Power Demand Response System

Team 21

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ECE445 Senior Design

The Problem

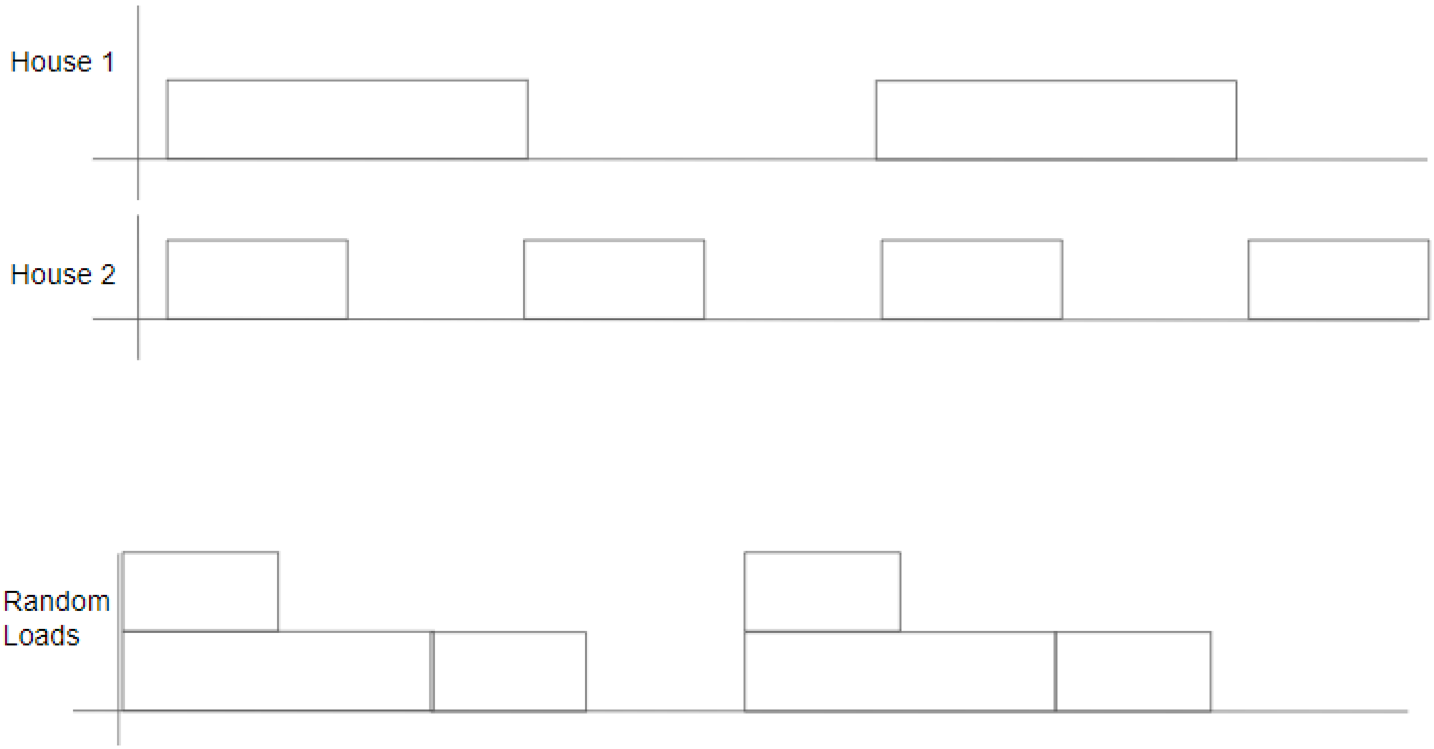
1. High demand for electricity creates stress on the grid
2. The increase in popularity of renewable resources lowers reliability of power generation
3. Together these issues result in low capacity factors of power plants, making them less efficient
4. Which increases costs.

The Objective and High Level Requirements

1. Create powerline communications between the supply and demand by transmitting bits at a reasonable speed
2. Use this communication to schedule power usage of homes
3. Make these schedules dynamic
4. Ultimately decrease the costs

