Integrated Electrical Project Report

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23-03-2017

1 Overview

The radio circuit was broken down into 4 sequentially connected modules (described briefly below):

1. **Tuner -** parallel resonant circuit with a variable capacitor
2. **Radio Frequency Amplifier -** dual capacitor circuit wired for high input impedance used to amplify signal ready for demodulation
3. **Demodulator -** circuit centred around schottky diode designed to separate the audio frequency modulating signal from teh radio frequency carrier signal
4. **Audio Frequency Amplifier -** dual op-amp circuit designed to amplify power to suitable level for loudspeaker

The completed circuit performed well on testing, successfully being able to pick up all three radio stations and play the signal at high volume and fairly decent fidelity.

The single most important change to the circuit would be the inclusion of a properly made antenna, which would greatly increase the volume and quality of the output.

2 Design

2.1 Tuner

The design of the tuner was fairly straightforward given the radio specification. This demanded a frequency range of 972-1422 kHz. The basic tuner circuit is shown in figure 1. It takes advantage of the resonant properties of an inductor and capacitor in parallel.

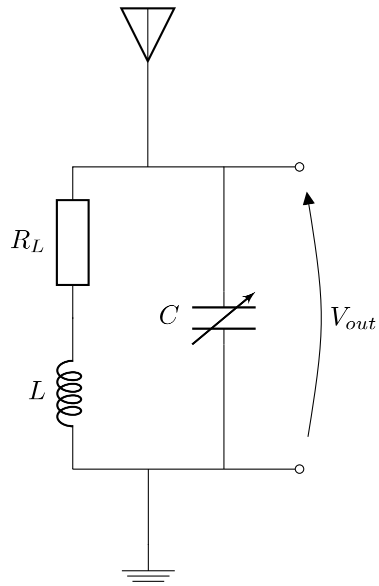

Figure 1: Resonant filter

The resistor R_L merely denotes the d.c resistance of the inductor itself. We had a limited choice of capacitor and opted for the smallest valued air-spaced capacitor with a nominal maximum capacitance of 320 pF. In reality from testing and by hooking it up to the breadboard we found the real capacitance to vary between $43\,pF < C < 374\,pF$.

Knowing the range of capacitance and frequencies to be tuned to it is easy to calculate an upper and lower bound for the value of the inductance. The equation for resonance is given in equation 1.

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

By substituting in values for maximum capacitance and minimum frequency and vice-versa it was found that L needed to be in the range $72-292\mu H$. In the end an inductor of inductance $L = 124\,\mu H$ and d.c resistance $R_L = 0.4\,\Omega$ was constructed by winding wire around a plastic sheath and inserting a ferrite core.

2.2 RF amplifier

This was perhaps the most complicated part of the circuit design. The goal was to amplify the signal received from the tuner circuit to a level that was suitable for the demodulator circuit (roughly 1V peak-to-peak). In order to achieve this the amplifier was broken down into two stages.

Unity gain source follower - this presents a high input impedance to the tuner circuit.

Common source amplifier - this is a versatile amplification circuit for high frequency a.c. signals.

Furthermore, to eliminate d.c. offset errors each stage of the circuit had to be linked to the next through a suitable de-coupling capacitor that would de-couple the a.c. signal from the d.c. component. The majority of the design work was done through intuition followed by LTspice simulation[1] and the complete circuit is provided in figure 2.

