PHY405 Lab P

FM Transmitter Circuit

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Abstract

The aim of this project was to create a circuit that takes an audio signal as an input and transmits the signal as an FM signal detectable by a radio. This lab report describes the construction and operation of the FM transmitter circuit based on a tutorial from circuitdigest.com [1]. The circuit consists of a microphone, audio amplifier, oscillator, frequency modulator, and antenna, and is powered by a 9V battery. The key components and their functions are explained, and the testing procedure involves using an FM radio to check for successful transmission.

The report concludes that the circuit successfully transmits audio wirelessly over a range of frequencies via a simple wire antenna, with the transmitter and radio being 5 metres apart. The audio was transmitted successfully one time, but it was difficult to replicate the transmission a second time. Possible sources of error are discussed such as testing flaws and environmental factors. The circuit described in the lab report has the potential for applications in wireless audio transmission systems, such as wireless microphones, or other short-range communication systems that use FM modulation.

The Circuit

Our circuit is based on a basic FM transmitter circuit tutorial from circuitdigest.com [1].

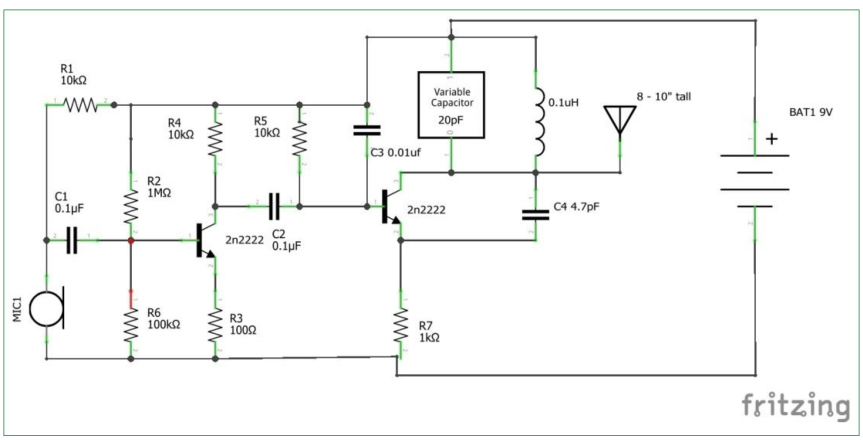

Figure 1: The circuit diagram that was followed, from the source mentioned above [1].

Wiring and Colour Scheme

- Yellow: internal connections
- Black: connections to -V line
- Red: connections to +V line
- Orange: output to antenna
- Green: output to oscilloscope

Components Used

The list of components below was taken from the tutorial [1].

- 2n2222 Transistor x2
- Electret condenser microphone x1
- 100 nF Ceramic capacitor x1
- 10 nF ceramic capacitor x1
- 4 pF ceramic capacitor x1
- 100 ohms resistor x1
- 10 k resistor x 3
- 1 k resistor x 1
- 100 k resistor x1
- 1 M resistor x1
- Variable Capacitor 6 - 30 pF x1
- 22 Gauge copper wire
- 9v battery x1
- 9v battery cap x1
- Jumper cables
- Breadboard

Using the components above, and following the circuit diagram, we built our FM transmitter circuit.