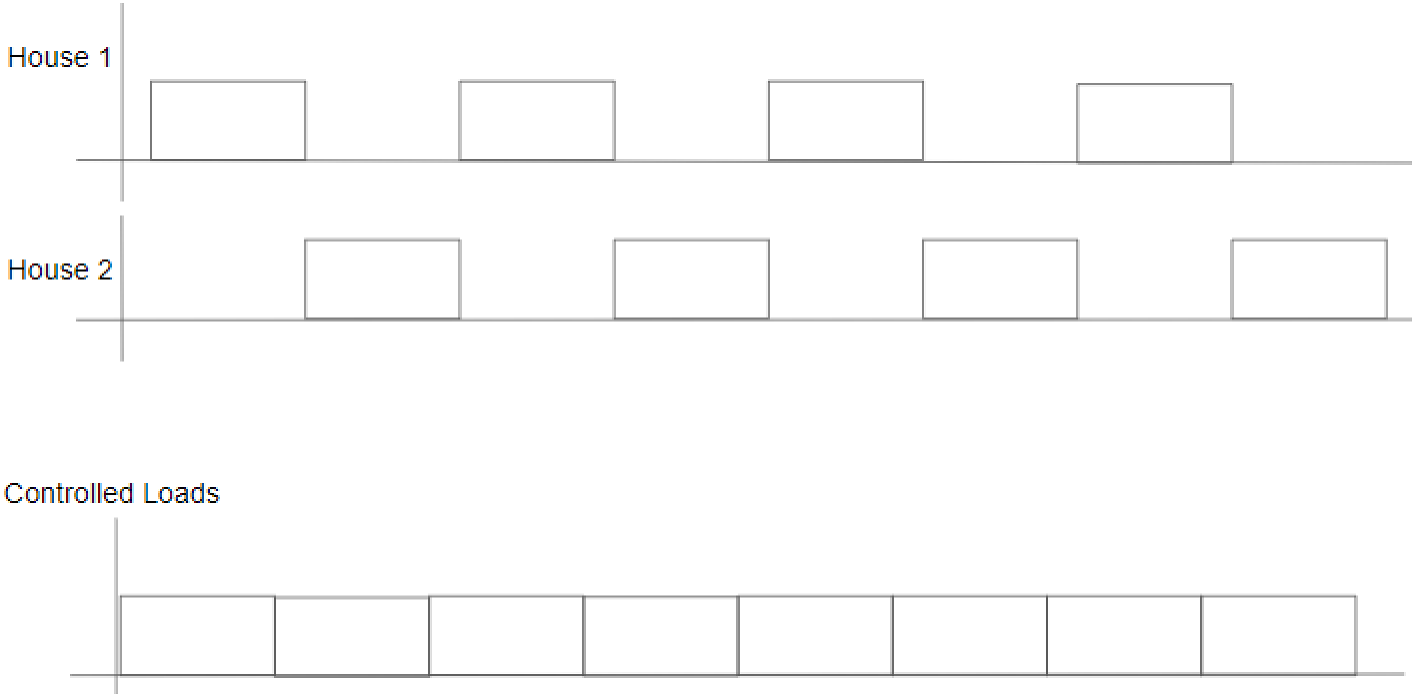
Unscheduled Loads

The Old Way



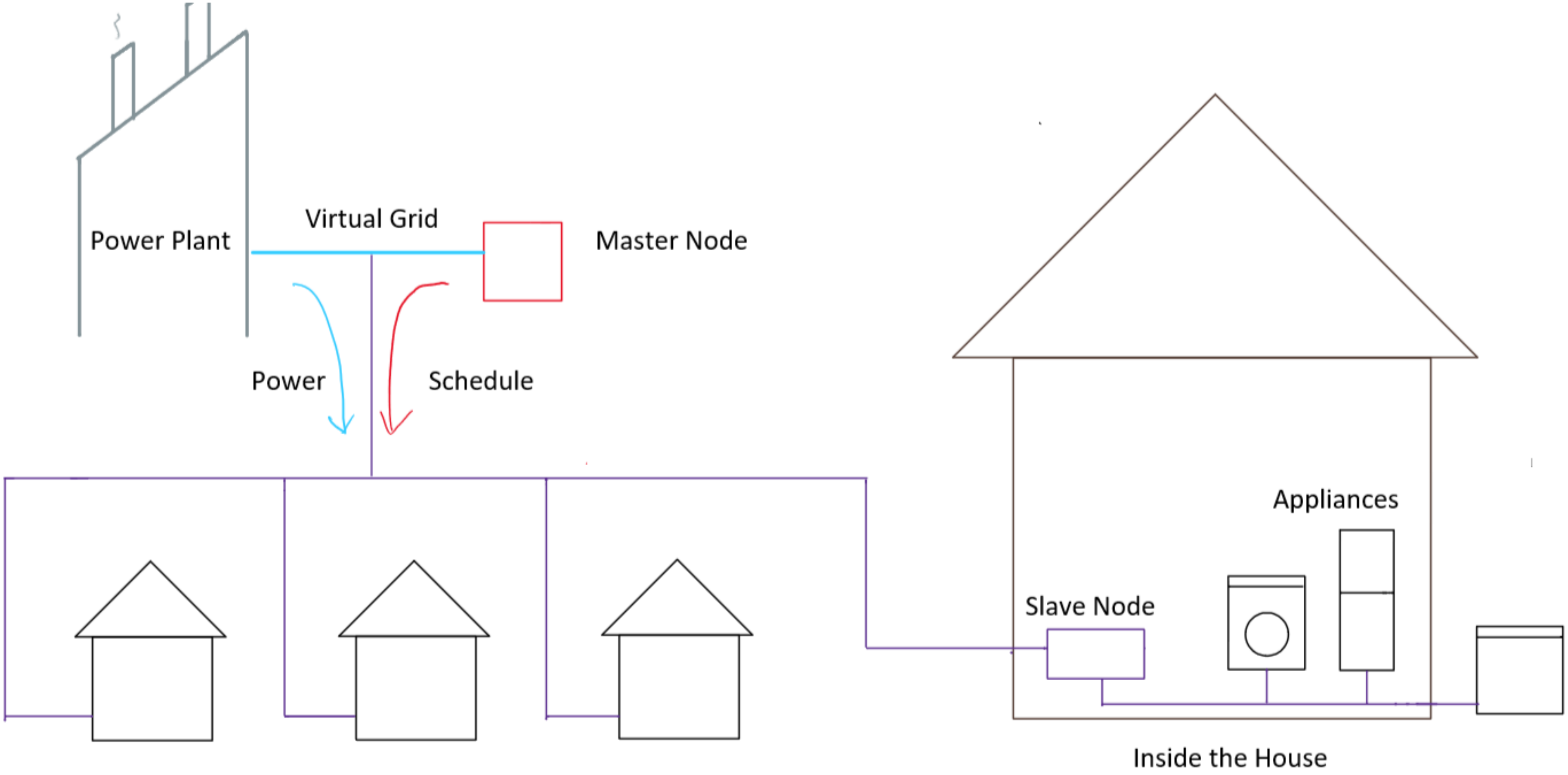
Scheduled Loads

The New Way



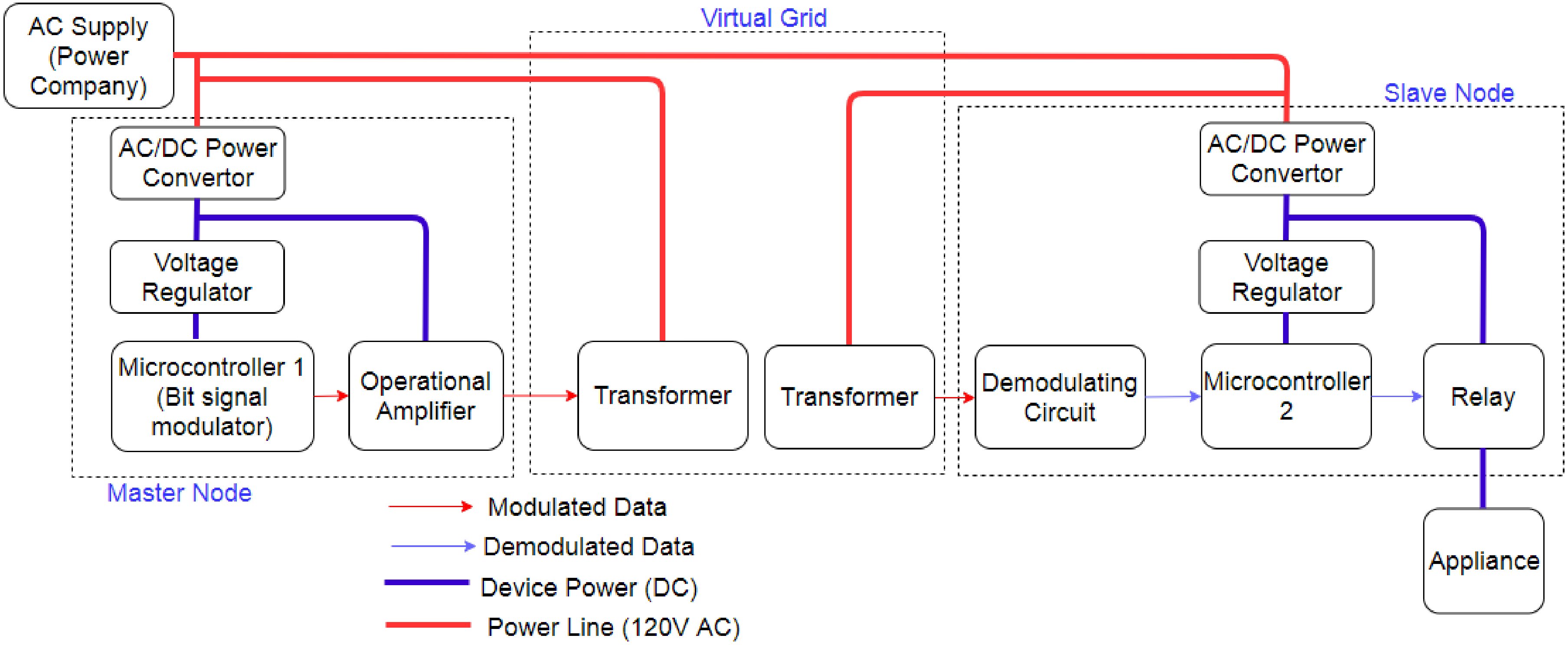
High Level Overview

The utility company dictates the schedules



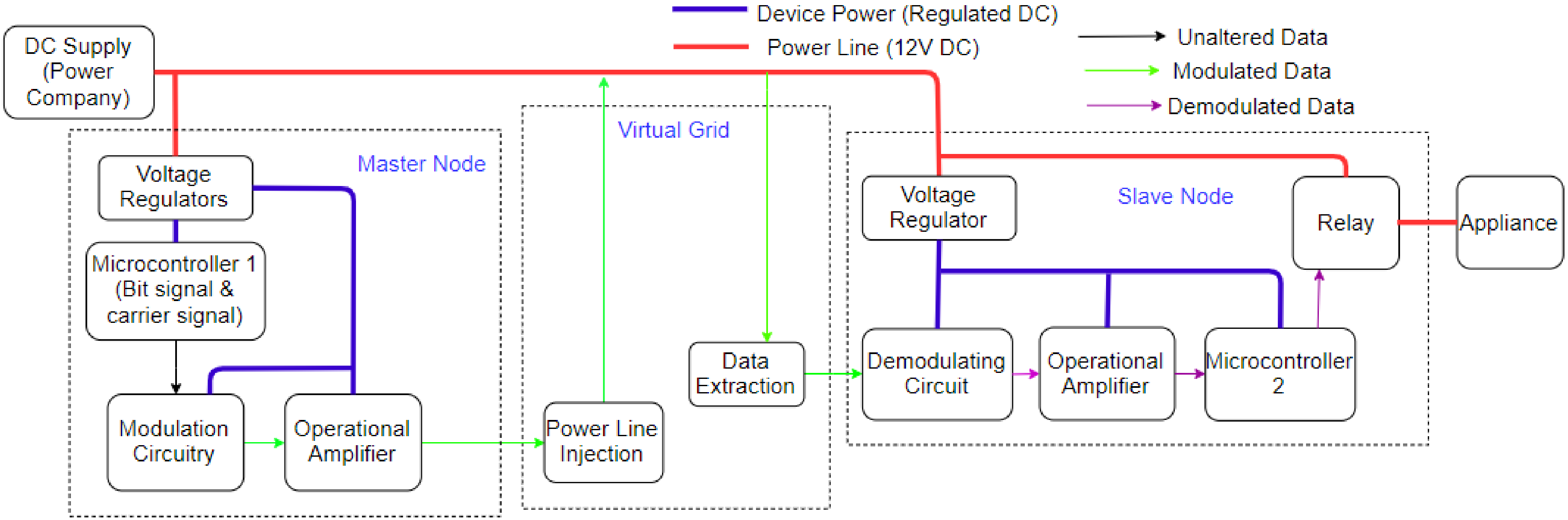
