Analog Miniature RF Walkie-Talkies

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Despite the increased use of digital devices, walkie-talkies are often used for rapid multi-way communication without requiring the presence of cell towers, in contexts ranging from recreational sports to emergency management. However, walkie-talkies haven't gone through many dramatic changes appearance-wise since it was invented, and their design has stayed clunky and outdated for many years. Understanding the components of a transceiver and how it is built would allow us to customize the shape of the classic walkie-talkie, and by minimizing the size of our circuit, we can design more discreet devices for low-resource communication. Our goal is to design an analog transceiver for short-range radio communication in the VHF (radio-frequency) band, which is in the band used by other amateur radio operators.

Our device will consist of two parts: a transmitter and a receiver. The transmitter will convert audio into frequencies in the VHF band and the receiver will be fine-tuned to demodulate signals from this band and reconvert the frequency back into audio. We will be testing our low-power device by transmitting to and receiving from a handheld transceiver belonging to a licensed member of our group.

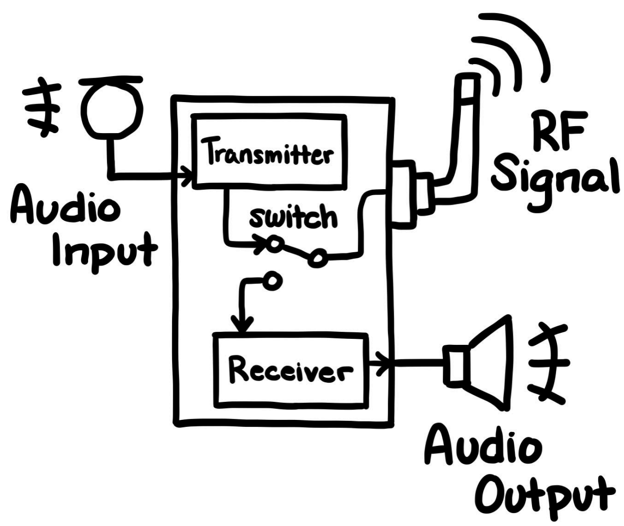

Figure 1. Diagram of a transceiver, composed of a transmitter and receiver. The transmitter takes audio input from a microphone and transmits its output as a radio frequency (RF) signal through the antenna and the receiver takes the RF signals from the antenna to convert to an audio output played by the speaker. These are two circuits within a single device that uses a switch to change states (Receiving Mode and Transmitting Mode).

Receiver

A receiver takes radio frequencies (RF) from a specific frequency band received by an RF antenna to analyze and decode into audio. Though we could produce a superheterodyne receiver for greater distance and frequency ranges, we instead opted for a simplified version of this circuit by creating a directly demodulated receiver. *Figure 2* depicts a block diagram of this simplified receiver, which consists of a filter, amplifiers, and a demodulator. At a high level, the RF filter and amplifier extracts the desired signal from all the radio signals received by the antenna, which is then demodulated to retrieve our audio signal and amplified as it is sent to the speaker. These components are discussed more thoroughly in the next sections.

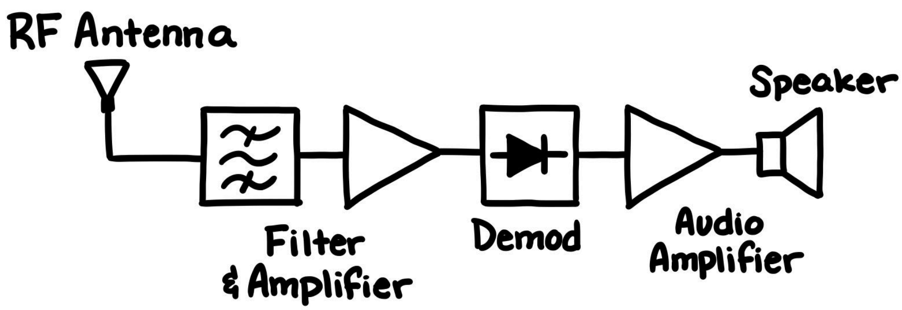

Figure 2. Block diagram of a receiver, consisting of filters, amplifiers, and a demodulator. The RF antenna sends RF signals through to the input of the circuit. This signal is then filtered and amplified based on the desired frequency band (144-148 MHz), then demodulated and amplified before its output is sent to the speaker.

