5G mmWave Project

High-Level Design

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1 Introduction

Current beamforming technologies require a large array of antennas and are subsequently very expensive. The antennas are active elements and must be individually tweaked to change directions. Using Nico and Dr. Chisum's novel lens antenna prototype, a simple, linear feed antenna can be used in series with GRIN lenses to beam form inexpensively without sacrificing performance.

2 Problem Statement and Proposed Solution

12. 5G mmWave transmission is difficult through modern windows because they are composed of low-emissivity glass to minimize the amount of infrared and ultraviolet light that can pass through glass. This leads to weak mmWave signals within indoor environments. Therefore, there is a need for a 5G WIFI repeater mounted on the inside of a window to bridge services from a 5G base station into a user's home, inexpensively.

13. This demonstration will prove that the GRIN lens antenna can be used to reliably receive mmWaves from a base station and effectively amplify the signal in an indoor environment. This lens technology allows for a signal to be detected through modern low-emissivity window glass. The overall system will include a window-mounted 5G repeater that relies on a stepper motor to scan feed antennae positions to optimize the direction of the beam formed by the lenses.

3 System Requirements

The microcontroller in our design must be able to do the following:

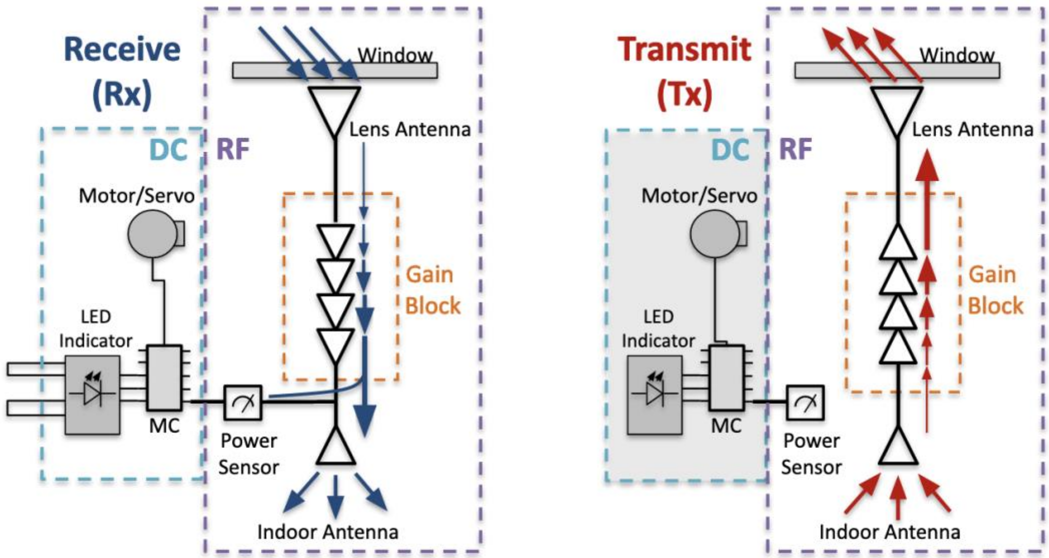
1. Move the lens antenna with a stepper motor and remember its location.
2. Take the information in from the power sensor and understand it.
    a. Display how powerful the signal is using an LED.
3. Scan the entire length of the lens and determine the optimal location for reception.

The device will be powered with a wall wart. Therefore, location to the nearest wall plug must be considered. For the user interface, the user will be able to see a power indicator LED showing the strength of the incoming signal. Installation of the system will require a couple fasteners to mount to the window, in order to amplify mmWaves from an outdoor base station and amplify the signal to broadcast in an indoor environment. Because of this, the proposed solution must remain compact and light without hindering view. In order to gain interest in the product, design must be considered. A sleek, streamlined design that does not become an eyesore when mounted to a window is the goal. Our design requires two systems, both a transmit and receive functionality. To do this, we plan on having two separate systems that are similarly built, one is focused on transmit and the other focuses on receive. We want to make sure that these systems do not take up too much space on the window ledge, so we are considering stacking these devices on top of each other.

4 System Block Diagram

4.1 Overall System:

A system block diagram of all the major components in our system is included below, detailing the separate transmit and receive components of the system.



The major components of our system are listed below:

- Feed Translation Mechanism
- Mounting Hardware
- Casing and Design
- Microcontroller and Associated Functions
- Parallel Plate Waveguide
- Indoor Antenna
- Gain Block
- Ability to adjust lens antenna across the GRIN lens
- Ability to mount the hardware to a window
- Design-conscious casing

4.2 Subsystem and Interface Requirements:

- **Feed Translation Mechanism**
    - Provides the electronic control of the feed antenna position to allow for beam control on the antenna. A proposed solution is to attach the feed antenna to a threaded bushing and the DC/servo motor to the rod to enable lateral shifting
- **Mounting Hardware**

    - Designing and fabricating the mount to attach the lens antenna and translation hardware to the window (i.e Suction Cups)

- **Casing and Design**
    - Inexpensive, 3D printed structure with metal layering
    - Modularize the major subsystems and iterate on the build

- **Microcontroller and Associated Functions**
    - Power reading/indicator
        - Responsible for displaying the current feed antenna position and the current strength relative to the optimal position
        - A power sensor will be used to determine the current strength
    - Translation control (DC Motor)
        - Allow the user to adjust the position of the feed antenna with a simple UI/buttons. Auto-adjustment feature as well to ensure maximum power.
    - Board Design
        - A PCB board will be designed to accommodate the serial communications between the sensors and the microcontroller

- **Parallel Plate Waveguide**
    - Designing and constructing the parallel plates to guide the propagation wave from the GRIN lens to the feed antenna
        - 3D-print the PPWG and add metal layering in the desired spots

- **Indoor Antenna**
    - Used to propagate the amplified outdoor mmWave signal in an indoor environment
    - Ideally a wideband antenna but either 28 or 39 GHz would work as well

- **Gain Block**
    - Allows for transmit and receive signals to/from the indoor antenna

4.3 Future Enhancement Requirements

The purpose of this demonstration is to illustrate proof of concept for the GRIN lens technology to a 5G WIFI repeater technology. The initial demonstration for this project will focus on a controlled stationary 5G base station that will employ static beamforming to provide a fixed radiation pattern. Upon successful demonstration of the system, the project can be enhanced to utilize adaptive beamforming to account for LEO satellite movement. As the position of the satellite changes, the system will dynamically change to measure and store power readings to find its optimal feed position.