Original Block Level Diagram

Our Initial Idea for the Project

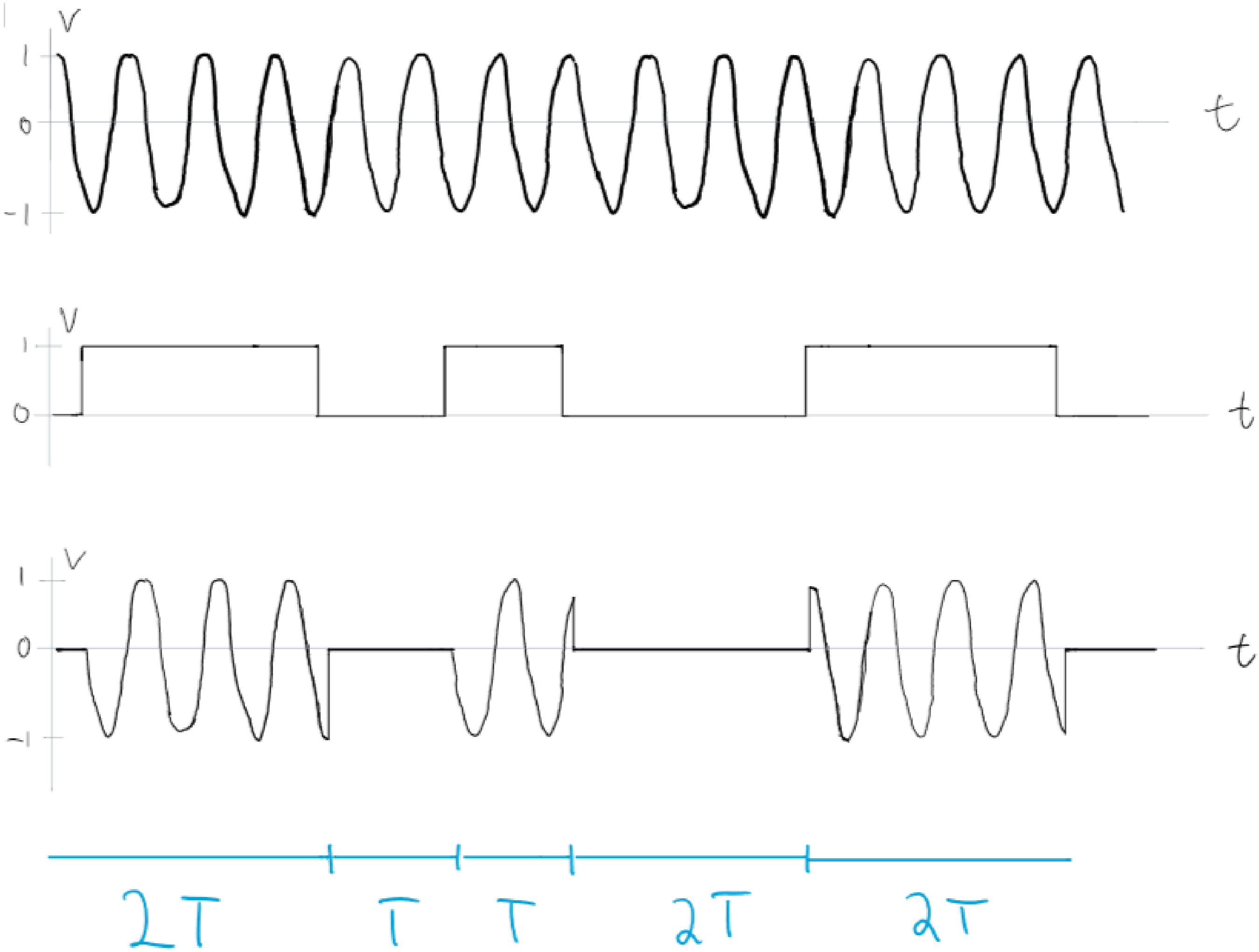


Current Block Level Diagram

Necessary Changes



Modulation for Power Line Injection

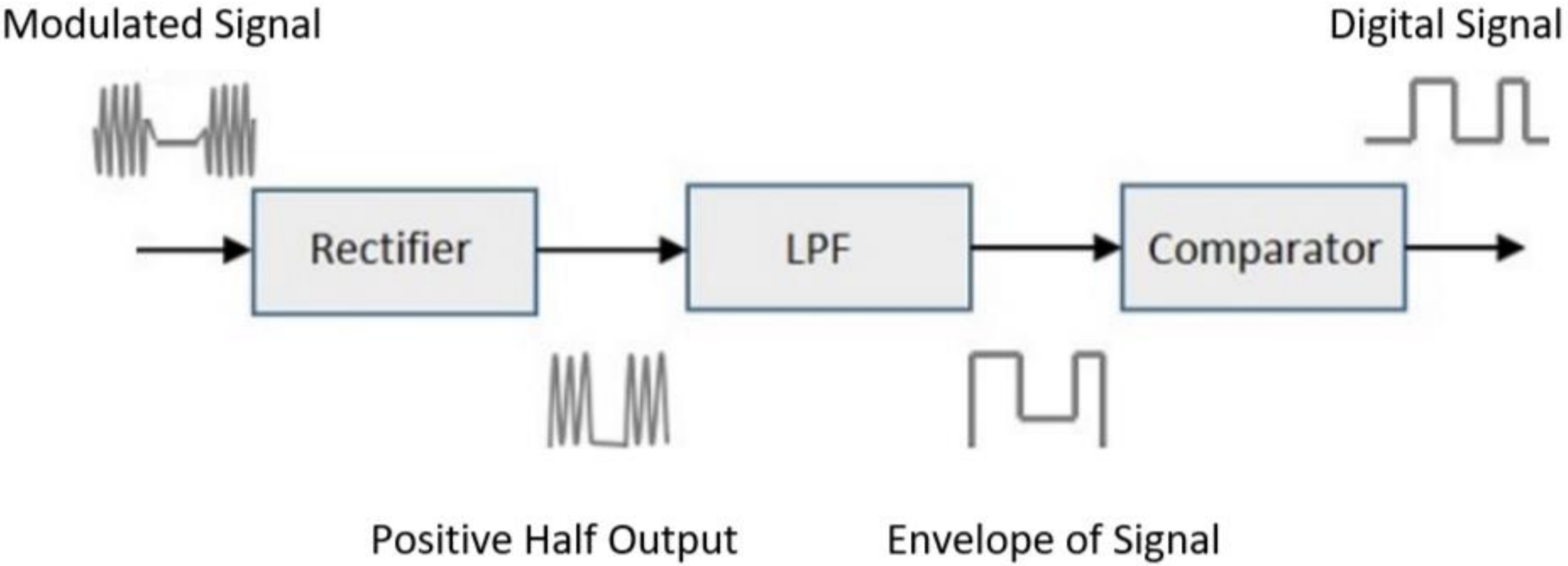


High Frequency Signal

Bit Signal
1 1 0 1 0 0 1 1