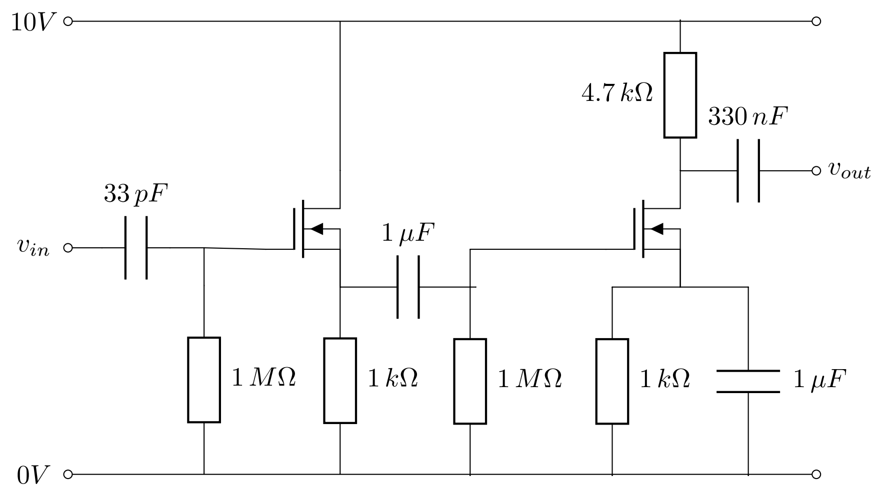

Figure 2: RF amplifier circuit

The left-hand of the circuit is the unity-gain buffer, while the right-hand side transistor circuit is what is actually amplifying the signal.

2.3 Demodulator

The demodulator is one of the most important part of any radio circuit as it extracts the audio frequency modulating signal from the radio frequency carrier signal. It is not necessary to go through the mathematics in detail. In summary, the demodulator works by passing the radio signal through a diode and a low-pass filter; this extracts the information signal from the carrier. The completed

[1] Please refer to the appendix 6.1 for these

circuit is shown in figure 3.

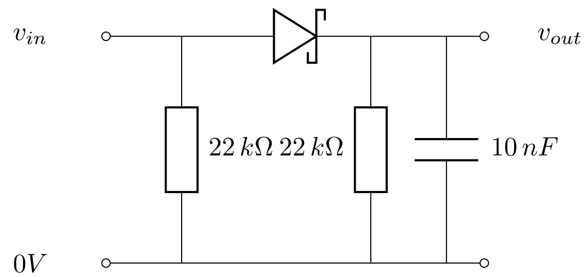

Figure 3: Demodulator Circuit

The resistor and capacitor values were chosen based on the specification that the lowest frequency in the carrier signal was 972 kHz and the highest frequency audio signal was 8 kHz. Please note that in this case the de-coupling capacitors have been omitted from input and output.

Furthermore, the output impedance of the previous stage was calculated based on the small signal model to be in the order of 5 $k\Omega$. This informed the choice of resistor value.

2.4 Audio amplifier

Due to impedance matching problems it was decided to include a buffer circuit based on the 741 op-amp in between the demodulator and audio amplifier circuits. This would present a high input impedance to the demodulator output. The circuit for this is shown in figure 4. It did not require many calculations, just a general intuition.

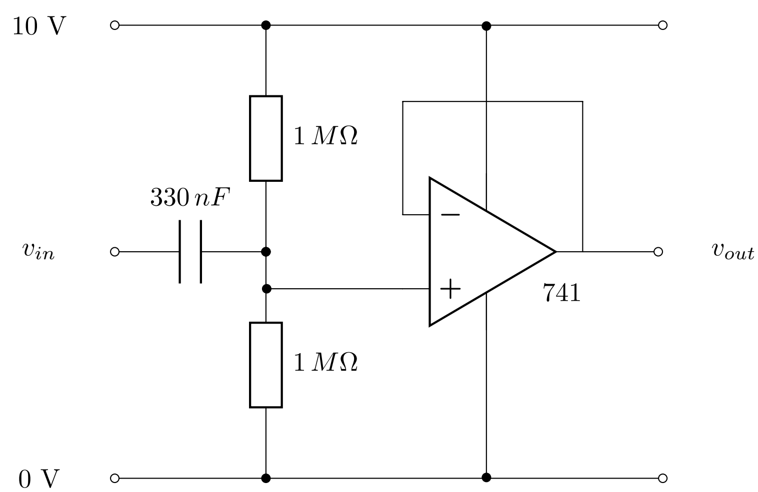

Figure 4: Buffer circuit

The actual amplification circuit was given to us and repeated in figure 5. The purpose of the potentiometer is as a volume control. Furthermore, the additional current path at the output is to provide a bypass for high frequencies, which may break the loudspeaker.