5 High Level Design Decisions

Our project will consist of 3 major subsystems: the lens antenna device, power detection and a feed translation mechanism. The 3 subsystems will communicate with the MCU in different ways which will be explained below.

5.1 Lens Antenna Device

This subsystem will handle the majority of the RF workload by receiving or transmitting mmWaves. The GRIN lenses will be used along with the PPWG to focus our mmWaves to maximize input power. In the receive case, these focused waves will be outputted through the device to a feed antenna that is controlled by the translation mechanism subsystem. From here, the gain blockers will be used to amplify the signal before outputting it to an indoor antenna to broadcast. Between the gain blockers and indoor antenna, part of the signal will be split off to the power detection subsystem for analysis. The casing and design of the device will be designed in a CAD software (i.e. Autodesk Fusion 360) and be large enough to hold all of our subsystems. The suction cups will be attached to the casing to provide window mounting capability.

5.2 Power Detection

The power detection subsystem will serve as the bridge between our RF and DC systems by translating the power of our incoming/outgoing RF signals into DC voltage values from 0 to 1.2 V. A 20 dB directional coupler will be used to siphon off 20 dB of the signal for the power sensor into a SMA input for the LTC5966 power sensor. The RF signal will be expected to handle input power from -25 to 0 dBm and output the data in DC values. The DC values will then be converted by an ADC in the MCU to translate the data into a workable form. A unity gain buffer will be inserted to stabilize the incoming analog signal before being sent to the MCU.

5.3 Feed Translation Mechanism

The subsystem will be controlled by the MCU and a stepper motor (Nema-17) that will act on information provided from the power sensor. A lead screw and bushing will be connected to the stepper motor to provide horizontal movement across the entire lens antenna device with 2mm sensitivity. The feed antenna will be connected to the bushing in order to be able to scan across the whole range of the device and determine the position with maximum input power. After an initial scan across the feed, the MCU will instruct the servo to move the feed antenna to the appropriate location.

5.4 Microcontroller

The MCU subsystem will have 3 major roles: Moving the lens antenna and remembering it’s position, converting the information from the power sensor using an ADC and outputting the strength of the signal to an LED, and determining the optimal position of the feed antenna based on the input power. A communication protocol will be needed to interface with the stepper motor. Regarding the determination of the maximum power, a simple algorithm will be employed to compare the previously stored max value to the present one alongside storing its position along the feed.

6 Open Questions

Here are the questions that our group has before we can move forward:

- How we will change between transmit and receive modes and if the two configurations interact. Whether this is possible using one device or if two are completely necessary.
- Our design is 3D-printed, but we need the waveguide to be lined with metal to successfully transmit/receive. We still need to determine how we will apply a layer of copper to the 3D-printed plastic. We want to minimize wrinkles in the thin layer of copper we will use for our project.
- The design of the readout for our available power relative to our optimal configuration of the stepper motor has yet to have been determined. This will need to be discussed more with Nico.
- Determining the microcontroller that we should use depending on the requirements of the ADC.
- Determine what communication protocol interfaces with the stepper motor and the MCU.
- The 3D printing accuracy or more specifically, the surface roughness of our PPWG
- Specifications on our unity gain buffer and ADC system design

7 Major Component Costs

Materials provided by Nico and Dr. Chisum's IP:

- GRIN lenses
- WR-28 Probe Antenna (Feed)
- Waveguide to Coax Adapter
- mmWave Patch Antenna
- 20dB Gain Blocks (4)
- Microwave 20dB Amplifier
- Direcational 20dB Coupler
- Linear-in-dB RMS Power Detector

Materials needed to be purchased:

Product	Quantity	Unit Cost ($)	Total Cost ($)
PCBs	1	15.00	15.00
Stepper Motor	1	8.56	8.56
Lead Screw and Bushing Kit	1	9.99	9.99

Casing[1]	1	Dependent on Final Design	TBD
Microcontroller	1	3.48	3.48
Suction Cups	4	2.49	9.99
3D printed Waveguides[2]	2	32.00	64.00
Coaxial Cable	1	96.18	96.18
Power Supply	1	12.33	12.33
Miscellaneous Electrical Components(Resistors Capacitors, LEDs, Etc…)	TBD	TBD	TBD

8 Conclusions

The problem presented by windows blocking 5G signals can be solved through a window repeater implementing Nico Garcia's GRIN Lens technology. This repeater will incorporate a Lens antenna device, power detection, and a feed translation mechanism controlled by a microcontroller in order to function. We hope that the development and demonstration of this repeater will allow for a proof of concept for Nico Garcia's startup and to help 5G signals enter homes more efficiently.

References
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https://www.omc-stepperonline.com/nema-17-stepper-motor/
https://amzn.to/3pSyqGL
https://bit.ly/3DNgLpc

[1] The 3D printing costs are subsidized by the College and are only included to give a better idea of realistic overall system cost.
[2] See [1]