Ambient Backscatter Communication Systems

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Abstract

Over the past few years, technology has advanced dramatically, but they still need to use external power sources such as batteries. Indeed, these power sources keep commonly used devices powered and eventually need of charging. What if there was a communication device that can send Radio Frequency signals without the use of batteries? We are creating a low power and battery less Ambient Backscatter Communication System (ABCS) using Wi-Fi as a source of communication. Indeed, the ABCS consists of a receiver, transmitter and an access point for Wi-Fi signals. Despite that we won't use a battery for the power supply, we can perform a RF-DC conversion using a power harvester (envelope detector) that stores Wi-Fi energy and convert it into a constant DC voltage to power the 1MHz oscillator for the transmitter. This innovative technology can be used one day on a larger scale to communicate with another device without the use of batteries.

Identification & Significance of the Problem

As the use of mobile technology increases, more power is consumed by these devices on a daily basis. According to Melanie Curtin, "the average person spends 4 hours on their smartphone every day." With that in mind, these devices need to be charged constantly. However in certain situations, one may not be able to charge their device and need to communicate immediately in an emergency situation. Ambient Backscatter could very well be the answer.

Backscatter communication is when one device absorbs the Ambient RF signals that are present in the air (i.e. Wi-Fi or Radio signals) to power and communicate with another device on low power or battery less. Also, Ambient Backscatter Communication systems do not need a dedicated RF source in order to communicate with other smart devices. As long as you are in range of an ambient signal, you can communicate with low power.

Now being mindful the communication of these devices is on a low scale, so it must be close to the access point for this communication to work. On a larger scale, this could potentially be implemented using cell towers that are far away. According to Veloxity, a Boston based company, after conducting a survey of 200 people about their phone's battery life, they found that "everyone needed a recharge from 1.8- 2.6 times a day, 4% carried a backup battery, 11% carried around their chargers and a staggering 85% carried nothing at all." Batteries have become an issue for technology advancement, but with Ambient Backscatter communication can be a grantee regardless of battery power in a mobile device.

Design Criteria

What consists inside of an Ambient Backscatter Communication System (ABCS) is a transmitter, receiver and an Access Point (AP) for the RF signals. Before the RF signals travel from the transmitter to the receiver, it needs to be modulated because the signal needs to travel from one device to another. Indeed, the transmitter has a switch at the end of a passive power supply, allowing the device to have two states (close (1) and open (0)). Hence, this process is called On-and-Off Keying (OOK). Also, OOK allows the transmitter to perform amplitude modulation and let the signal store useful information.

Despite that the ABCS has a simple configuration for the transmitter, we need to find a way to harvest RF energy into the receiver. There are two methods that my partner and I came across: making a bridge rectifier or a power harvester (a band pass filter and a voltage multiplier rectifier). We decided that the power harvester will be the best RF-DC conversion because of the diode's low voltage drop and its cost efficient. Now, the RF signals are converted into DC, the voltage obtained from said harvester will be used to power the ultra-low power comparator TS881 inside of the receiver. The Receiver ultimately will be used to capture the transmitted signal and digitizing its average envelope by comparing the two different signals through its various stages.

