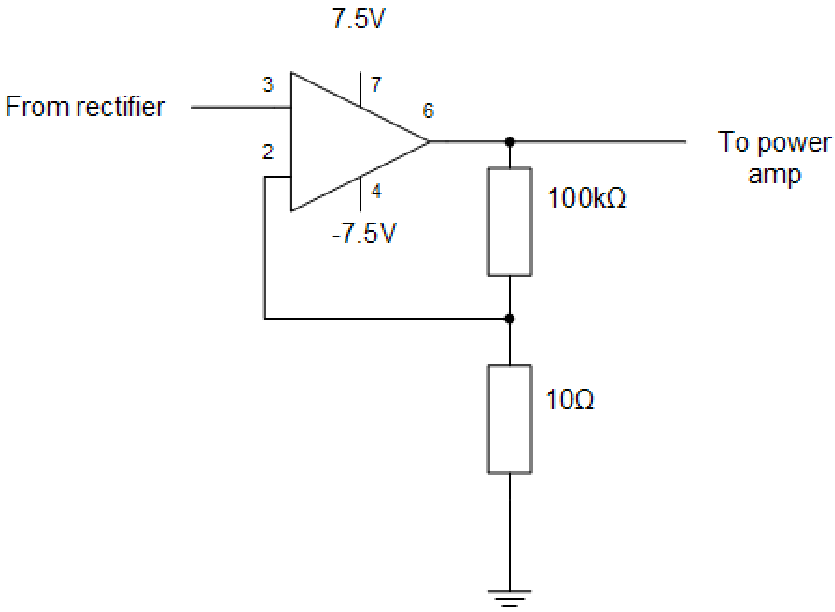

Figure 4: Operational Amplifier Configuration

The last stage of the radio is to give the signal the power it needs to drive the speaker. As the output impedance of the Op-amp is quite high, not much current can be supplied. This means that it can't drive the speaker directly. Thus a power amplifier is needed to increase the current. I chose a Class AB amplifier because it has less cross-over distortion and is much more efficient than a Class A amplifier. The Class AB amplifier is a composite of the Class A and Class B stages. In Class A, two equavalent BJTs are biased in sucha way that the input signal never causes the collector current to reach zero. The advantage f this is that the transistor is always conducting so it can respond quickly to changes in the input. The disadvantage is that because the BJTs are always conduction it makes it very inefficient. This configuration can be modified into a Class B amplifier by biasing the BJT such that the collector current is non-zero only during the positive or negative half cycle of the signal. The advantage of this is that it is more power efficient but is not usable for audio signals. The Class AB takes the best of both A and B by biasing a pnp and npn BJT such that it conducts for all of the positive half cycle plus a little of the negative. This means that is is very efficientand the BJT always is conducting. If the input increases slightly, the npn starts to turn on, whereas the pnp starts to turn off. Biasing the transisitors this way removes the dead band and crossover diestortion. This makes it that natural choce for audio applications. The configuration is shown below.

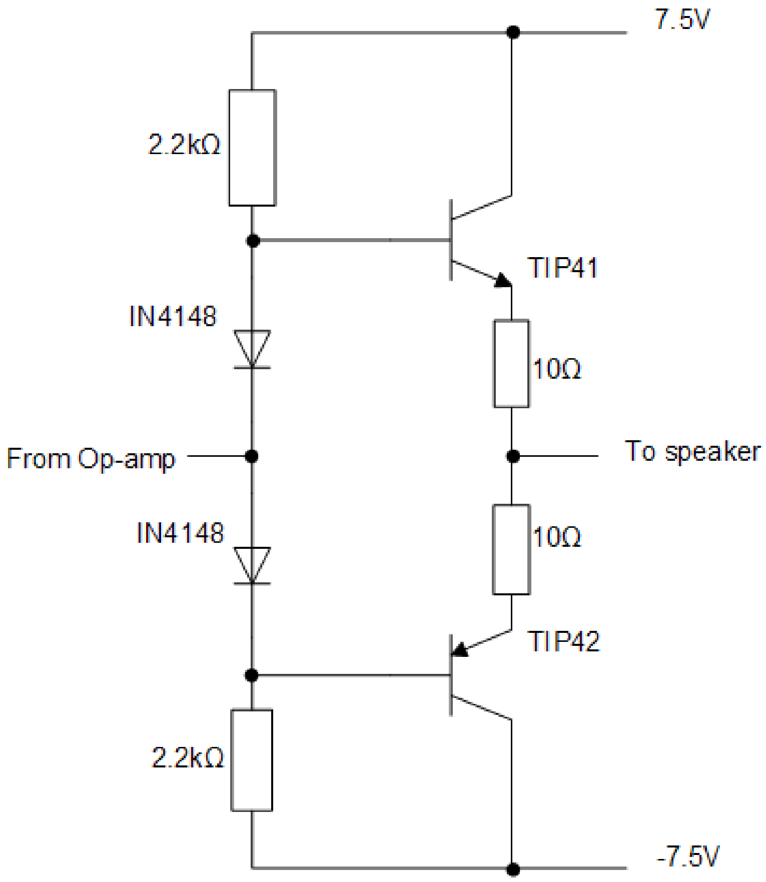

Figure 5: Power Amplifier Configuration

Performance, Problems and Improvements

The the biggest problem is that the radio doesn't actually work. This could be caused by many things, but I suspect that it is caused by the impedance not being matched between the Op-amp and the power amplifier. With the oscilloscope (and the help of Peter Coard), I can see that there is an RF signal at the output, but it is very noisy. This is probably caused by the impedance between stages not matching. I have tried to modify the input and output impedances, but to no avail.