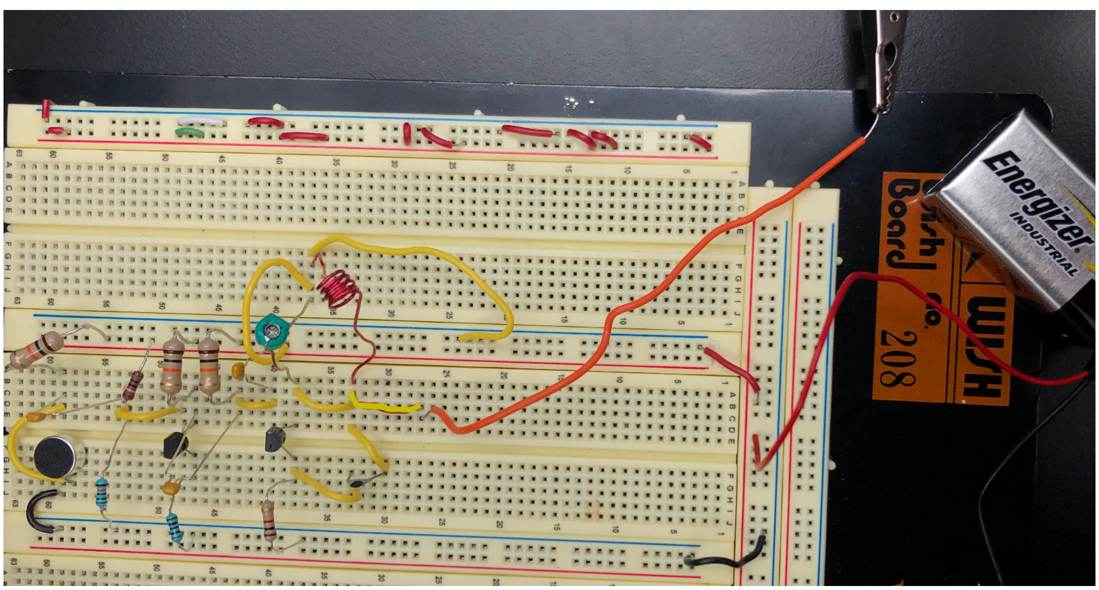

Figure 2: Our FM transmitter circuit

Note that this image is slightly edited by colouring one of the wires so that it follows the colouring scheme.

Basic Theory of the Circuit

An FM (Frequency Modulation) transmitter works by modulating the frequency of a carrier signal with the audio signal being transmitted. This modulation causes the frequency of the carrier signal to vary in proportion to the amplitude of the audio signal, allowing the audio signal to be transmitted wirelessly over a range of frequencies. Some of the key components involved in an FM transmitter include a microphone, audio amplifier, oscillator, frequency modulator, and antenna.

Microphone:

This is the input device that converts sound waves into an electrical signal. For our circuit, an electret condenser microphone was used.

Audio Amplifier:

This amplifies the audio signal from the microphone to a level suitable for modulation. The audio amplifier in our circuit is based on a single 2n2222 transistor. When an audio signal is applied to the input of the amplifier (in this case, the electret condenser microphone), it modulates the bias voltage applied to the base of the transistor, causing the transistor to amplify the signal. The amplified signal is then passed to the frequency modulator.

The 2n2222 transistor is used in a common-emitter configuration [2], with the microphone connected to the base of the transistor, a bias voltage applied to the emitter, and the amplified signal taken from the collector.

Oscillator:

This generates the carrier signal at a specific frequency. The oscillator in our circuit is an LC oscillator consisting of a variable capacitor and an inductor made by coiling 22 gauge copper wire. The oscillator is used to generate a carrier signal at a specific frequency. The frequency of the oscillator is determined by the values of the capacitor and inductor, and can be adjusted by varying the capacitance of the variable capacitor. The frequency of the LC oscillator can be calculated by $f = \frac{1}{2\pi\sqrt{LC}}$.

Frequency Modulator:

This is the component that actually modulates the frequency of the carrier signal with the audio signal. The frequency modulator in our circuit is also based on a single 2n2222 transistor. The modulator works by varying the resonant frequency of the LC circuit, which is used to generate the carrier signal for the transmitter. The audio signal from the amplifier is used to modulate the capacitance of the LC circuit, causing the resonant frequency to vary in response to the audio signal.

The frequency modulator transistor in our circuit is connected in a common-emitter configuration [2], where the amplified audio signal is fed to the base of the transistor through a coupling capacitor. The collector of the transistor is connected to the variable capacitor in the LC oscillator, while the emitter is connected to the inductor and the antenna through a coupling capacitor.

When the audio signal is applied to the base of the frequency modulator transistor, it modulates the collector current, causing variations in the voltage across the variable capacitor in the oscillator circuit. These voltage variations change the capacitance of the capacitor, which in turn changes the resonant frequency of the oscillator circuit. The resulting frequency variations in the oscillator circuit are then amplified and transmitted through the antenna.

The coupling capacitor between the emitter of the frequency modulator transistor and the inductor of the oscillator is used to isolate the DC bias of the transistor from the oscillator circuit. This capacitor allows the audio signal to pass through while blocking any DC voltage from the transistor. Similarly, the (same) coupling capacitor between the emitter of the transistor and the antenna is used to block any DC voltage and to allow only the modulated radio-frequency signal to pass through to the antenna for transmission.

Antenna:

The antenna in our circuit is a simple wire antenna consisting of a long banana cable taped to a piece of wood to keep it straight. The antenna is used to transmit the modulated signal wirelessly. When the modulated signal is applied to the antenna, it radiates the signal out into space as an electromagnetic wave.

Overall, these components work together to create an FM transmitter that takes an audio signal from an electret condenser microphone, amplifies it, modulates it onto a carrier signal generated by an LC oscillator, and transmits it wirelessly via a simple wire antenna. The circuit is powered by a 9V battery.