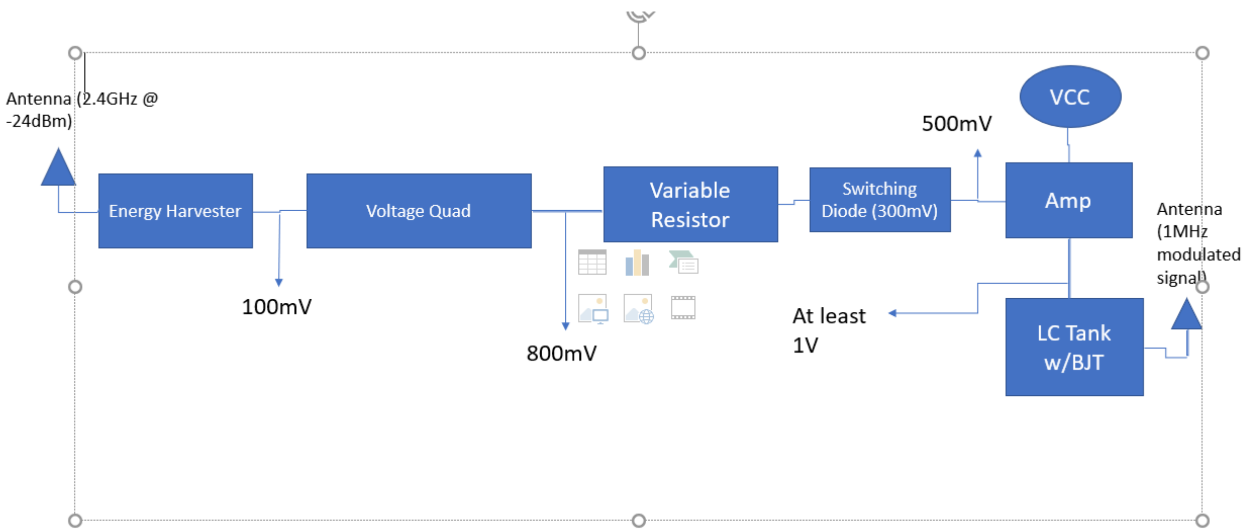
Applications of ABCS

One of the applications of ABCS is to send coded messages. This can consist of a set of logic high and low signals in any particular sequence the sender wishes to send to the recipient. This message can be intercepted, however the interceptor would have no way of knowing the meaning behind the signal or if it's even a message at all. This can be used in an emergency situation like if someone is kidnapped and needs to send an emergency SOS discreetly, or it could be used if you are lost and need help as long as there is ambient RF it can happen. Similarly, the life alert device sends an SOS signal when someone is in need of help, the press of the life alert button can relate to on-off keying in signal transmission. You can push a switch to close or open the circuit and that will in turn switch the signal from logic high to logic low of its average envelope.

Transmitter Discussion

Within this device, there are three key components: the power harvester, oscillator, and a switch for amplitude modulation.

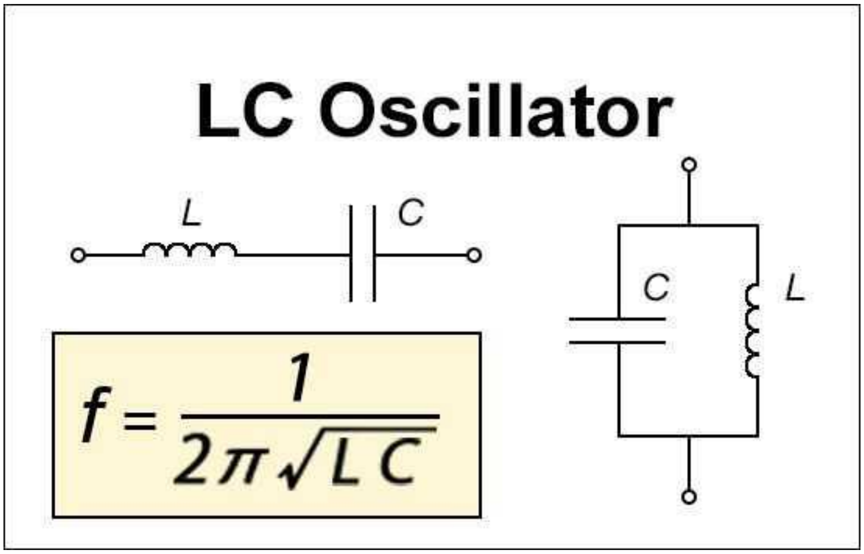
Transmitter Block Diagram (Old Design)



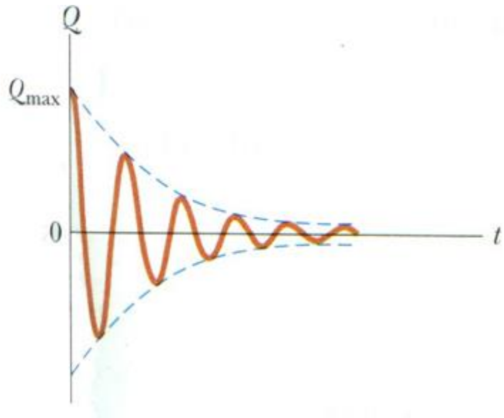
Indeed, the energy harvester main function is to capture any ambient WiFi signals at a strength of -24dBm and convert it into a 100mV DC signal. Next, the voltage quadrupler rectifier take the DC signal and increase it to 800mV. Afterwards, we suppose to use a potentiometer, so we can vary DC signal strength. If the DC voltage is 300mV or more, the Schottky diode will conduct (On state). Additionally, the DC signal will be amplified, while powering the 1MHz LC oscillator. Otherwise, the diode will be reversed biased (Off state); Hence the process of amplitude modulation or on and off keying. Finally, those signals will be radiated out of an antenna, while being transmitted to the receiver.