Modulated Signal
1 1 0 1 0 0 1 1

Demodulation: Digitization


Modulated Signal

Rectifier

LPF

Comparator

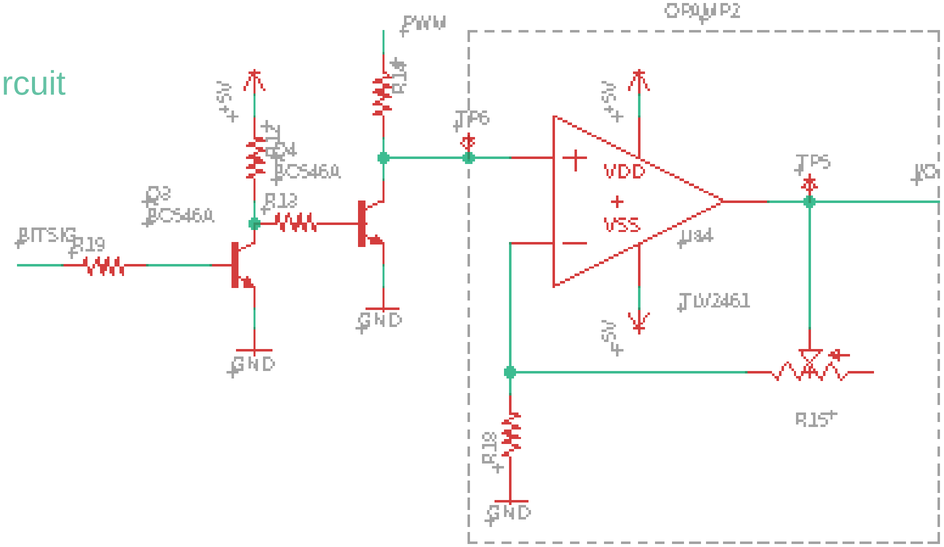
Digital Signal

Positive Half Output

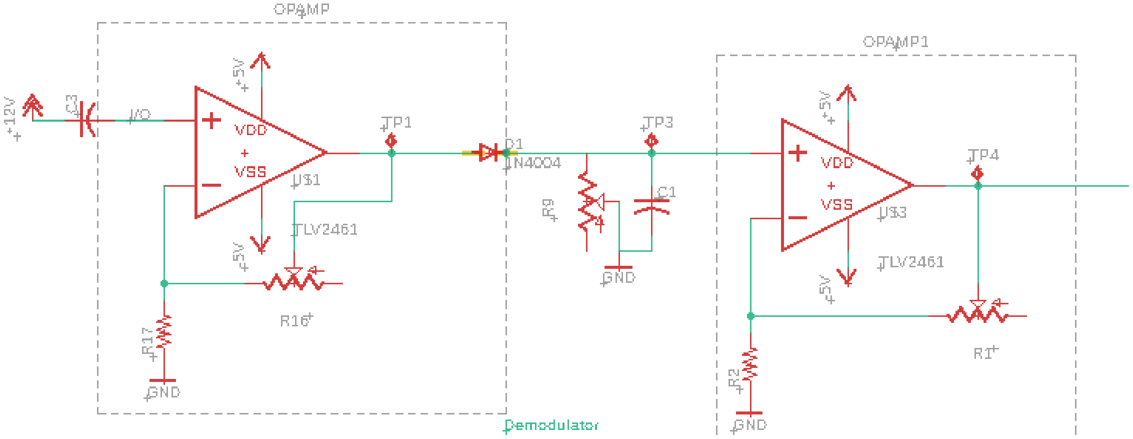
Envelope of Signal

EagleCAD Schematics