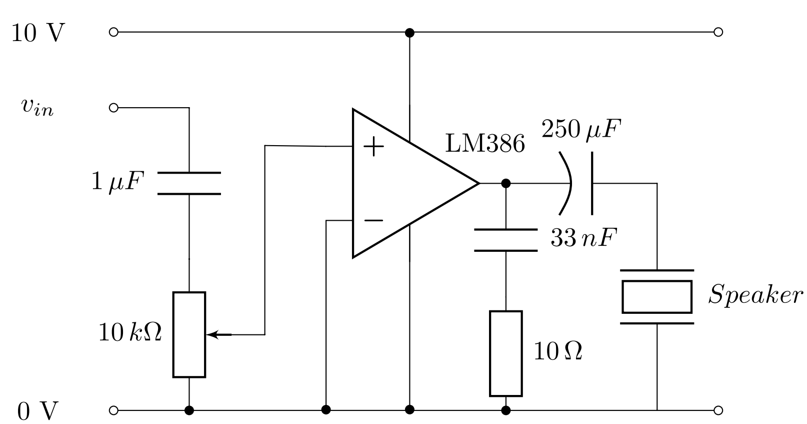

Figure 5: Audio amplifier

2.5 Design modifications

It was found that when the LM386 op-amp was powered on and on its maximum gain setting, there would be unstable oscillations in the power rails. This led to nonsensical static being sent to the loudspeaker. To circumvent the issue a very large coupling capacitor (1 mF) was placed across the power rails in order to smooth the supply. It is unclear why the power supply did not already have this smoothing in place, but the capacitor worked as expected.

2.6 Complete circuit diagram

Figure 6 is a hand-drawn complete circuit diagram.

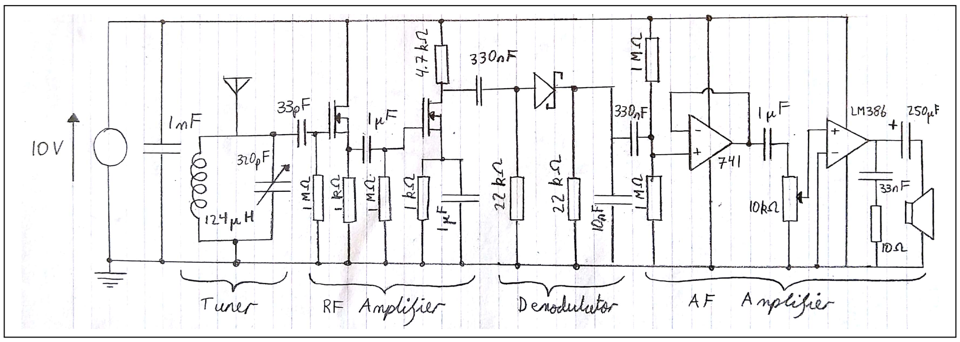

Figure 6: Complete circuit diagram

3 Build

It was decided to build the circuit from left-to-right using only the top half of the breadboard. The different modules were pieced in sequentially, once the proper functioning of the previous and current modules had been assured. The top and middle rails were used for +10V and 0V respectively, this allowed for a very neat and tidy breadboard, with easier to spot wiring problems. The completed breadboard is shown in figure 7.

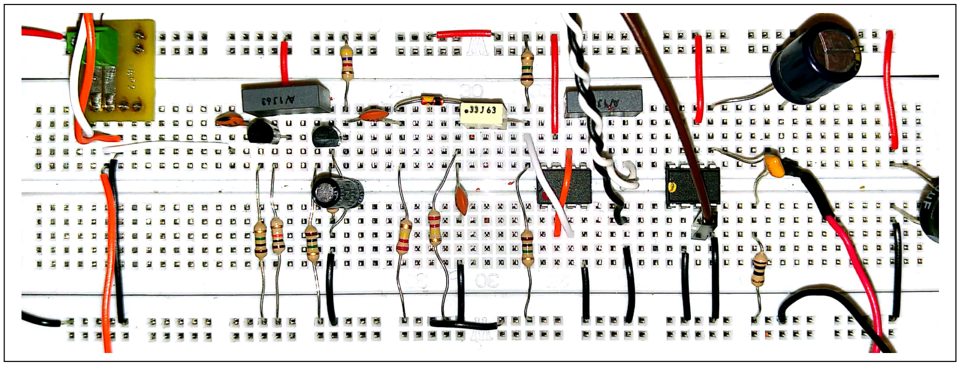

Figure 7: Breadboard layout

4 Testing

4.1 Tuner

The circuit was able to tune to all frequencies within the specified range and achieved a Q-factor of 123.5 at its lowest tunable frequency (741 kHz) and one of 60.9 at its highest tunable frequency (1950 kHz). The Q-factor is reduced at higher frequencies due to power losses in the ferrite core and the skin effect increasing the d.c resistance of the inductor.