LC Oscillators

Before we build an AM transmitter, we need an oscillator that has a frequency range that can undergo amplitude modulation (Frequency range between 300 kHz - 1.6MHz). As a result, we calculated the desired LC resonant frequency to be 1MHz. Also, we choose our inductor value to be 0.5uH and capacitor value to be 2uF. For the circuit to resonate, the capacitor needs to discharge into the inductor, while the coil stores the current and produce a magnetic field. Once the capacitor is completely discharged, the current from the inductor will flow into the capacitor in the opposite direction and go into the other side of the coil, while changing its polarity. As soon as all the current leaves the inductor, the cycle continues, while the resonating signal damps overtime.

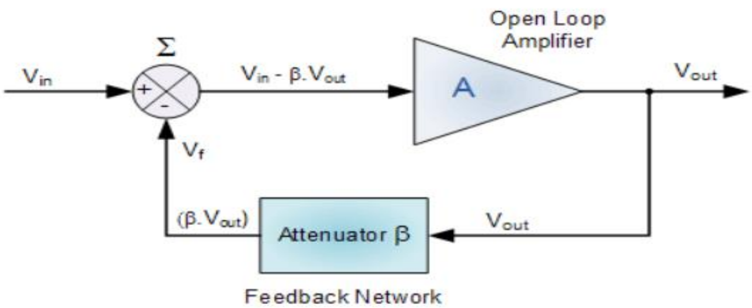


Damped Signal for the LC Tank Circuit



Since we're working with low power, an LC tank circuit will not be a good choice for the transmitter because it generates a damped signal. Now, we need to find a way to allow an oscillator to generate a constant 1MHz signal. The only solution is to use a Bipolar Junction Transistor (BJT) as an amplifier with a gain factor of 100 with a regenerative feedback into its output. Despite that a BJT is an active component, it generates a constant sinusoidal signal we desired.

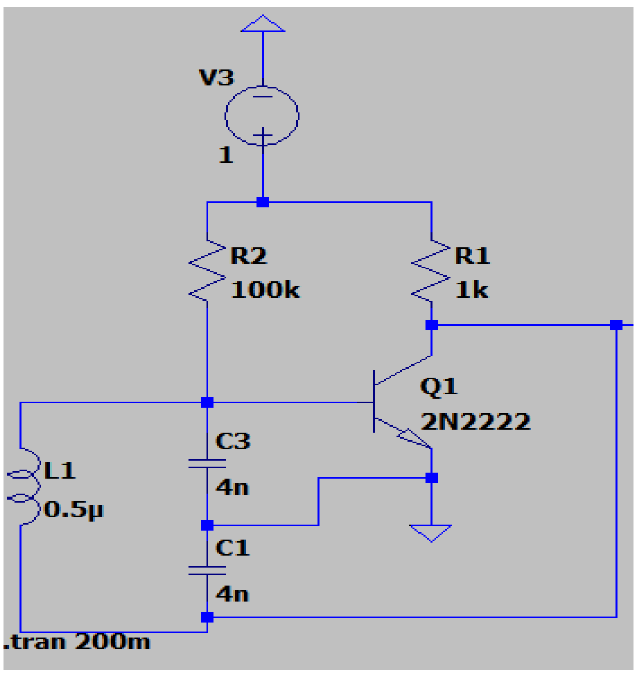
The concept of a Regenerative Feedback Oscillator



After all the research of regenerative feedback oscillators, we decided to build and use the Colpitts oscillator implementation. Indeed, this design doesn't use any transformers, it can operate in lower voltages and we can use a BJT (Common Emitter) to amplify the signal. The

