AM Radio Transmitter: A Gilbert Cell, an Operational Amplifier, and an Antenna

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Abstract

This application note described the creation and successful use of an AM radio transmitter circuit. It uses a gilbert cell and a differential amplifier to generate and transmit AM radio waves. The circuit was successful in its simulation and in its prototyping. However, the completed project has a large room for improvement.

Background

The radio is a century old invention that allows for wireless communication by using radio waves. There are two types of waves, amplitude modulation (AM) and frequency modulation (FM). The difference between the two is how the sound information is carried. In the AM band, this is done by varying the amplitude of the signal while in the FM band it is done by varying the frequency of the signal. For this project, we will be focusing on the AM band.

There are numerous ways to create a radio transmitter. The one used for this project is a heterodyne transmitter shown in figure 1. A heterodyne is a signal that gets created when mixing two frequencies together. The full circuit includes a low-pass filter (LPF), two amplifiers, the mixer, a bandpass filter (BPF) and an antenna.

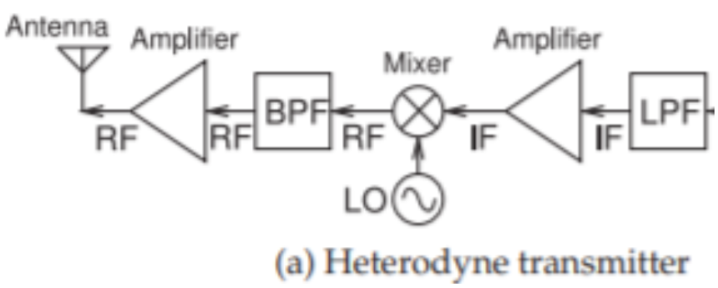

Figure 1. Heterodyne Transmitter Circuit

For the mixer, we created a circuit called a Gilbert Cell. A Gilbert Cell will create output signals that are proportional to the product of two input signals, which is a different way of saying that it will mix them together. It uses resistors, transistors, and capacitors to create this affect as shown in figure 2. The transfer function of a Gilbert cell is as shown in equation 2

$$V_{out} = S(\omega t) * B(\omega t) \tag{1}$$

Where:

B is the baseband carrier signal
S is the modulating frequency

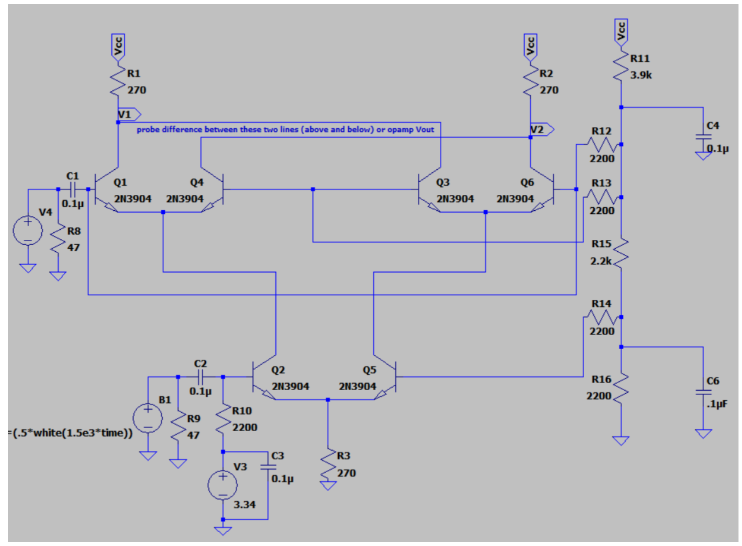

Figure 2. Gilbert Cell Schematic

For the amplifier circuit, we used a differential operational amplifier topology. In figure 3, R6 and R7 were the same value, and R4 and R5 were the same value to simplify the equation for the gain. This is shown in equation 2.

