Zhejiang University/University of Illinois Urbana-Champaign Institute

A Direct Digitally Modulated Wireless Communication System

Senior Design Final Report

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Abstract

In modern wireless communication systems, digital information is traditionally converted into an analog signal using a digital-to-analog converter. This analog signal is subsequently combined with high-frequency microwave signals and transmitted through various devices, including modulators, mixers, amplifiers, filters, and antennas. Upon reaching the receiving end, the signal undergoes a reverse process to extract the original digital information.

However, we are exploring a new method that enables the direct transmission of digital information using programmable coding metasurfaces. These metasurfaces consist of digital units with opposite phase responses, represented by '0' and '1'. By modulating the digital information onto the metasurface using specific coding sequences, it can be transmitted through space under the illumination of a feeding antenna. The information is encoded within the radiation patterns of the metasurface and can be accurately received by receivers located at different positions.

This approach offers a novel architecture for wireless communication that eliminates the need for complex digital-to-analog conversion. Experimental prototypes have been developed to validate this new architecture, and it shows potential for applications where information security is highly important.

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1 Introduction

In the era of ubiquitous connectivity, the rapid growth of communication capacity and the proliferation of wireless devices pose urgent problems and challenges in achieving full-dimensional coverage in the pervasive Internet of Things world. For instance, the complexity of the constructed networks far surpasses that of existing wireless networks, with a significant increase in the number of base stations leading to higher hardware development and maintenance costs. Moreover, the high power consumption of these systems results in substantial energy consumption. As the spectrum gradually moves towards millimeter-wave and terahertz frequencies, more expensive hardware equipment and complex signal processing architectures are required. Therefore, reducing system complexity while developing devices that offer high reliability, large communication capacity, low cost, and low power consumption is a pressing concern for researchers today. Programmable metasurfaces enable flexible control of the amplitude, phase, polarization, and frequency of electromagnetic waves in space.

This project aims to develop and implement an advanced communication system for the next generation of technology, characterized by its streamlined design, superior efficiency, and enhanced security compared to existing systems. The primary objective of this system is to transmit data, particularly images, through the utilization of innovative methodologies.The proposed approach involves encoding information into digital signals, which are subsequently transmitted to a metasurface. This metasurface serves as an interface that scatters electromagnetic waves into space, thereby effectively carrying the encoded information. Upon reception, the transmitted signal undergoes a decoding process, facilitating the recovery of the original information.

The envisioned communication system offers several notable advantages. Firstly, it promises to significantly enhance transmission efficiency, enabling rapid and reliable data transfer. Additionally, the system incorporates robust security measures, ensuring the protection of sensitive information during transmission. Lastly, the proposed system aims to reduce the complexity typically associated with current communication systems, thereby simplifying operation and maintenance.

Furthermore, this innovative communication scheme holds substantial potential for revolutionizing information technology and exerting a profound impact on various domains. Telecommunication and scientific research are among the fields that stand to benefit significantly from this advancement. In its final form, the communication system will comprise three major components: the Transmission Control Unit, responsible for managing the transmission process; the Signal Receiving End, tasked with receiving and decoding the transmitted signal; and the Signal Emitting End, which utilizes the metasurface for efficient signal transmission.By employing a metasurface in the signal-emitting module, the proposed system takes advantage of its unique characteristics to facilitate effective and optimized signal propagation.

In summary, this project endeavors to design and implement a sophisticated communication system that surpasses current standards in terms of simplicity, efficiency, and security. Its potential implications in diverse fields highlight its significance for the future of information technology.