Each component is working correctly in isolation. The gain of the emitter follower is almost exactly one, and as shown in the appendices the output impedance is 440Ω and an input impedance of $270k\Omega$. This is quite low, meaning that the output current is quite high. The common base amplifier is also doing it's job correctly. When a sinusoidal wave of a few tens of millivolts is fed into the emitter follower, the output of the common base is about a few volts, thus giving an amplification of a about a thousand. The output at this stage is almost a perfect sine wave. The input impedance was discovered to be 800Ω and the output impedance was $9k\Omega$. The input impedance is too low and the output impedance is toohigh. This could be contriruting to the radio not working.

The signal then passes through a diode and a low-pass filter. At the output of the diode, only the positive component is then filtered. The time constant was set by the product of the capacitance and resistance of the circuit. This part also works correctly in isolation.

The op-amp was tested and found to have a gain of about 10. The input impedance is and the output impedance is. When a signal from the signal generator is applied, the output is approximately ten times larger, and is a true sign wave with no distortion.

The power amp increases the current so as to drive the speakers. This was tested by measuring the current flowing into and out of the amplifier. The input impedance was found to be 9Ω, and the output impedance was 318Ω. The voltage gain of the device was approximately one. The very low input impedance could also attribute to the radio not working. This means that is was drawing too much current from the Op-amp stage. The output impedance however was at a quite an acceptable level.

One improvement that could be made is the inclusion of a variable resistor to work as a volume control. This would involve replacing the 10Ω resistor with a 10Ω 'turn-pot' resistor. This would modify the gain, thus modify the speaker volume.

Cost Estimate

This is a rough estimate of the cost of resources and time. It is assumed it would be made on a printed circuit board with a case.

- IC's $\times$ 3 = \$6
- Capacitors $\times$ 4 = \$2
- Power transistors $\times$ 4 = \$2
- PCB $\times$ 1 = \$200
- Case $\times$ 1 = \$100
- Labour: \$40/hr $\times$ 18 = \$720

  Grand Total: \$1030

Appendices

Biasing the Emitter Follower

Calculate V_E

$$\begin{aligned} V_E &= \frac{1}{2} \times V_{CC} \\ &= \frac{1}{2} \times 7.5V \\ &= 3.75V \end{aligned}$$

Choose R_E

$$V_E = 7.5k\Omega$$

Calculate R_1 and R_2

$$\begin{aligned} V_B &= V_E + 0.7V \\ &= 4.35V \end{aligned}$$

So, the ratio of R_1 to R_2 is 1:1.17
$\therefore$ $R_1 = 120k\Omega$ and $R_2 = 150k\Omega$

Calculate Z_{in} and Z_{out}

$$Z_{out} = \frac{R_{out}//R_E + R_{in}}{\beta + 1}$$

$$\begin{aligned} V_E &= V_{CC} - V_{CB} \\ &= 7.5V - 0.7V \\ &= 6.8V \end{aligned}$$

$$\begin{aligned} I_E &= \frac{V_E}{R_E} \\ &= \frac{6.8V}{7.5k\Omega} \\ &\approx 9mA \end{aligned}$$

$$
\begin{aligned}
R_o &= \frac{V_A}{I_C} \\
&= \frac{3.75V}{9mA} \\
&= 416\Omega
\end{aligned}
$$

$$
\begin{aligned}
R_o &= \frac{V_{BE}}{I_E} \\
&= \frac{0.7V}{9mA} \\
&= 77.8\Omega
\end{aligned}
$$

$$
\begin{aligned}
\frac{R_{in}}{\beta + 1} &= 13k\Omega \\
&= \frac{13k\Omega}{406 + 1} \\
&= 31.9\Omega
\end{aligned}
$$

$$
\begin{aligned}
\therefore \; R_{out} &= 416//(77.8 + 31.9) \\
&= 416//\frac{1}{\frac{1}{77.8} + \frac{1}{31.9}} \\
&= 440\Omega
\end{aligned}
$$

As the input resistance is simply the two input resistors in series,

$$
\begin{aligned}
R_{in} &= 150k\Omega + 120k\Omega \\
&= 270k\Omega
\end{aligned}
$$

Biasing the Common Base

Calculate R_E

We want $I_C \approx 0.5mA$

$$
\begin{aligned}
\therefore R_E &= \frac{V_{CC} + V_{CE}}{I_C} \\
&= \frac{7.5V + 0.6V}{0.5mA} \\
&= \frac{6.9V}{0.5mA} \\
&= 14k\Omega
\end{aligned}
$$

Calculate R_C

We also want $V_o \approx 3V$

$$\begin{aligned}
\therefore R_C &= \frac{V_{CC} - V_o}{I_C} \\
&= \frac{7.5V - 3V}{0.5mA} \\
&= \frac{4.5V}{0.5mA} \\
&= 9k\Omega
\end{aligned}$$

Rectifier

The rectifier circuit forms an RC circuit with time constant τ = RC. This time must be short compared to the period of AM radio frequency band (500kHz to 1.6MHz), but long compared to human speech (20Hz to 20kHz).