Transmitter

A transmitter takes audio input and converts it into frequencies in the VHF band for the receiver to detect and demodulate. It does this by passing the audio signal recorded by the microphone through a series of filters, amplifiers, and modulators and converting it into an RF signal at the same frequency bandwidth the receiver filters audio from. Similar to the receiver, we plan to use a simpler configuration, which does not require a mixer or intermediate frequencies. The signal is amplified and sent straight to the modulator to be modulated with the local oscillator as the carrier frequency. *Figure 3* depicts a block diagram of this simplified transmitter. Audio signal from the microphone is amplified and subsequently modulated with the local oscillator (LO) through the modulator to be released into the air by the RF antenna.

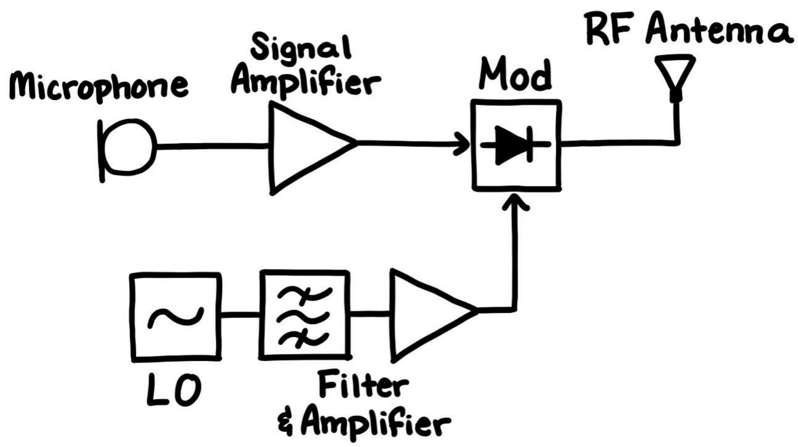

Figure 3. Block diagram of a transmitter, consisting of filters, amplifiers, a modulator, and a local oscillator. The microphone sends an audio input to the circuit, which is then amplified and sent to the modulator along with a filtered and amplified local oscillator signal to be modulated. The resulting signal is sent to the RF antenna to be released into the air.

Amplifier

Amplifiers are used in various locations throughout the circuit, as the signals we use very often have low amplitudes that require amplification. Although some can be combined using active components, in which amplification is built into the circuitry itself, our circuit also requires a few standalone amplifiers to prepare our signals, either for modulation or outputting on a speaker. A familiar, simple circuit learned in class is the non-inverting amplifier, which only uses a single op-amp, and two resistors to amplify its input signal.

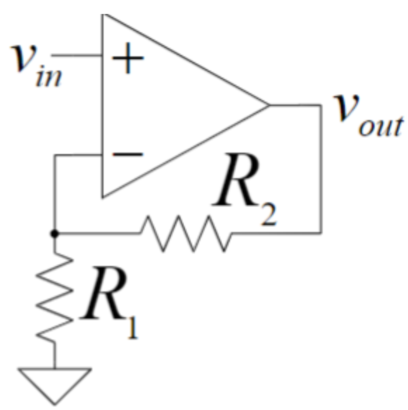

Figure 4. Non-inverting Amplifier from Lecture 9. The op-amp takes an input at its non-inverting terminal and uses a feedback loop connecting the output to the inverting terminal and ground using resistors to amplify the input voltage.

Active Filter

For the receiver, a filter and amplifier takes radio frequencies (RF) detected by the RF antenna, filters the appropriate signal at the frequency and bandwidth transmitted by the transmitter, and amplifies this signal for the rest of the circuit to analyze and decode into audio [1]. The transmitter also uses a filter and amplifier to enhance and amplify the desired output signal from the local oscillator before passing it through to the modulator.