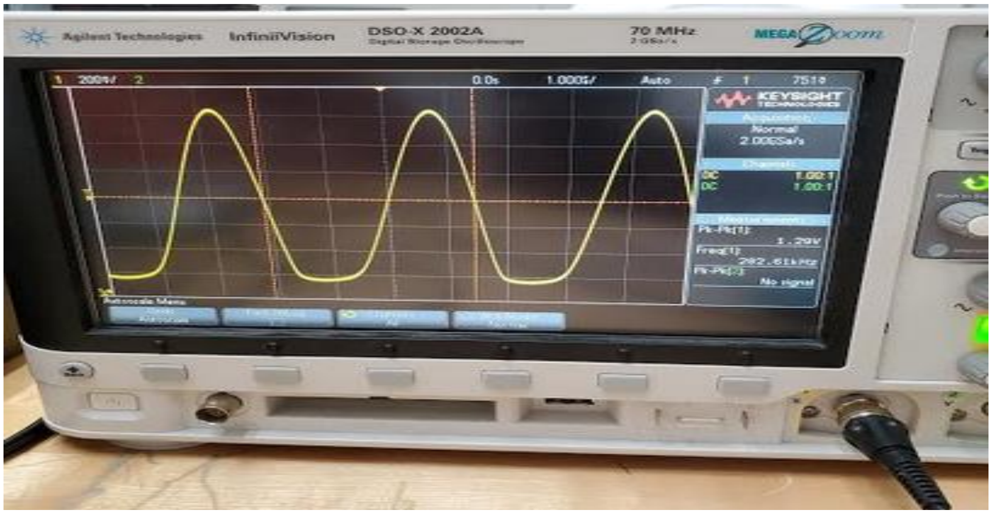
Colpitts oscillator has a tank circuit that's located in the base-emitter junction of a BJT with a capacitive voltage divider (C1 and C2 in series). Between the two capacitors, it's grounded because it's the most effective way to connect the tank circuit with the emitter. Despite that we know the output signal is a continuous sinusoidal wave, C1 and C2 can affect the amount of feedback for the oscillator. Indeed, if C1 is too high, the output signal can have distortions. In contrast, if C1 is too small, the output signal will not oscillate; therefore, we kept C1 = C2, giving us a 1% feedback (Feedback = (C1 / C2) %).

BJT LC Oscillator and Results (1MHz Signal)



Note: The capacitors of the tank circuit are in series; therefore Ctotal = C1*|C2 / C1 + C2.

As a result, Resonant Frequency should be f = 1 / 2pi * sqrt(L * Ctotal).



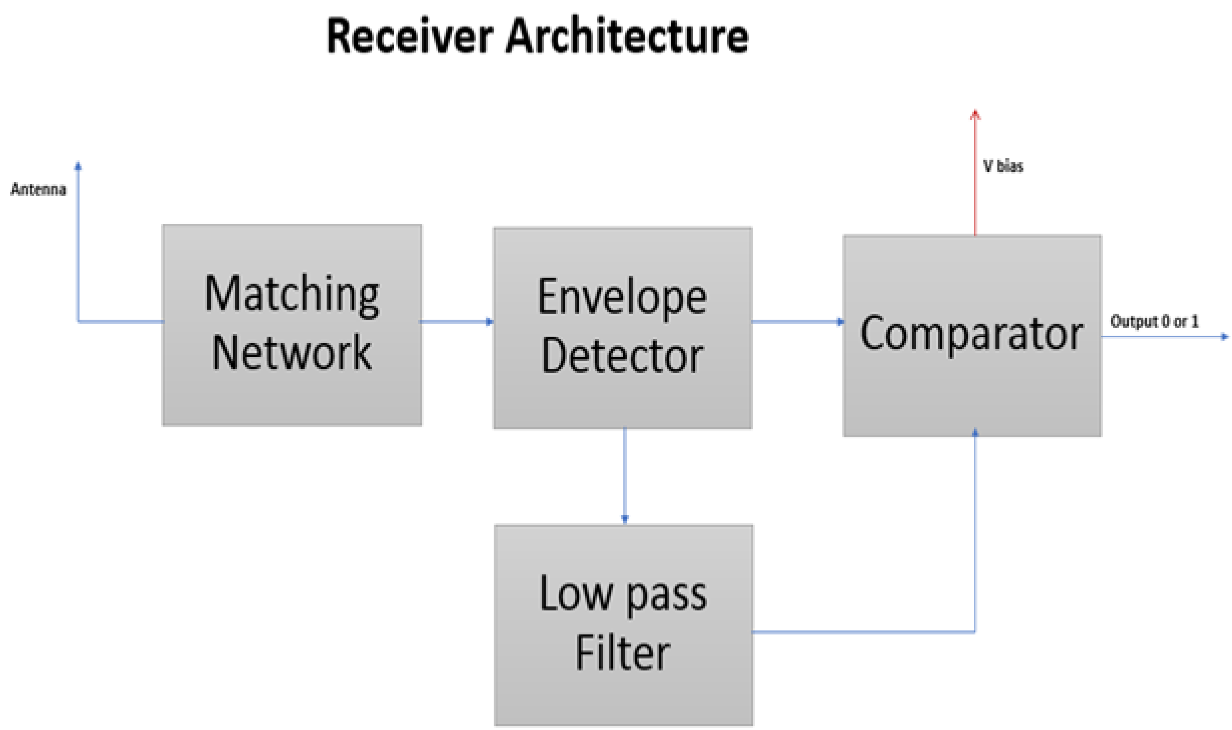
Despite that this LC oscillator produces a continuous sinusoidal wave, it has two trade-offs: we need to supply the rail that's higher than the BJT's base-emitter voltage (0.7V) and the signal lowest amplitude is 0V. Indeed, if the rail isn't greater than 0.7V, the BJT will cut-off and there's no oscillation at the output.