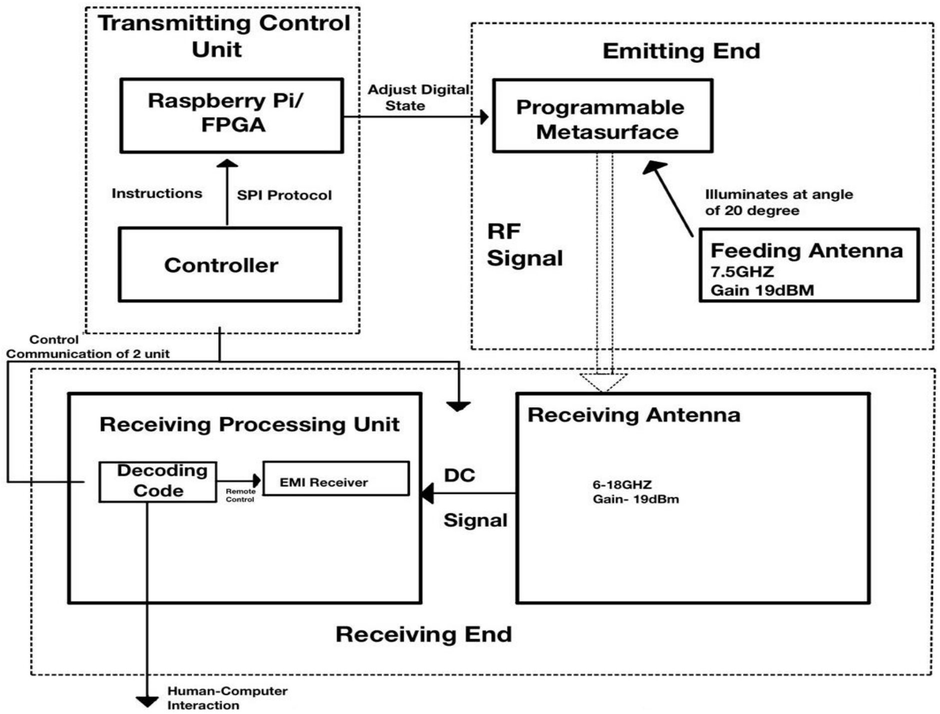

Figure 1: Block Diagram of the System

Before embarking on our project, it is essential to conduct an analysis to identify the constituent parts. Figure 1 illustrates the Block Diagram of our project. From this diagram, it becomes apparent that the project is divided into three main modules: the Transmission Control Unit (TCU), the Signal Emitting End, and the Receiving End.

Before introducing the function of each module, let us first show you the workflow of our design. First of all, we will provide the TCU with a picture, and the Raspberry Pi should decode the picture into binary sequences and then control the state of metasurface respecting to different sequences. Meanwhile, the feeding antenna will constantly emit EM wave to the metasurface and the metasurface may scatter the EM wave corresponding to different states. After that our receiving end will receive the EM wave anddecode it and output the image.

Now let us show you what our individual module consists of. As the name suggests, the Signal Emitting End is responsible for the signal generating, the transmission control unit contributes to controlling thew whole data transmission process by giving orders. And the Receiving End is obliged to receive the data sent from the Emitting End and process it to generate the output. The Transmission Control Unit primarily relies on a Raspberry Pi for controlling the input side of the metasurface. The Signal Emitting End, the focal point of our project, encompasses the key component, the metasurface, along with a Feeding Antenna. The Receiving End consists of two main modules: the Receiving Processing Unit and the Receiving Antenna.

During the actual design process, significant modifications were made to the Receiving End. Initially, our plan involved using a detector for waveform sampling. However, due to the Raspberry Pi's filtering of DC signals, we had to adopt an alternative approach, employing an EMI receiver connected to a computer for signal processing.

Since all of the modules mentioned above is strongly related to each other, the absence of any module of these three may cause the system failure. Therefore, in the introduction part we may not show you the individual performance of the modules separately, we will show your our design of the each module in our following sections concretely.

2 Design

2.1 Design Procedure

According to our block diagram, we have given careful consideration to the implementation of the three modules. The first and most crucial module is the metasurface. To begin with, we conducted research based on the academic papers provided by our advisor, which enabled us to develop the structural design of the metasurface. Our metasurface structure is relatively simple, consisting of 625 diodes arranged in a 25x25 grid. Initially, our design involved using 1,225 diodes arranged in a 35x35 grid. However, to ensure that we could complete the testing within the given time frame, we decided to limit the number of diodes in the metasurface to 625. As a result, the metasurface has a degree of freedom of 5, meaning that each column of the metasurface is connected, and every 5 columns are connected to an input port controlled directly by the Raspberry Pi. The overall structure is shown in the Figure 2.