Thus:
AM Radio: 500kHz to 1.6MHz
Period: 2μs to 0.67μs

Human Speech: 20Hz to 20kHz
Period: 50ms to 50μs

$\therefore$ we want:

$$\begin{aligned}
\tau &= R \times C \\
&= 1k\Omega \times 4.7nF \\
&\approx 5ms
\end{aligned}$$

Gives a time between the ranges, and a frequency of about 200kHz.

Full circuit diagram

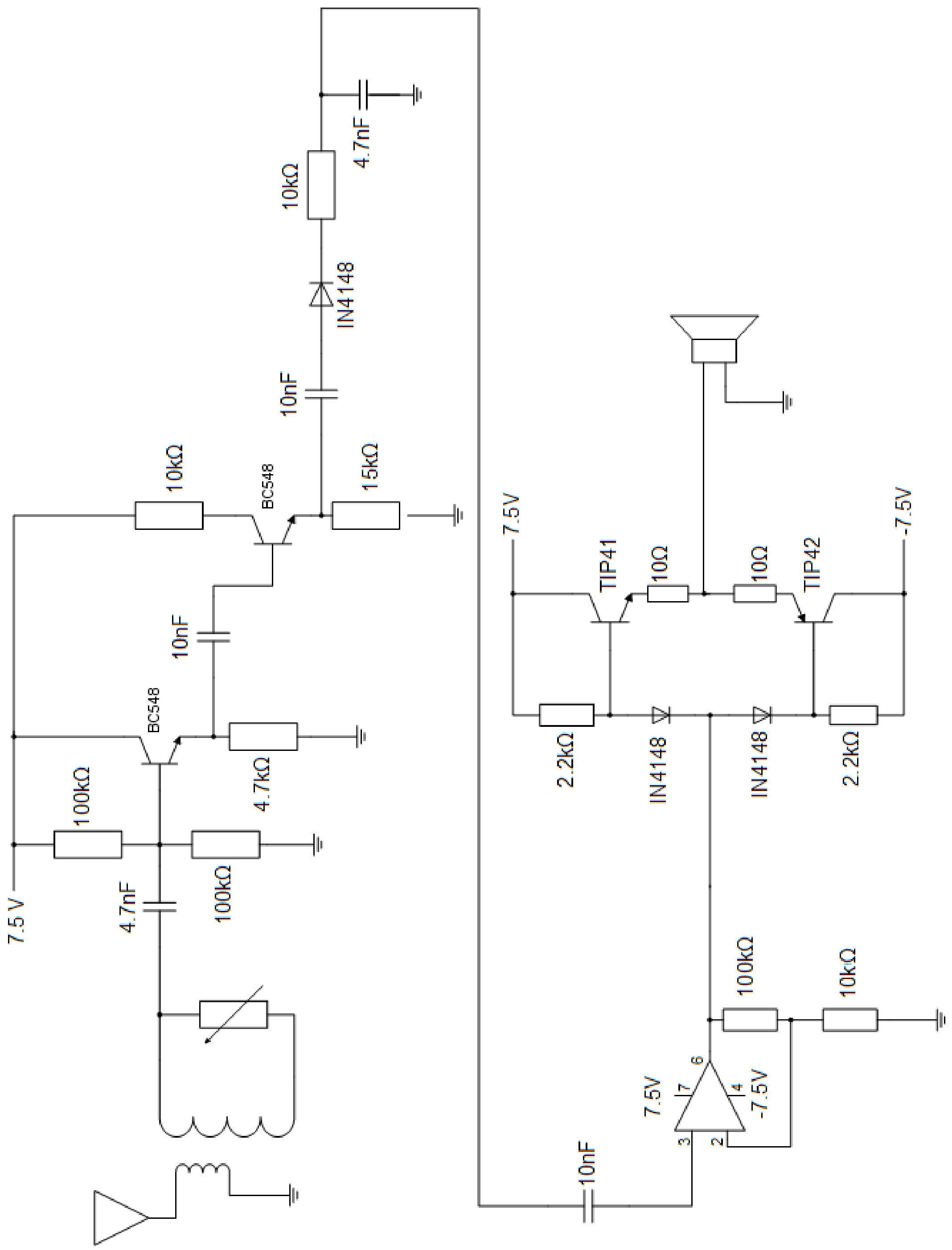

Figure 6: Full Circuit Diagram of the radio