Challenges of the Transmitter

Due to time constraints, we are unable to build and simulate a passive AM transmitter. As a result, we used active components to implement our prototype. Indeed, for the oscillator, we used a BJT as a regenerative amplifier because the basic LC tank circuit produces a damped harmonic signal (due to the reactance of the lumped components, the signal experiences some loss). Also, in our original design, we need to find weird components that can operate with neglect able amount of power; therefore, we have to implement the project with surface mount components. Additionally, we have a person to fabricate the patch antennas, but not our original transmitter design. We want to generate a 1MHz signal, but the lowest available inductance is 10mH. Instead, we make the oscillator to generate a 518 KHz signal by changing each capacitor value into 15pF.

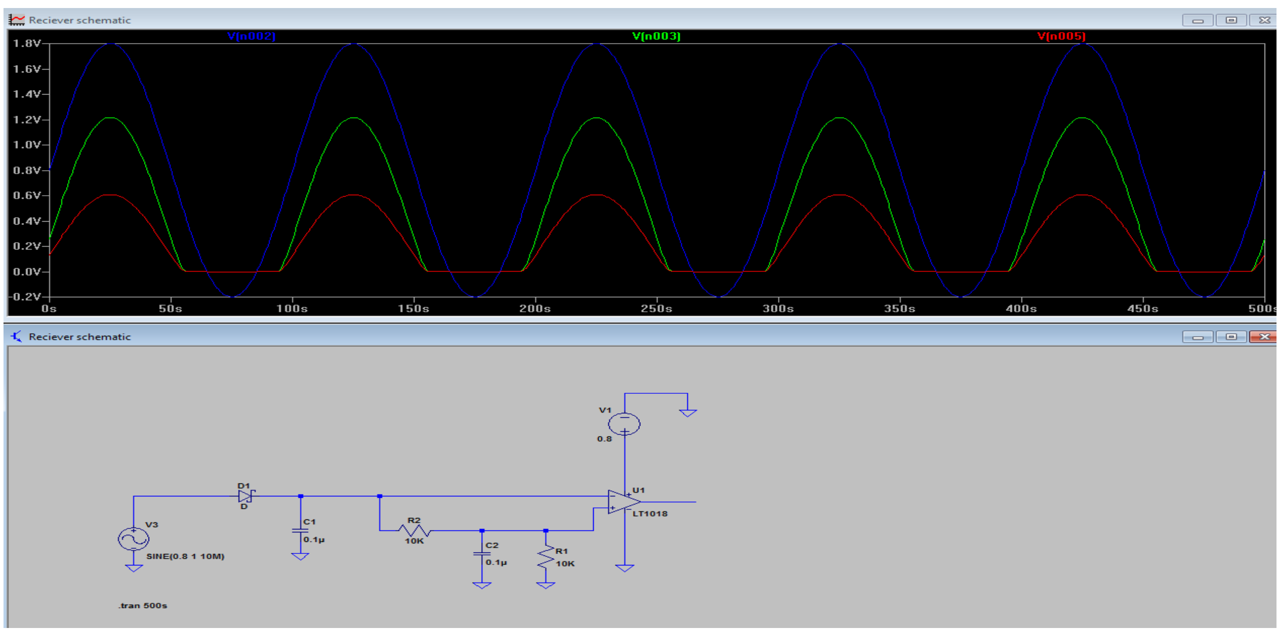
Receiver Discussion

Taking a step back, the receiver will consist of several different circuits to capture, filter and digitize the incoming signal from the transmitter