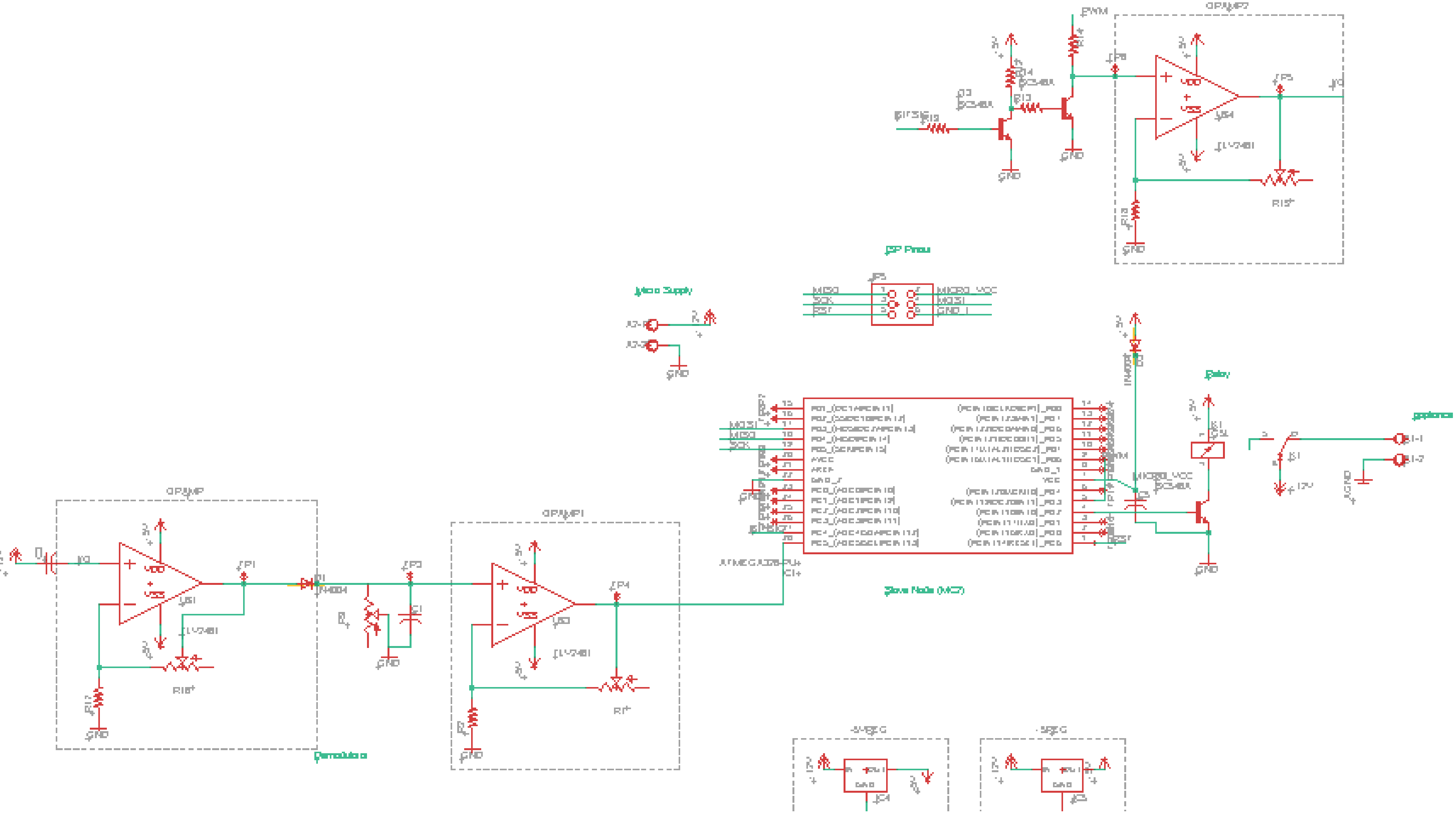
Modulator Circuit



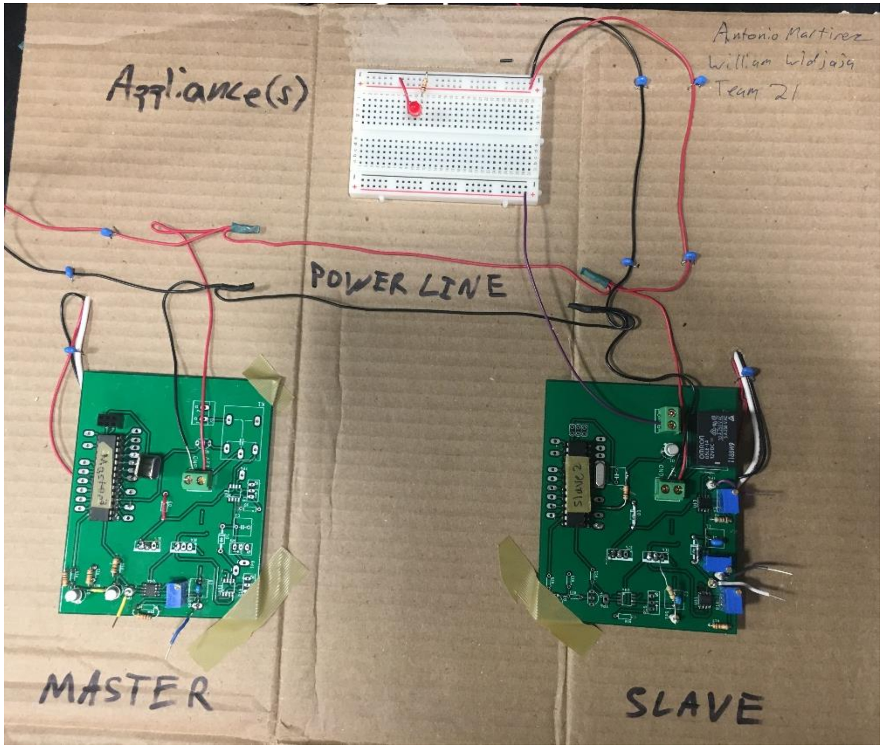
Demodulator Circuit



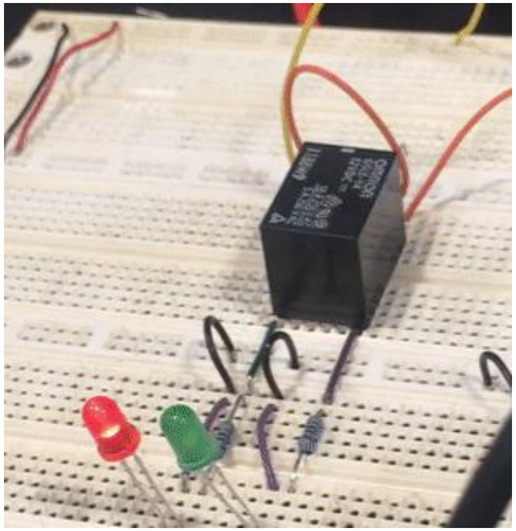
Entire Schematic



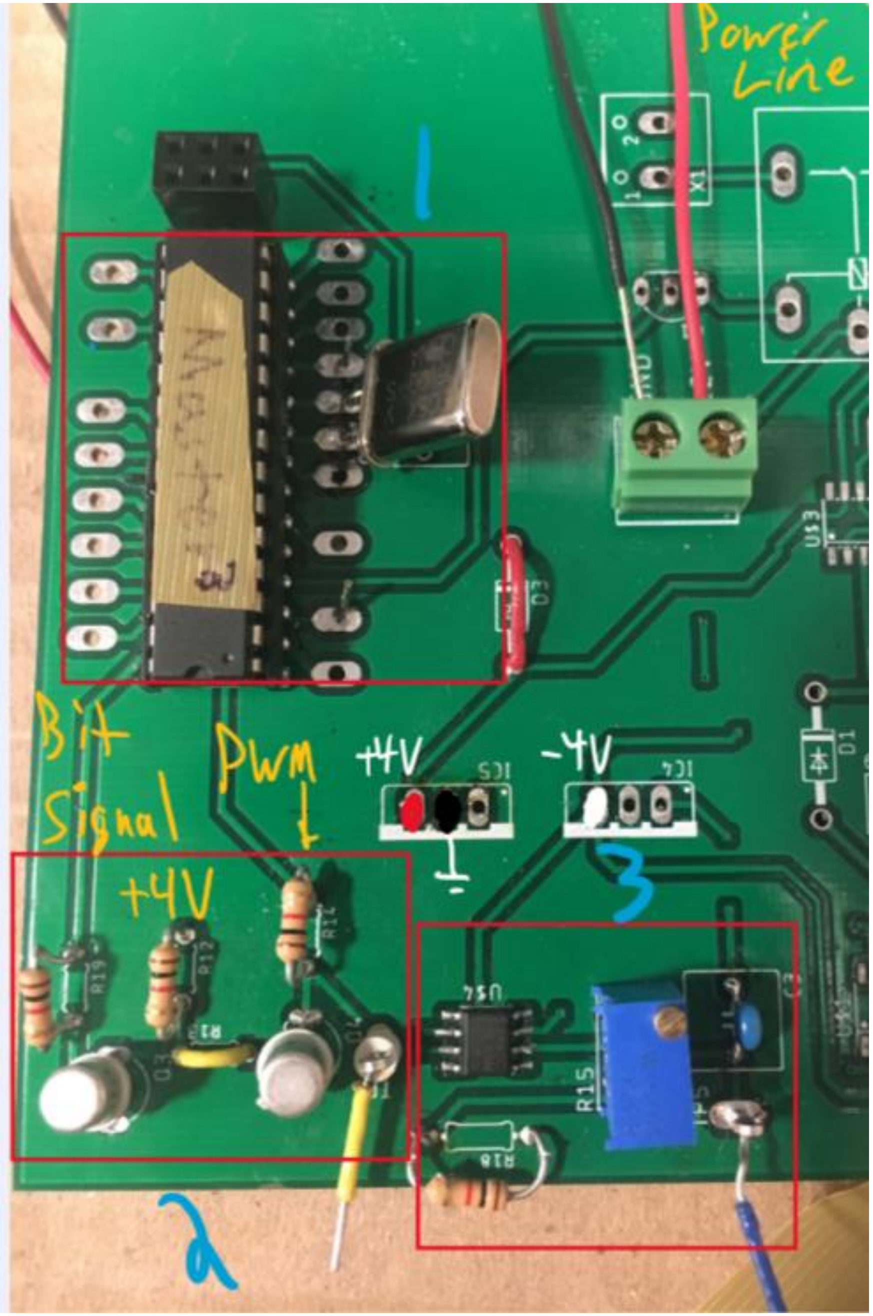
Complete Project Build



Above is the final product that we used for our demo.