In both cases, the filter rejects frequencies outside the desired bandwidth, and is therefore effectively a bandpass filter, which only allows a select frequency range to pass through the circuit. Bandpass filters and amplifiers have been discussed and built thoroughly throughout the semester in labs, however developing a filter and amplifier would require more fine-tuning at the correct frequencies. An active bandpass filter can be built with capacitors, resistors, and a single op-amp, which can be used as both our filter and amplifier, as shown in *Figure 4*. We aim to transmit and receive frequencies in the 144-148 Hz band, therefore this filter should ensure that only these frequencies pass through our circuit.

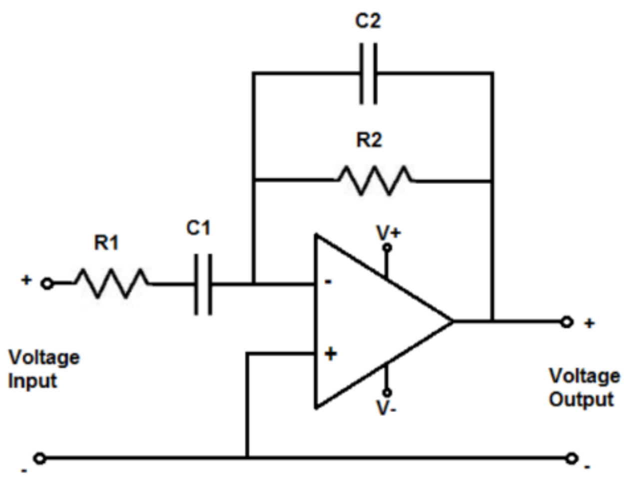

Figure 5. Bandpass filter using op-amps [2]. An RC circuit is used in series and in parallel to an op-amp in order to form a bandpass filter that takes in a voltage input of noisy signals and outputs only the signals within the desired frequency range.

Local Oscillator

The local oscillator (LO) performs an upconversion when it is mixed with the audio input in the modulator. Since we are operating at a singular fixed frequency without a VFO, we aim to use a crystal oscillator for its stability and frequency customization. While we originally planned to use a Colpitts crystal oscillator, as it is one of the most common crystal oscillator circuits for our purposes, we opted for an overtone crystal oscillator, shown in *Figure 5* to be able to multiply the frequency of a lower value crystal [5][7]. For example, a 16 MHz crystal multiplied by 9 would land us at 144 MHz, exactly in the

VHF band. We would then filter out other overtone frequencies with a bandpass filter. Note that the local oscillator must be turned off when in the Receiver state and shielded to prevent extraneous transmission of random signals into the air.

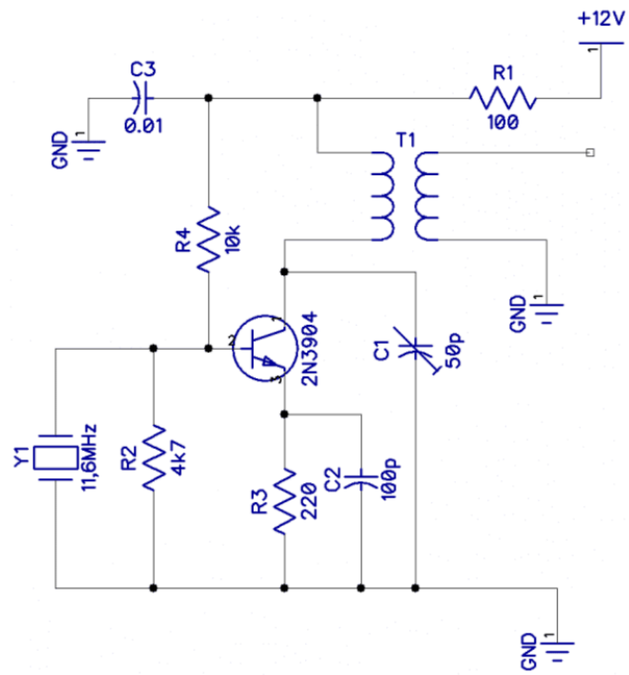

Figure 6. Overtone Crystal Oscillator [7]. This circuit creates a sinusoidal oscillating signal using a crystal oscillator and multiplies its original frequency using a transformer, which allows us to use smaller crystal oscillator values. Current values displayed are intended for a resulting signal frequency of 144MHz.