if we take a look at the block diagram above, the receiver's front end consists of an antenna matched to a 50 ohm impedance connected to a matching network. The matching networks purpose is to match the impedance of the transmitter for maximum power transfer. Now in the real world there is no such thing as a perfect match, however this will maximize the power transferred to get the most of the transmitted signal with a minimal amount of loss. Following the matching network our signal will enter the envelope detector. This is essentially what we need to capture the average envelope of the signal and zero out the negative swing of the received signal. Ideally, we need this because ultimately what we want to receive is a logic 0 and 1 of the signal to indicate on and off in a real world application. Imagine sending a coded message to a recipient, If the recipient receives the message, they will see logic levels 1 and 0 this can be excellent if you need to send a message that is only meant for the recipient and no one else would understand the sequence of the on off indicators. Moving on from the envelope detector the signal then branches off as one side goes straight to the comparator and the other end goes to a low pass filter which is essentially needed to filter out unwanted noise and clean up the signal and then to the comparator. Now that we have two versions of the signal going to the comparator, it can now compare those two signals and swing a digital high and low output depending on its reference.

Original Receiver Schematic



If we take a look at the schematic above, the 10MHz sinusoidal source represents our antenna at the front end of the receiver Noted as the blue signal on the graph. The received signal then travels to the envelope detector circuit which will cut off the negative swing of the signal and take its averages assuming there is no on-off keying involved on this simulation highlighted in green on the graph. The last signal represented in red on the graph is the signal that passes through the low pass filter. This low pass filter as stated cleans up the signal and filter out any unwanted noise. The expected output from the comparator will be a digitized bit line of 1s and 0s

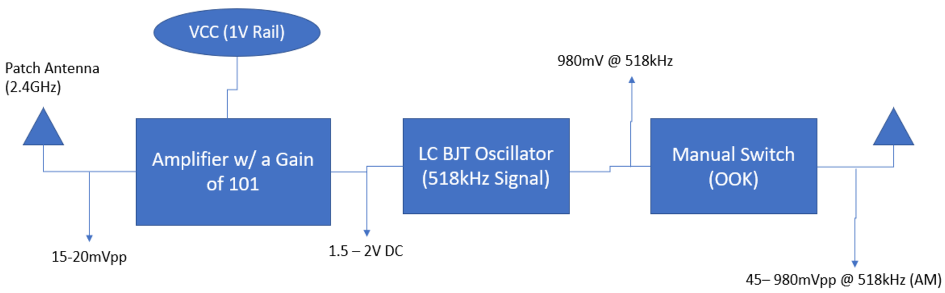
Challenges of the Receiver

The challenges that we faced in aspect of the receiver is that the power received from the energy harvester (v bias) is so insignificant on the scale of microwatts, that were initially unable to use even a low power comparator to view the digitized output signal from the transmitter. This caused a host of problems and resulted in attempting to manually digitize the signal using 2 schottky diodes in parallel facing opposite directions known as “clipping” instead of a comparator.

Project Design

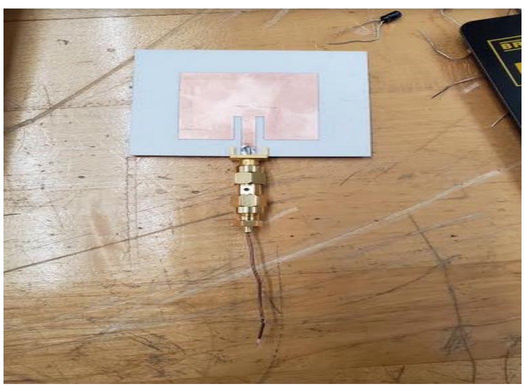
Given that we have been limited on the time and resources for this project, we have developed a system that will absorb the ambient RF, in our case Wi-Fi, amplify that signal using an op amp (that’s railed with 1V) and use that saturated voltage to power up our oscillator. As a result, we used the ambient Wi-Fi signal to be the voltage reference for the op amp. As we read the peak voltage from the patch antenna, it only gave us approximately 20mVpp. We expected to have a small amount of voltage, so we configured the amplifier into a non-inverting configuration, whereas the calculated gain is 100. Afterwards, the op amp’s output is used to power up the BJT oscillator. According to the LC tank circuit, it should produce a 518 KHz signal. Finally, I can perform OOK using a manual switch that’s located at the output of the oscillator.