4.2 RF Amplifier

By testing this circuit using the signal generator at 1 MHz, we noted the gain of the amplifier to be in the order of 7, which was satisfactory.

4.3 Demodulator

It is hard to provide quantitative results for the testing of this module. However, given that the output signal was recognisable music it must have performed its task satisfactorily.

4.4 Audio Amplifier

The gain of this module was observed to be in the order of 20, which provided a suitably high power output to the loudspeaker.

5 Conclusions

End Result We successfully managed to build a fully-functioning radio. We saw first hand how the theory covered in lectures applied to real life. Time management was very good as we finished with about 4 hours to spare. Nevertheless, there was much potential for improvement in both sound quality and volume.

Improvements The quality of the radio was very good but not incredible, this suggests that either the Q-factor of the tuner circuit was not high enough or there was some distortion of the signal. The former is unlikely to be the culprit as the Q-factor was in the order of 100. The latter is therefore most probable. From testing it appeared that this distortion was occurring in the demodulator circuit. This is because the output of the RF amplifier did not have a sufficiently high peak-to-peak voltage and so the imperfections in the schottky diode were felt (the fact it requires a small forward bias voltage). There are two ways to increase the amplitude of the signal:

1. **Additional amplification stages -** this is the most obvious solution. However, it may potentially introduce additional distortion. Indeed, it was attempted to put in an extra common source amplifier circuit for increased gain but this yielded a hugely distorted output.

2. **A good antenna -** both the volume and quality of the output signal was greatly increased by the use of one of the power wires as a makeshift antenna. With a professionally-made antenna, the amplitude of the signal output from the tuner circuit would be hugely increased and consequently the input to the demodulator.

Therefore, the second option is the easiest way to increase the volume and quality of the radio circuit.

6 Appendix

6.1 LTspice Simulations

This section contains all the LTspice simulations for the design of the rf amplifier.