Modulator/Demodulator

The modulator is used to encode a signal using another frequency and to help the receiver better identify which signal to take and decode [3]. A demodulator is then used to decode the signal back into its original audio to be played. The transmitter uses a modulator to modulate the audio signal using the local oscillator as its carrier frequency and turn them into an RF signal, and the receiver demodulates this signal after it passes through the rest of the circuit and reconverts it back into the original audio.

Since we are using amplitude modulation (AM), we can use a simple Envelope Detector, like the one built in Lab 1 Experiment 3 as shown in *Figure 7a*, for our demodulator. This circuit requires very few components (one diode, one capacitor, one resistor), which allows for greater optimization of space. The modulator is more complicated, as it requires modulating two different signals. The simplest circuit for AM modulation is a single diode modulator, as shown in *Figure 7b*. It uses a single diode to modulate the two frequencies and an inductor (or an LC tank if we would like finer tuning) to drive the signal [4].

The impedance of the inductor should be negligible to the modulating frequency so that it passes through to ground but high for the carrier frequency such that its modulated output gets passed to the rest of the circuit.

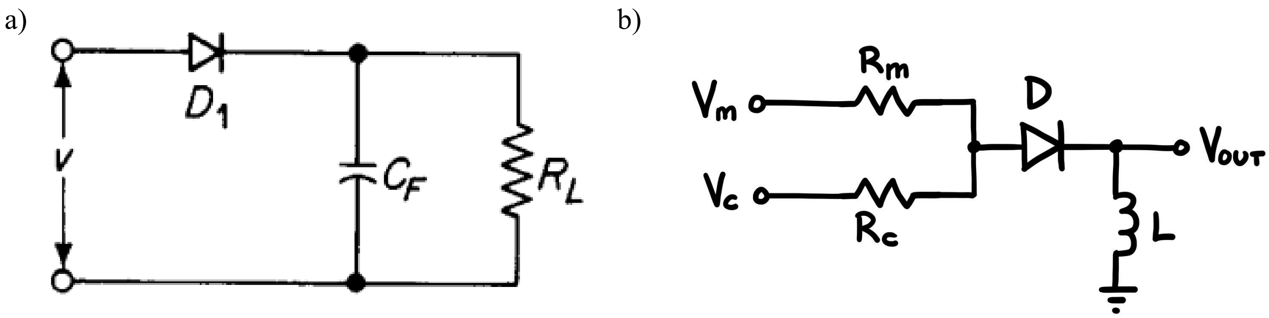

Figure 7. (a) Envelope Detector for AM demodulation from Lab 1 Experiment 3 and (b) a single diode modulator for AM modulation [4]. Circuit (a) performs an AM demodulation on the input signal using an RC circuit and a single diode, as the diode gives the signal a DC voltage shift while the RC circuit smooths it out. Circuit (b) takes two inputs, a modulating signal and a carrier signal, and uses a diode and inductor (which may be replaced by an LC tank) to modulate the amplitude of the carrier by the modulating signal's frequency.

Additional Components

If we have time, we would like to also test other components to further improve our circuit. For example, superheterodyne transceivers feed RF and local oscillator signals to a mixer, which returns an intermediate frequency (IF) that subtracts or adds the two frequencies at the output. Though this may be excessive for our purposes, it may still help to further explore this type of circuit. A Gilbert cell mixer, shown in *Figure 6*, commonly used in ICs for radio receivers may be something to try, as it is.