New Block Diagram

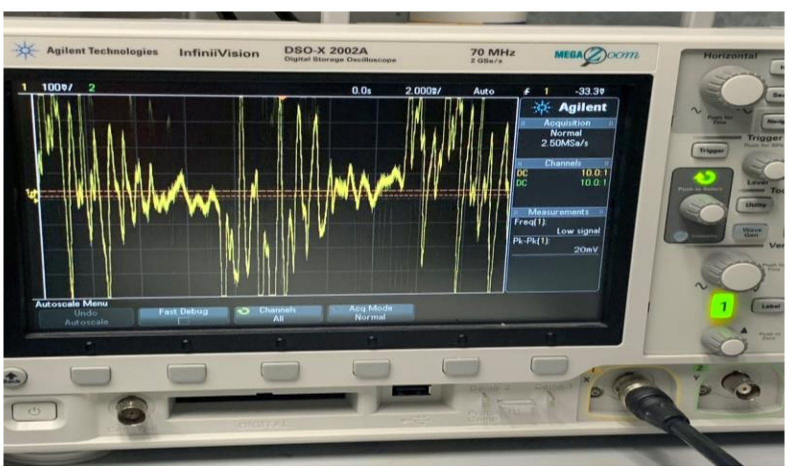


Most Important Features of the Design

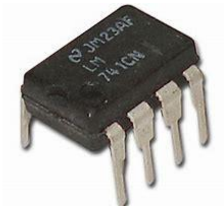
2.4GHz Patch Antenna

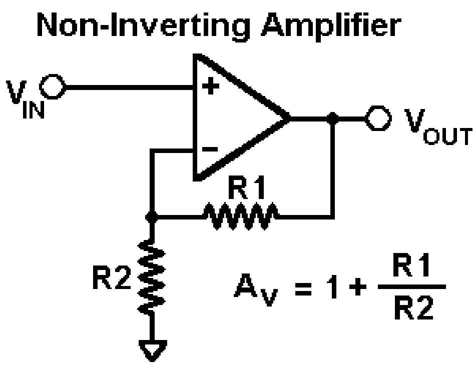


Input Signal of the 2.4GHz Patch Antenna



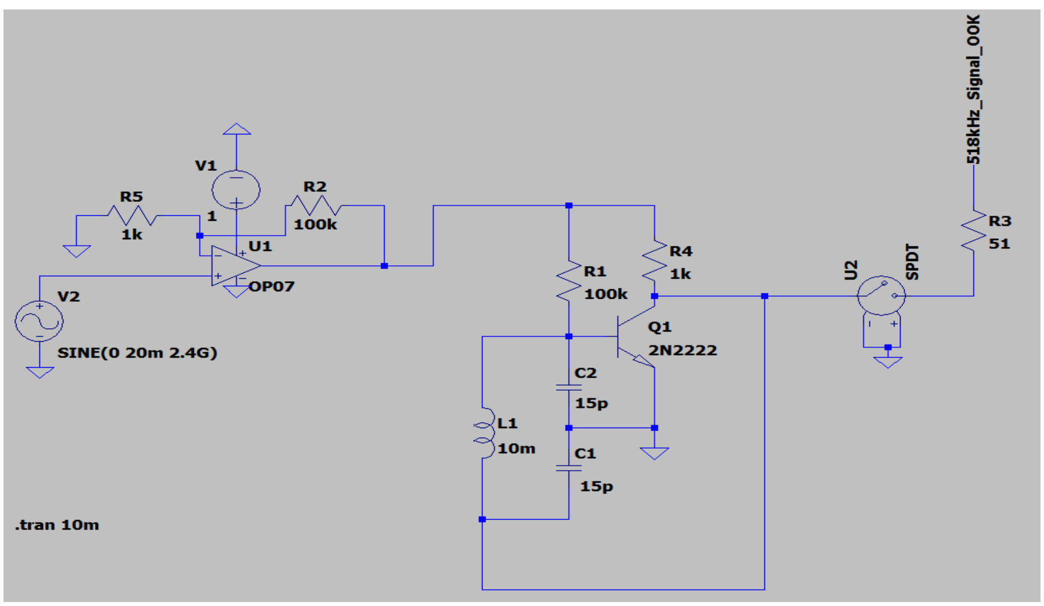
741CN Operational Amplifier and Non-Inverting Configuration