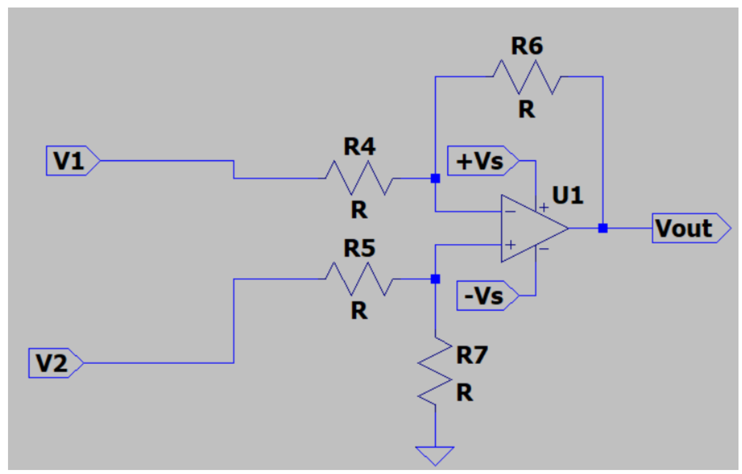

Figure 3. Differential Amplifier Schematic

$$V_{out} = (R_3/R_1)(V_2 - V_1) \tag{2}$$

Design Constraints

This circuit could be constructed with ease if the world had unlimited resources and each piece was ideal. However, the world is not ideal, so there are constraints that had to be followed when creating this system. First, the system had to be run off of 12VDC or less for safety reasons. Second, it had to have an array of electronic components, specifically modern ones. Third, it had to be low power. Fourth, it had to have a mixed signal/embedded element. Overall, the system had to be edited and unique to fit within these specifications.

One way we fit these constraints is by using an MSP430FR2355 Launch Pad from TI (figure 4). This embedded system would allow us to easily adjust the modulating signal of the AM wave. We used it to specifically make 10 different musical notes that could be played at the touch of a button.

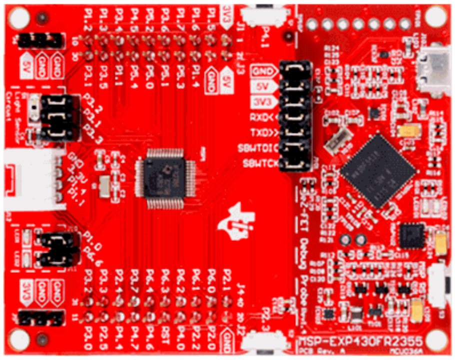

Figure 4. MSP430FR2355 Launchpad

Approach

The first step of this experiment was to simulate the circuits. It is essential to make sure that the theory works. We did this using the program LTSPICE. We created schematics of each component of the transmitter to ensure that we would be able to get the output signals we expected. This also allowed us to vary any values to see what could be changed in our designs if issues arise later in the process.

The second step is to prototype. We used both bread boards and protoboards to recreate the circuits in real life. Utilizing an oscilloscope, function generator, and power supply we tried to see if the LTSPICE results could be recreated.

The third step was to take any successes from the prototype and redraw the schematic. If there were issues found or improvements that could be made, we made the changes and then re-drew the schematics to make sure the changes were reflected there. With this new schematic, we created a printed circuit board (PCB) that networked all the needed components of the system.

The last step was to build and test the PCB. After creating the PCB schematic using a software named Altium, we sent out files to a PCB manufacturer. Once the PCB was received we could then solder all the components onto the PCB. After soldering was completed the radio was ready for final testing.

Results

The results of the LTSPICE simulation are shown in figures 5, 6, and 7. The green and blue plots are the outputs of the gilbert cell circuit. They form a nice radio wave as expected. The red plot is the output of the differential amplifier. It is what is the final signal that would be transmitted to radio receivers.