Demonstration of microcontroller controlled relay switching two LEDs representing appliances

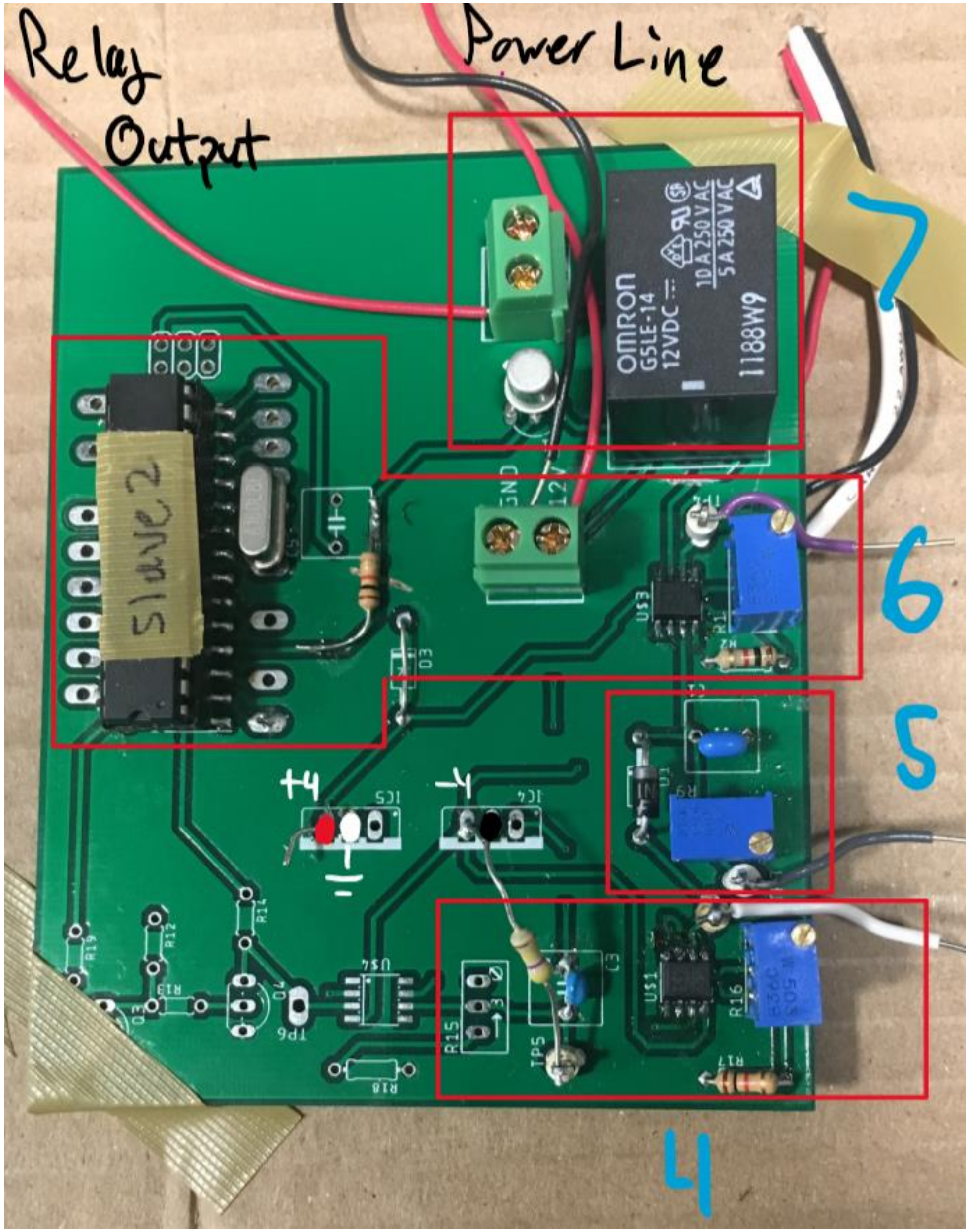


Master Node

1: **Microcontroller 1: G**enerates the bit signal and the PWM high frequency carrier

2. **Modulator Circuit:** combines these signals through the use of BJTs

3. Powerline Injection Circuit: The operational amplifier gives the modulated signal some gain before the signal passes through a capacitor, onto the power line.



Slave Node

4: **Data Extraction:** Another capacitor is used to only retrieve the AC component of the virtual grid, our modulated signal. It's then amplified to make up for losses

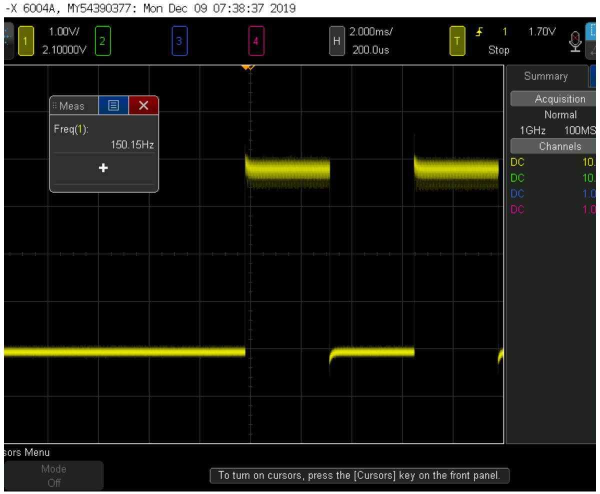
5. **Demodulator Circuit:** We use a half-wave rectifier (diode) and low-pass filter to convert our signal to entirely positive, then rid of the high frequency carrier.

6. Microcontroller 2 (MC2): Another OpAmp is used to compensate signal amplitude loss during rectifying and filtering. The digital signal can now be read by MC2, which controls the relay

7. Relay: Switches supplied power to appliances

Scoped Modulation

Illustrative Verification

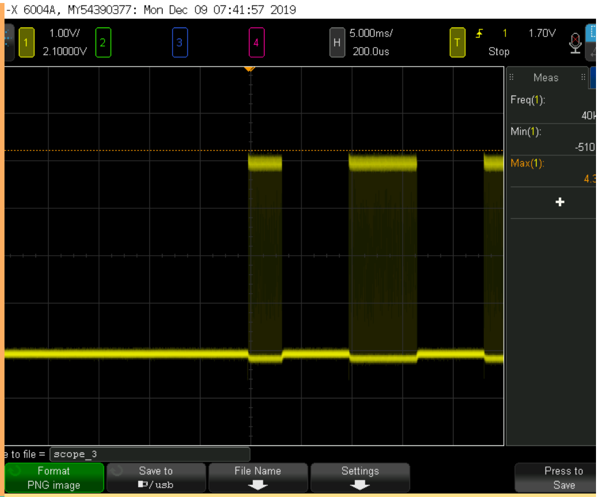


-X 6004A, MY54390377: Mon Dec 09 07:38:37 2019

Freq(1): 150.15Hz

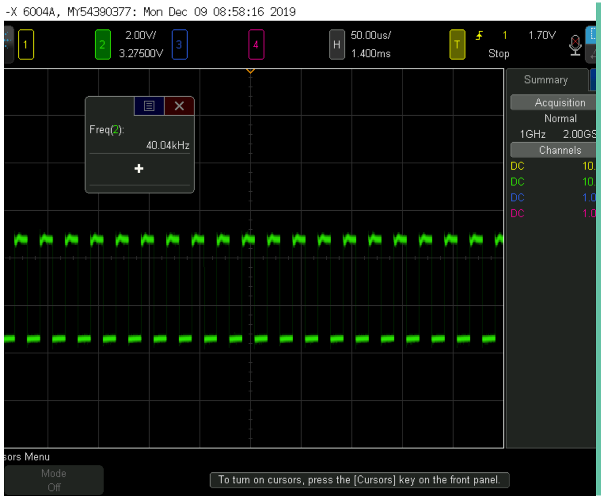
To turn on cursors, press the [Cursors] key on the front panel.