Testing Procedures and Data Analysis

An FM radio was used to test the FM transmitter. The frequency created by the LC oscillator was too high to be measured by the oscilloscopes in the lab, and the inductance of the coiled inductor we created was too low to be measured by any of the multimeters. Thus, we were left to check if the FM transmitter works for any capacitance value in the trimmer capacitor's range. We varied the trimmer capacitor very slightly, and for each time the capacitance was varied, the radio's (FM receiver) frequency was varied throughout the entire FM frequency range (88 MHz to 108 MHz) to detect if any audio was being transmitted by our circuit and being received by the radio.

Results:

For some capacitance value as one of us was speaking into the microphone and the other was tuning the radio, the radio detected the speech from the FM transmitter at around 108 MHz. In hopes of receiving a clearer signal, the radio was adjusted some more. After adjusting the radio slightly, the signal was lost before we could get a recording. The transmitter and radio were about 5 metres apart.

Testing:

In order to detect the signal again, the following idea was proposed:

Since a signal was detected, there are five possible cases for how the FM transmitter's frequency range overlaps with the FM receiver's frequency range. Figure 3 can be used to visualise these five cases. In the figure, for each case, the top set of brackets represents the frequency range produced by the LC oscillator (by adjusting the trim cap) and the bottom set of brackets represents the frequency range of the FM receiver (radio). The vertical line "|" represents the frequency on the receiver at which the signal was detected. In our case, the "|" is at the upper bound of the receiver's range since the signal was detected at around 108 MHz. Note that the sizes of these sets of brackets relative to one another is not meant to represent the true relative sizes of the frequency ranges.

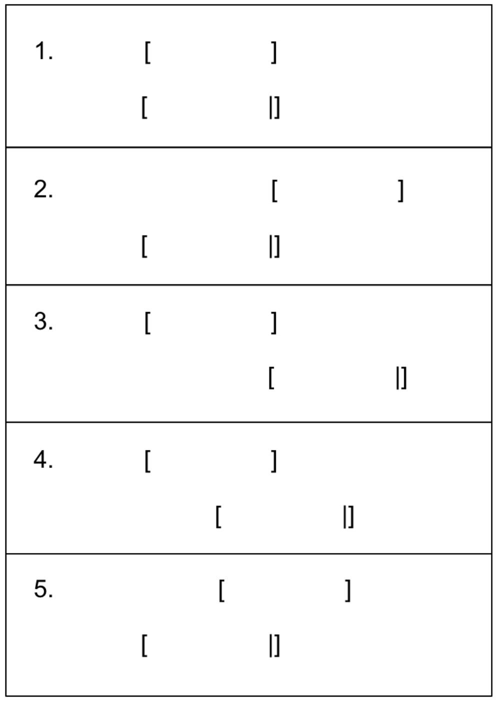

Figure 3: Visual aid for our testing scheme

Case 3 and 4 can be ruled out since the LC frequency range does not overlap with the upper bound of the FM receiver's frequency range.

To test out case 1, the case where the upper bounds for both ranges line up, we set the trim cap at its minimum capacitance and thus setting the oscillator's frequency to its upper limit (since the frequency is inversely proportional to the square root of the capacitance). When setting at this capacitance, we went through the entire FM receiver's frequency range and no signal was detected. Thus, we ruled out case 1.

To test whether either of the cases 2 or 5 hold true, we set the trim cap to the maximum capacitance and thus set the oscillator to the minimum frequency. Even in this case, no signal was detected by the receiver.

Since none of the above cases held true even though the signal was initially detected, something must have changed within the circuit or radio to change our results. See the 'Sources of Error' section below for possible explanations.

This testing was done on another day, in the lab. When the signal was first detected, the tuning and measurements were done at home and not in the lab. This will be important when evaluating the sources of errors (see section 'Sources of Error').

Correctness of Circuit:

Since this project is based on a circuit that is proven to work (see the video within the tutorial source [1]), our circuit should be correct. In addition, the theory behind the different parts of the FM transistor (see section 'Basic Theory of the Circuit') is common to many different FM transmitter circuits.

Every capacitor and resistor was measured and confirmed to be the expected values (considering the tolerances), and the battery was measured to have a voltage difference of 9.2 V.