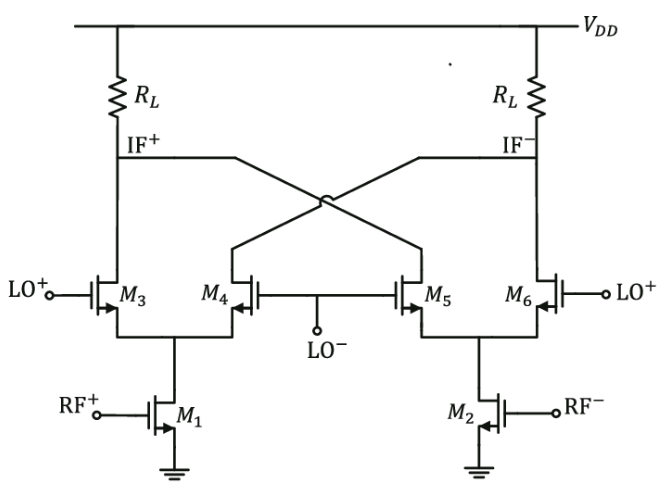

Figure 8. Gilbert Cell Mixer [2]. This circuit is commonly used for radios and transceivers as it performs well in isolating the radio frequency (RF), local oscillator (LO), and intermediate frequency (IF) signals as it mixes. The mixer can output the original inputs, the sum of the inputs, or the difference of the inputs. The difference of the RF and LO would be useful for a receiver, and the sum of the IF and LO would be useful for a transmitter.

PCB and Hardware Design

Due to the need for fine tuning of our bandwidth and frequencies, testing our circuits with breadboards is unlikely to work. Therefore, we plan to use a printed circuit board (PCB) (short traces, via stitching, etc) to minimize parasitic capacitance and optimize the size of the device to be as small as possible. However, since it is not feasible to design and build multiple PCBs throughout the project, we will instead attempt dead bug testing or directly soldering components together.

Additionally, due to the customizability of our circuit and PCB, we may create additional hardware components to improve the design and look of our device, such as the addition of a wristband or a custom case for the walkie-talkie.

Purchase List

To successfully build our circuit, the following items should be purchased to begin testing our proposed circuits:

- 446MHz Crystal Oscillator
- Surface mount and through hole Inductors
- Surface mount resistors and capacitors
- Solder-on SMA connectors
- 12V battery
- Op-Amps (NE5532 Dual Low Noise Op-Amp)
- NPN BJTs (2N3904, 2N4265)
- Diode (1N4148)
- VHF Monopole Radio Antenna
- Transformer (Amidon T-50_6 type with 15 turns)

Division of Work and Timeline

The following table showcases the planned division of work and timeline among the team. Since the transmitter and receiver consists of similar components (amplifier, active filter, local oscillator, modulator/demodulator), each member will research, design and test the different blocks using LTSpice and lab material by Week 2. Then, as a team, we will combine the components to design a working receiver and transmitter by Week 3, and build a PCB (and other hardware components) by Week 4.

Week	Aimee Liu	Anika Huang
Week 1 (4/15)	Design: Modulator/Demodulator	Design: Local Oscillator
Week 2 (4/22)	Design: Amplifier & Active Filter	Design: Local Oscillator
Week 3 (4/29)	Synthesize Components: Create a Receiver and Transmitter	
Week 4 (5/6)	Design and Build a PCB (+ other components)	

References

[1]https://www.rfwireless-world.com/Terminology/RF-vs-IF.html#:~:text=The%20incoming%20RF%20signal%20is%20mixed%20with%20a,enhance%20the%20desired%20signal%20and%20reject%20unwanted%20frequencies.

[2]https://www.learningaboutelectronics.com/Articles/Active-op-amp-bandpass-filter-circuit.php

[3]https://www.etechnog.com/2019/05/best-application-and-advantages-of.html

[4]https://www.ee-diary.com/2023/03/different-types-of-am-modulator-and.html

[5]https://www.electronics-tutorials.ws/oscillator/crystal.html

[6]https://www.researchgate.net/publication/333988417_Linearity_improvement_in_a_CMOS_down-conversion_active_mixer_for_WLAN_applications?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoiX2RpcmVjdCJ9fQ

[7]https://www.circuitbasics.com/crystal-oscillators/