Top left, is the MC1 generated bit signal running at a desired 150Hz



-X 6004A, MY54390377: Mon Dec 09 07:41:57 2019

Freq(1): 40k
Min(1): -510
Max(1): 4.3



-X 6004A, MY54390377: Mon Dec 09 08:58:16 2019

Freq(2): 40.04kHz

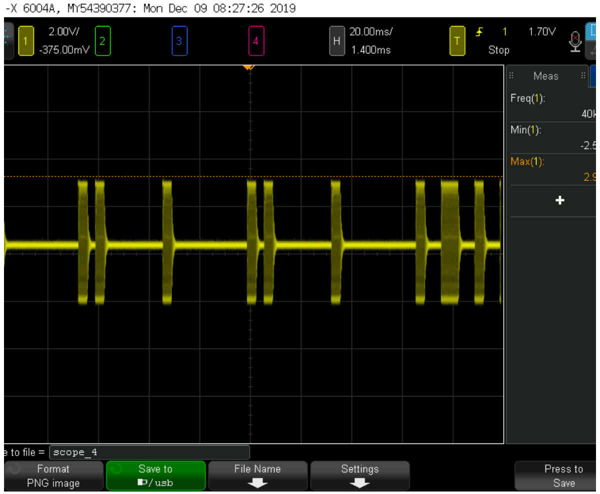
To turn on cursors, press the [Cursors] key on the front panel.

On the left, is the MC1 generated high frequency carrier signal running at 40kHz

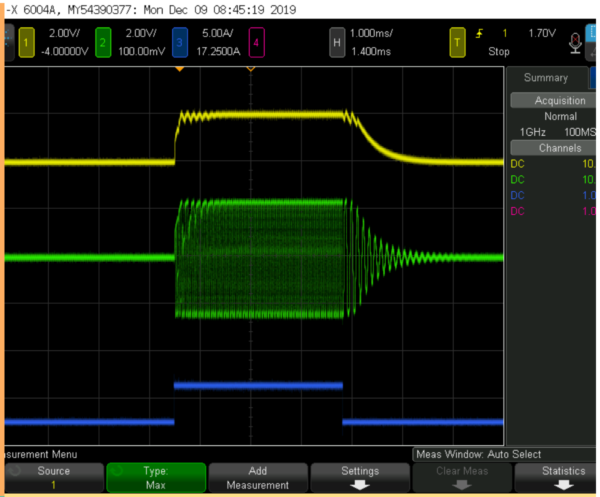
Above is our modulated signal, the final output of the Master node

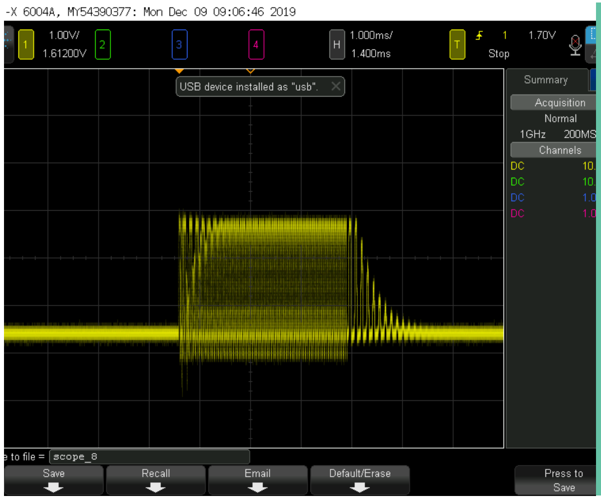
Scoped Demodulation

Illustrative Verification



Top left is the extracted modulated signal from the virtual grid. A closer look is the green signal on the image to the right.



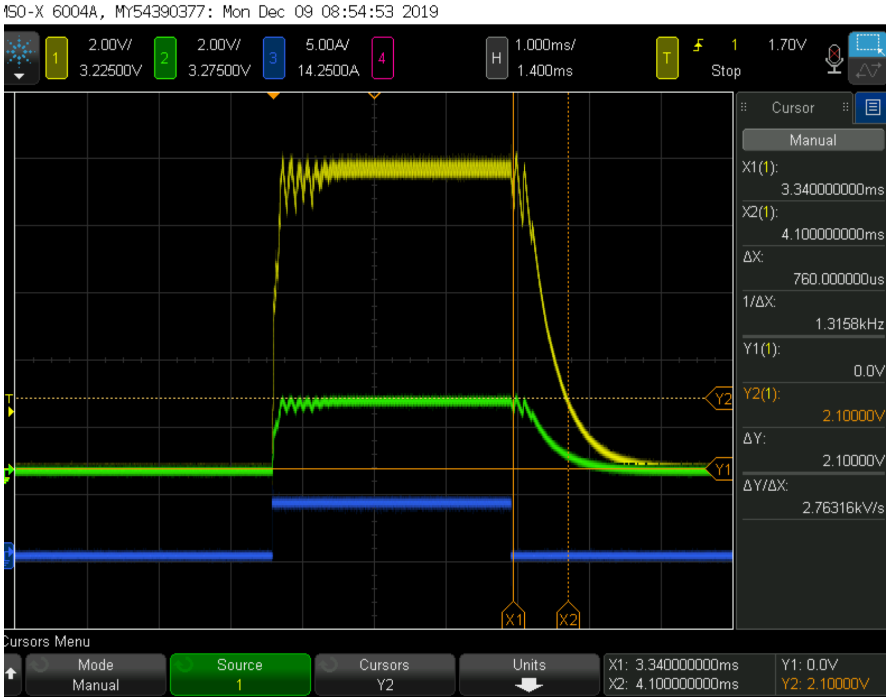


Bottom left is our half-wave rectifier output

Above is the comparison of three signals. From bottom up we have the original bit signal, the extracted modulated signal, and the envelope signal after filtering

Overall Comparison

Before and After



ISO-X 6004A, MY54390377: Mon Dec 09 08:54:53 2019

X1(1): 3.340000000ms
X2(1): 4.100000000ms
ΔX: 760.000000us
1/ΔX: 1.3158kHz
Y1(1): 0.0V
Y2(1): 2.10000V
ΔY: 2.10000V
ΔY/ΔX: 2.76316kV/s

X1: 3.340000000ms
X2: 4.100000000ms
Y1: 0.0V
Y2: 2.10000V

In yellow is the final result from our demodulator. It's amplified so its max value is well above the digital threshold of 2.1V. The frequency of the demodulated signal is off such that the length of digital 1 is 0.8ms longer than the original bit signal's 1.

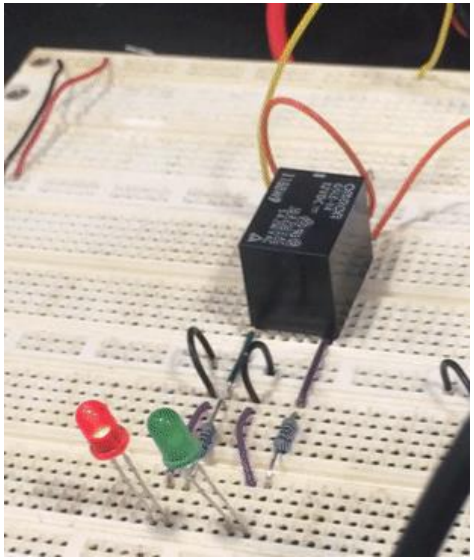
In green is the demodulated signal before amplification

In blue is the original bit signal

UART requires the baud rates of transmitter and receiver to be within 10% of each other. Currently, they are off by 24%. This explains why our message was not properly received and thus why our relay did not function on our PCB.