To test the electret microphone, the following circuit was used:

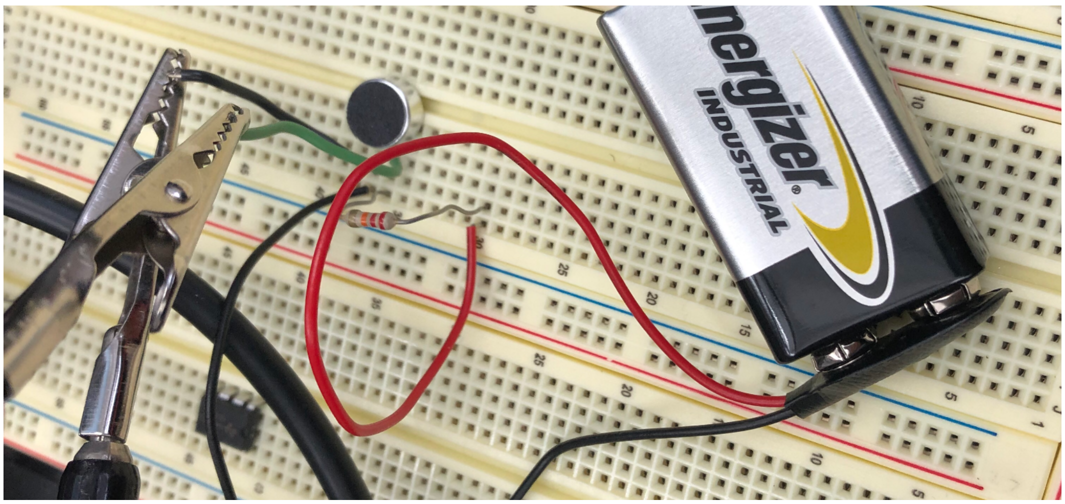

Figure 4: Circuit for testing electret microphone, with a 22 k resistor

The output signal from the microphone detected on the oscilloscope responded to claps near the microphone. Thus, the microphone was confirmed to be working.

Sources of Error:

Considering the fact that the circuit was working at some point, there could be several reasons why it failed to work again.

After revisiting our testing scheme, we realised that it is possible for case 2 to be false while case 5 could possibly hold true. This can happen if the LC oscillator's frequency range is greater than the FM receiver's frequency range. Then it would be possible that both the upper bound and lower bound of the LC oscillator's frequency range do not fall within the FM receiver's frequency range.

The true minimum and maximum capacitance for the trimmer capacitor, as measured on a multimeter, was 15 pF and 45 pF respectively. For the above issue to be true, we would need $f_{min} = 1/2\pi\sqrt{L \cdot 45 \cdot 10^{-12}} < 88\ MHz$ which give us $L > 0.0727\ \mu H$ and we need $f_{max} = 1/2\pi\sqrt{L \cdot 15 \cdot 10^{-12}} > 108\ MHz$ which gives us $L < 0.145\ \mu H$. If our coiled inductor was built correctly, this case is definitely possible since the expected $L = 0.1\ \mu H$ falls within this range. Thus, one possible reason why the signal was not detected a second time is that our testing scheme was flawed.

Aside from the flawed testing, there are three other possible reasons why the circuit worked the first time and did not the second time.

Component ageing: Transistors, resistors, and other electronic components can degrade over time or with use, which can affect their performance. It is possible that one or more components in our circuit degraded or changed between the first and second tests, causing the circuit to fail. One example could be the coiled inductor which could have changed shape as it was carried to the lab from home.

Environmental factors: Interference from other electronic devices or electromagnetic fields in the environment can affect the performance of the circuit. It is possible that the first test was conducted in a relatively interference-free environment, while the second test was conducted in an environment with more interference. This could make sense since the first test was done at home with little possible source of interference while the second test was done in the lab surrounded by many other circuits and electronics.

Device precision: It can be difficult to tune the radio to an exact frequency, especially if the tuning knob is not finely calibrated, and the same applies to adjusting the trimmer capacitor to an exact capacitance. As a result, it is possible that the first test happened to have the radio and the trimmer capacitor tuned to ideal frequencies that matched perfectly, and it was difficult to replicate those exact values again during the second test. Repeating the test multiple times and taking multiple readings may help to determine whether the circuit is consistently working or not, and may help to account for any slight variations in device precision.

Conclusion

In conclusion, the FM transmitter circuit described in this lab report successfully transmitted audio wirelessly over a short distance, demonstrating its potential for use in wireless audio transmission systems or other short-range communication systems that use FM modulation. While the circuit was successful in transmitting audio once, replication of the transmission was difficult due to possible testing flaws, environmental factors, and other sources of error. Further experimentation and optimization may be necessary to improve the reliability and consistency of the circuit's performance.

References

1. https://circuitdigest.com/electronic-circuits/how-to-build-fm-transmitter-circuit
2. https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/transistors/bipolarjunctiontransistor/commonemitterconfiguration.html