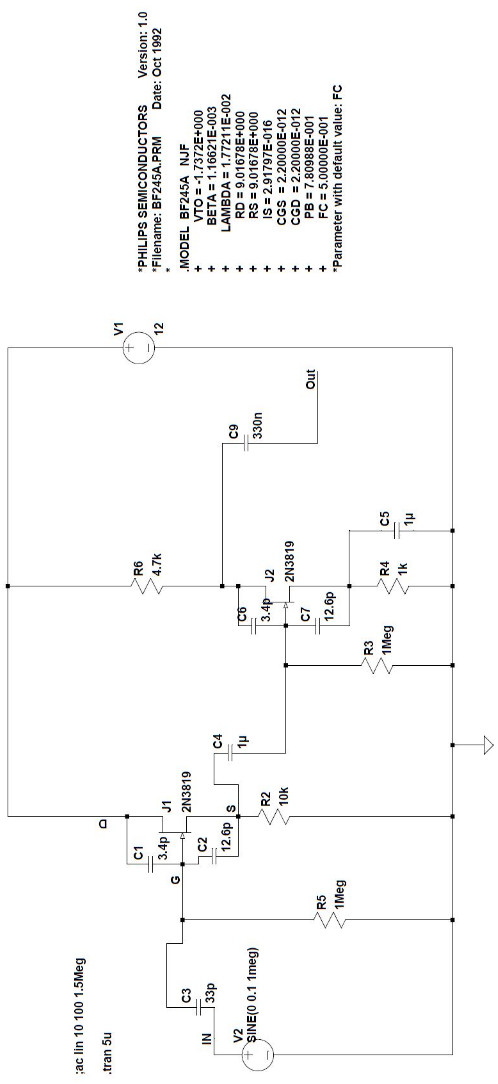

Figure 8: RF amplifier LTspice schematic

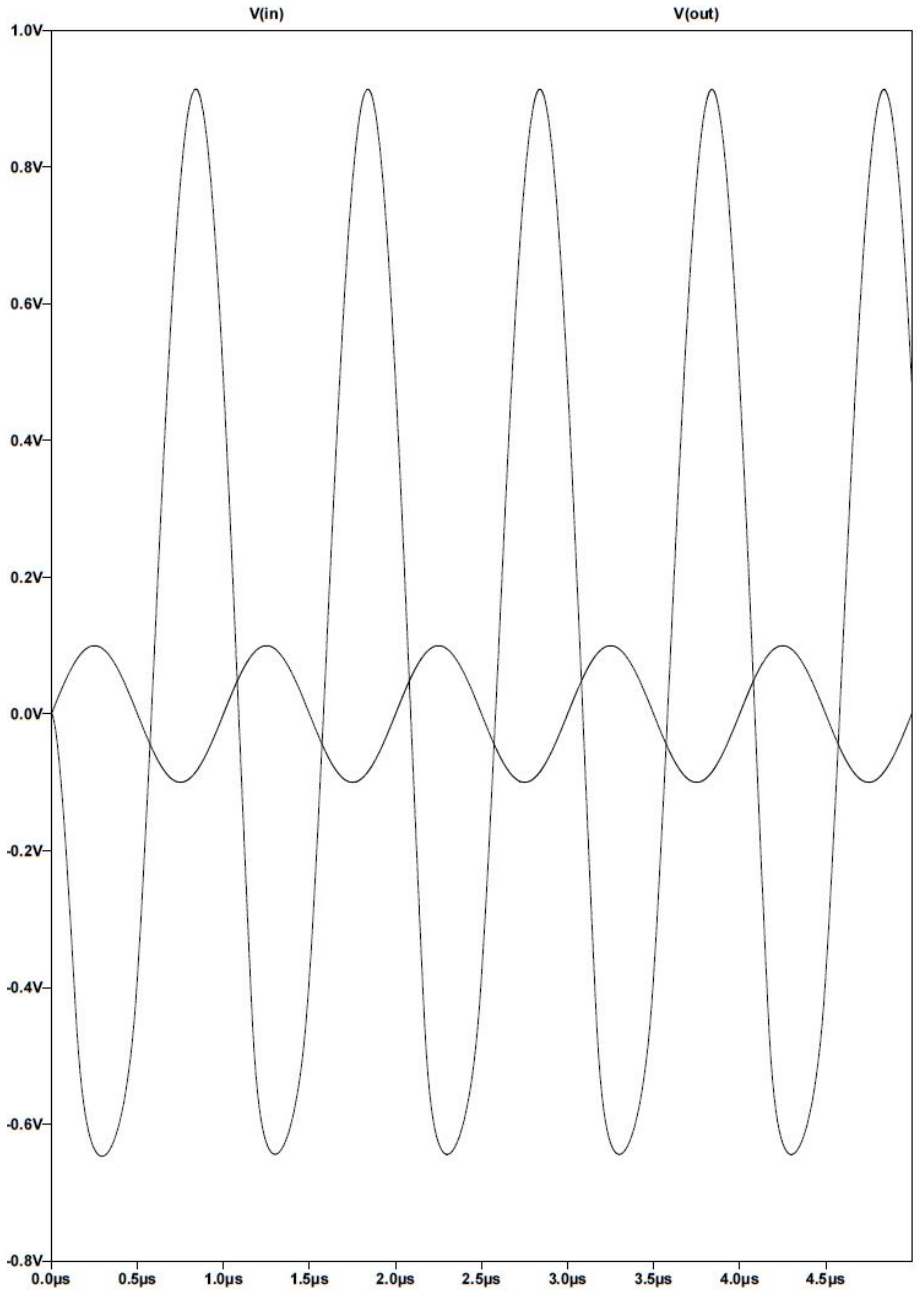

Figure 9: Simulation output