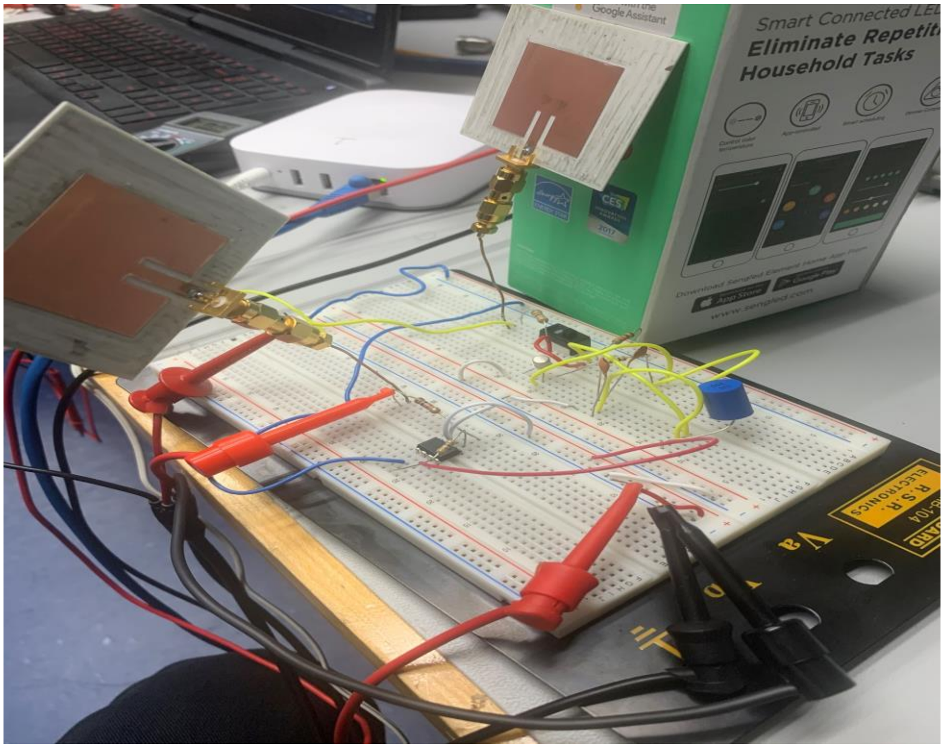
Note: We chose R1 = 100kOhms and R2 = 1kOhms; therefore, Av (Gain) = 1 + 100kOhms / 1kOhms = 101.

Full Schematic



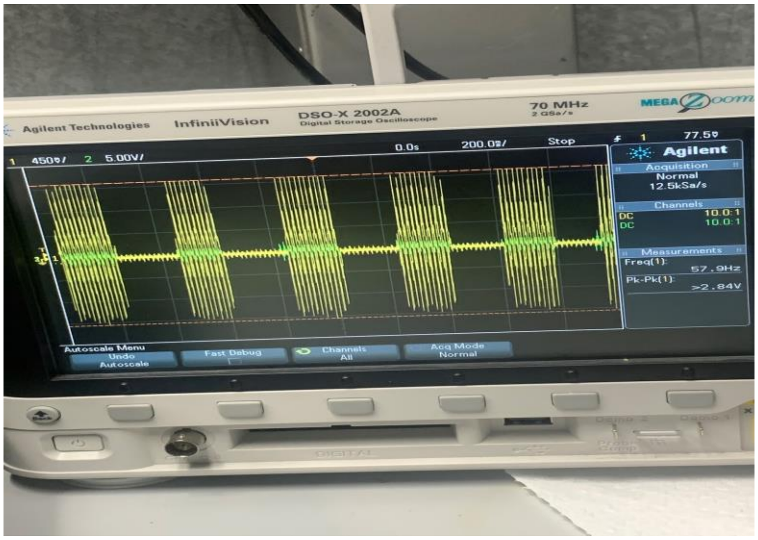
Note: The 51 Ohm resistor function is to match the impedance of the output patch antenna.

Prototype



Results

Amplitude Modulation



As shown in the picture above, the carrier signal (from the LC Oscillator) is represented in yellow and the input signal (WIFI) is represented in green. The carrier signal's amplitude is increasing and decreasing by the imposed input signal, this is known as amplitude modulation. As we bring the WIFI router closer and further away from the antenna, the amplitude of the carrier is directly affected. This is what we want as it is a technique to transmit information via our oscillating carrier wave.

ON-OFF KEYING (OOK)