Appliance Control

Video Verification

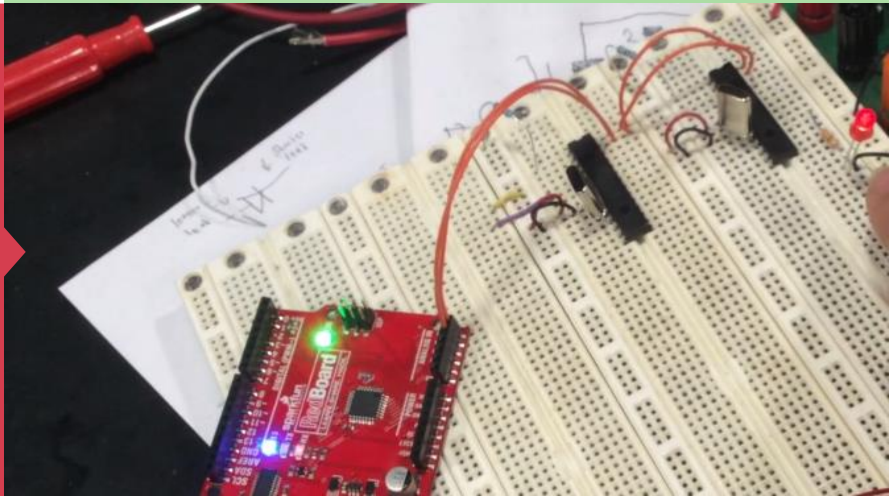


The Relay Switches

A relay controlled by the slave microcontroller does activate when pulsed through a transistor.

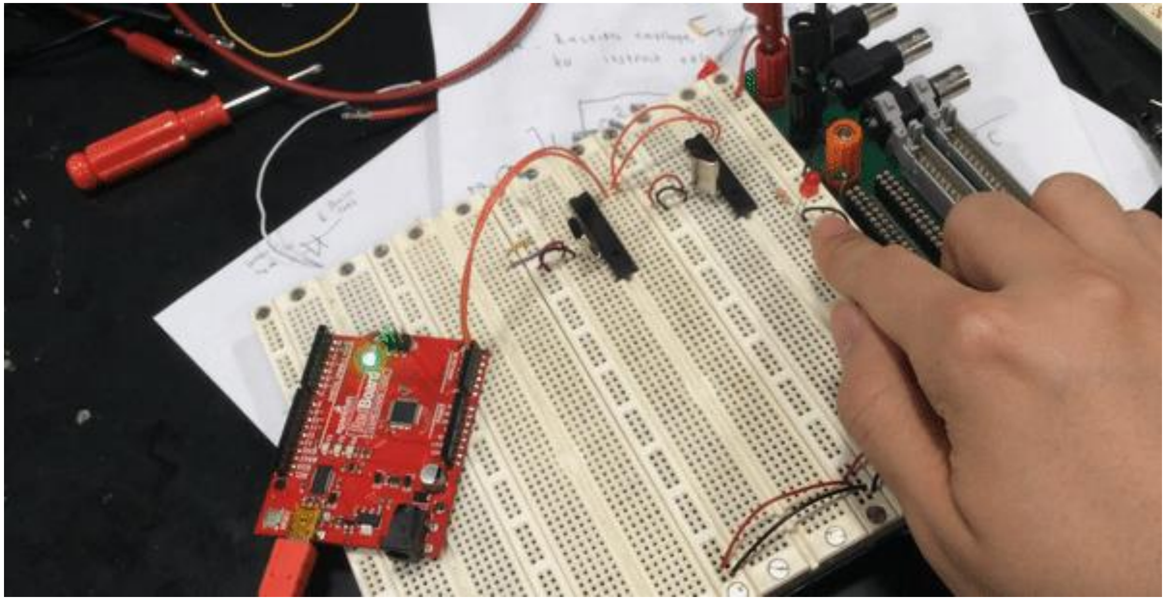
Serial Asynchronous Communication

After a signal is sent, the receiver MC waits until a special start character is detected. It then controls the relay and changes its own global variables based on the received data to store a schedule.



Multiple Schedule Control

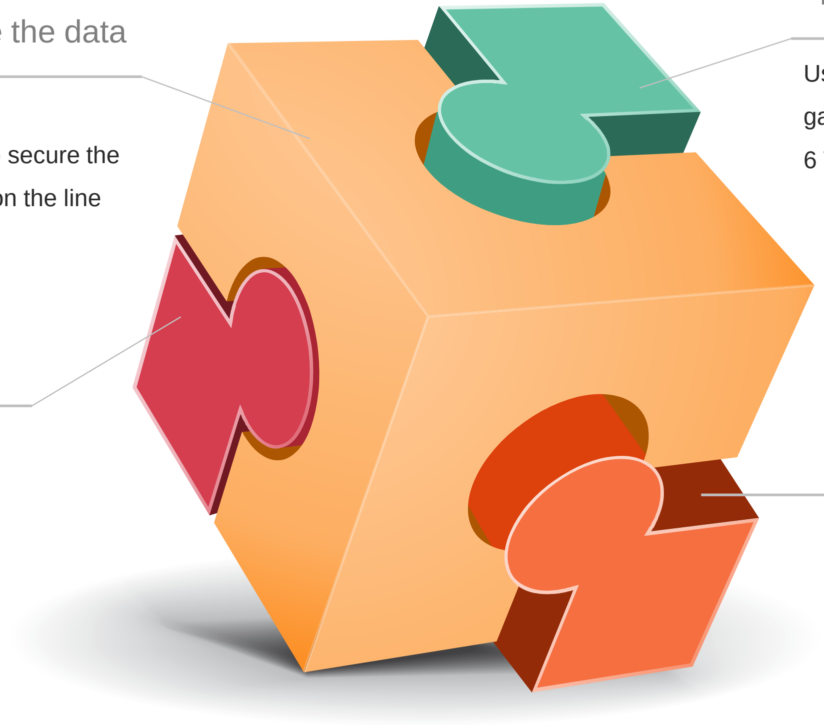
Video Verification



Demonstrated here is a single microcontroller dictating the schedules of two slave nodes (one is an Arduino board and one is another microcontroller). I2C is a protocol that would enable one master MC to control multiple follower nodes.

Future Consideration

Areas where we can improve the project



Secure the data

Add public key cryptography to secure the data once it is on the line

Improve the gain

Use an op amp with larger gain. Current one only allows 6 V/V rail to rail

Better rectifier

Implement a full wave rectifier instead of a half wave.

Relay

Use a lower rated voltage relay so it can be flipped directly with a lower supply voltage

Ethics Considered

Disclosures

Disclose complete limitations of system and testing results honestly. Share all possible conflicts of interests to end user customers and power companies

Data Vulnerability

Currently, the scheduling data can be intercepted. Even with cryptography, good op-security across all levels is needed.

Power Dependent People

We will not market this product to people who depend on power and cannot work their schedules around times without it

Fire and Shock Hazard

Components worn or destroyed from weather damage could cause unintentional shorts.

Thanks for listening to this presentation!

We hope to bring this technology to a whole city in the future

Any Questions?

Thanks So Much
ECE @ Illinois!