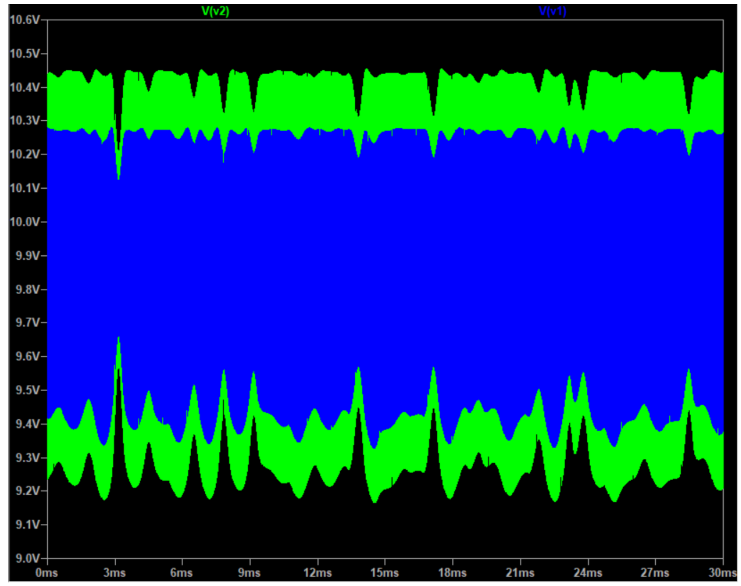

Figure 5. LTSPICE output of gilbert cell circuit

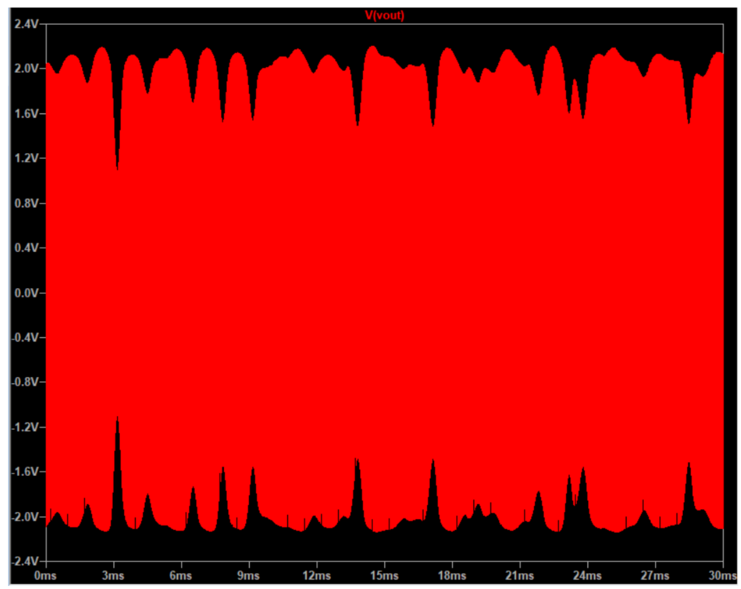

Figure 6. LTSPICE output of differential amplifier

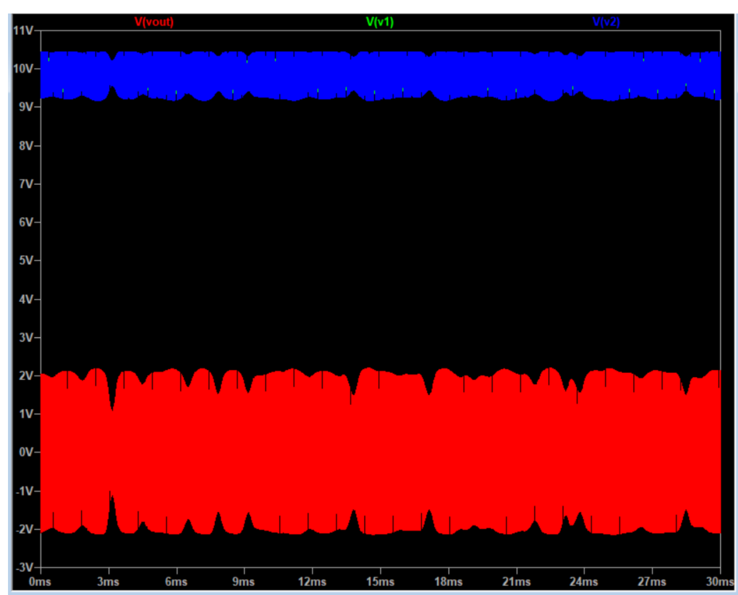

Figure 7. Combined LTSPICE output

Results from the breadboard prototype of the gilbert cell circuit are shown in figure 8. This also is the expected result. It gives a waveform that is characteristic of AM radio waves. The results from the differential amplifier were not pictured, but they were as expected too.

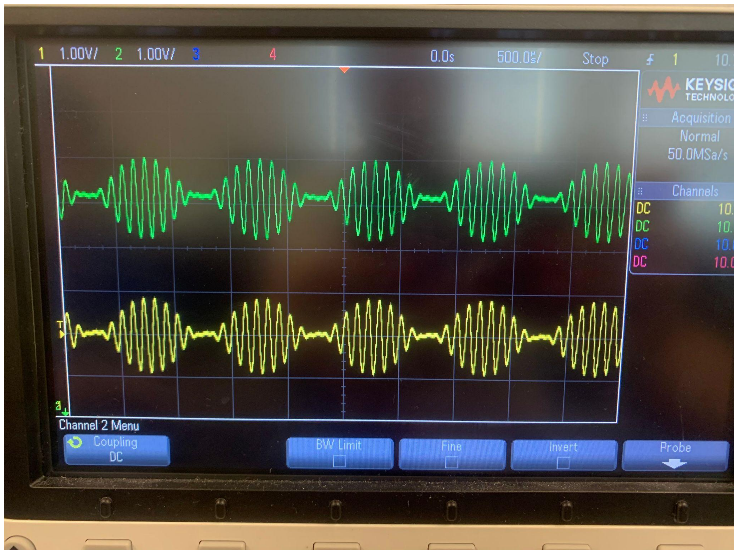

Figure 8. Prototype Output on oscilloscope

The fully soldered PCB is shown in figure 9. The gilbert cell circuit is soldered at the bottom of the PCB along with the operational amplifier. The potentiometer at the top of the board is there to try and create an offset for the unipolar op-amp we created. The jumpers are where we are able to hook up external function generators, power supplies, and the MSP430. The last part of the board, located at the bottom, is a coaxial SMA hookup that connects to the antenna.

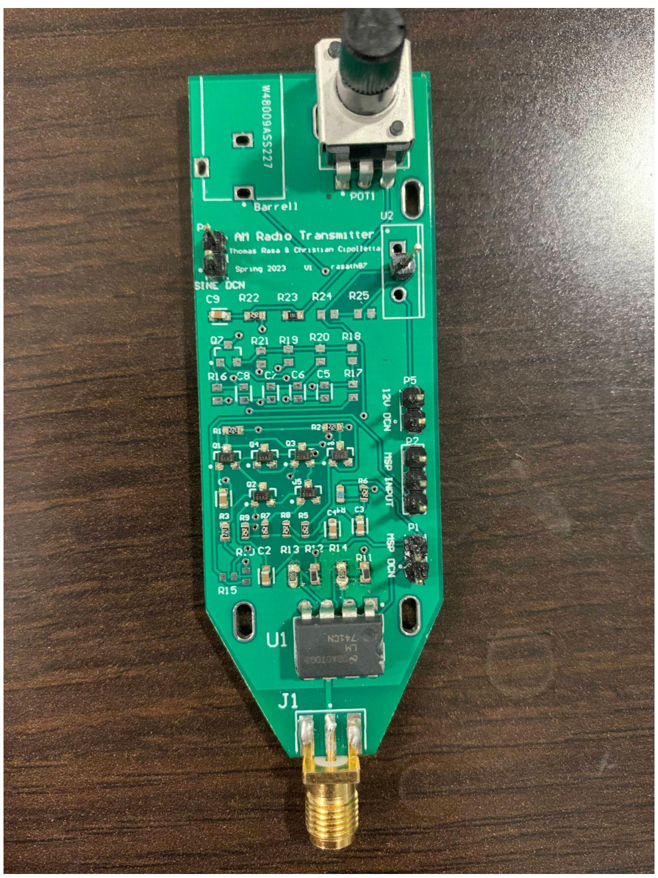

Figure 9. Final Soldered PCB

Discussion

The final product functioned within acceptable limits for the time constraints we were working under.. The simulations had promising results that were reflected in the prototype and PCB. When the power was supplied to the circuit, we were able to receive the transmission through a battery-powered radio receiver. The MSP430 was successfully able to change the note being received by the radio as well. It was a success as a proof of concept, but there are places where it can be improved.

In the future, there are some improvements to be made. First, we would like to have a working sine wave generator. This way we would not have to hook the system up to a function generator, and rather just a power source like a battery or the wall. Second, we would like to build an antenna that is better tuned with the frequency we transmit at. The antennas we had access to are tuned for the FM band which reduces the gain we can achieve since we are transmitting in the AM band. Lastly, we would like to understand why our unipolar op-amp is not giving a large gain like we had designed it to.

References

[1] W. Storr, “Differential amplifier - the voltage subtractor,” Basic Electronics Tutorials, https://www.electronics-tutorials.ws/opamp/opamp_5.html (accessed May 9, 2023).

[2] R. Mancini, Texas Instruments, Dallas, Texas, rep., 2001