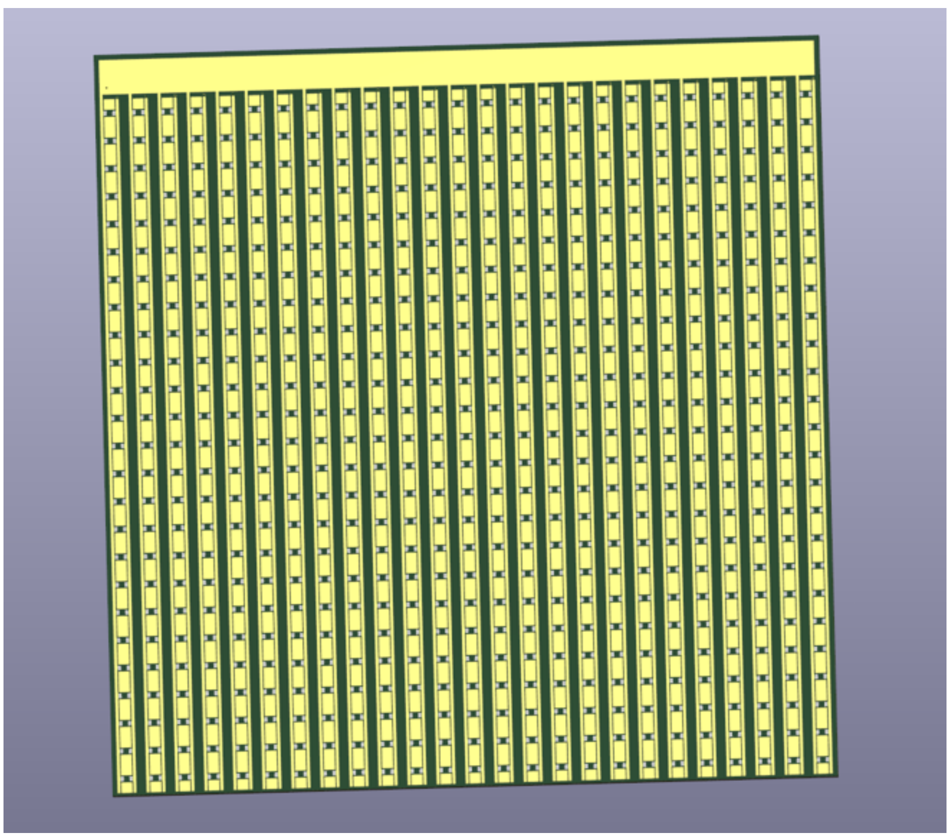

Figure 2: The Structure of the Metasurface

This configuration allows for efficient control and manipulation of the metasurface, facilitating the encoding and transmission of the information-bearing signals. The simplified structure of the metasurface, while reducing the complexity of the implementation, still provides sufficient capability to scatter electromagnetic waves and carry the encoded information effectively. For the feeding antenna, we simply borrow it from the lab, since we need a signal generator to help generate the EM wave we need.

For the TCU, we mainly use Raspberry Pi to control the states on the metasurface.The code for controlling is simple, just some codes controlling pins on the Raspberry Pi. And the Raspberry Pi should be connected to the metasurface. The connection between the Raspberry Pi and the metasurface is the coaxial cable, which will greatly reduce the signal reduction during the transmission.

For the Receiving End, we first want to use the radio detector to sample the EM wave from the receiving antenna, however, we soon find out that the input portal that we choose to receive the data from the radio detector will filter the DC signal, which means that our radio detector could not transmit the sampling results to the processor. Therefore, we find an alternative method, we use the EMI receiver connected with the receiving antenna along with a computer to receive and then process the sampled signal.

2.2 Design Details

From the previous section, we can see that not all the components in our project need to be designed. The following subsections talk about the things that are originated by us.

2.2.1 Metasurface

The reference paper uses 35*35 pieces of metasurfaces and 7*35 particles form a unit which means 5*1 DOF. And my final design use 25*25 particles of metasurface and 5*25 particles form a unit for saving cost and has the same transmitting efficiency.

As the Figure 3 suggests, the PCB has 3 main layers, a substrate layer between two copper layers, the substrate material is F4BM265 which has 0.001 loss tangent and 2.65+i*0.003 permittivity. And the thickness of substrate layer is 3mm, thickness of two copper layers is 1oz. The particles' structure is same as the reference paper, with another copper layer is entire whole copper to avoid penetration of EM waves and can be regarded as GND of all channels of signals. The diodes we use are Skyworks, SMV-1231, which is also different from the reference paper.

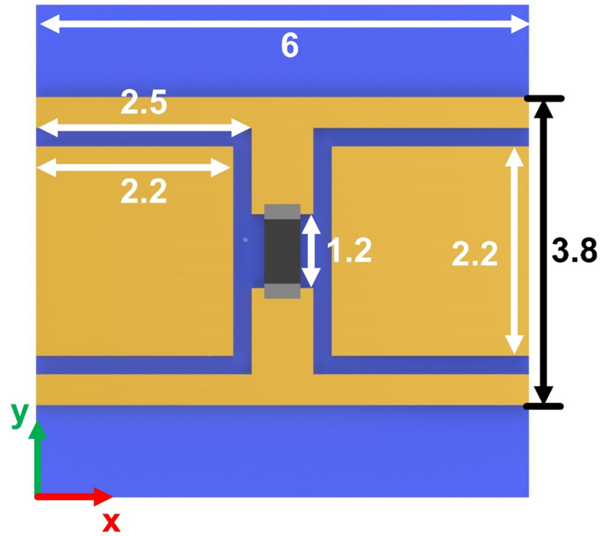

Figure 3: Metasurface Particle's Structure

As the Figure 4 suggests, the blue part in red rectangle is bonding pads I prepared for the pin header connector. And they are placed at the back of board in order to keep scattering characteristics of the front of the board. And 5 digits signals will share the same ground wire. The arrangement of wires is also showed in Figure 4.

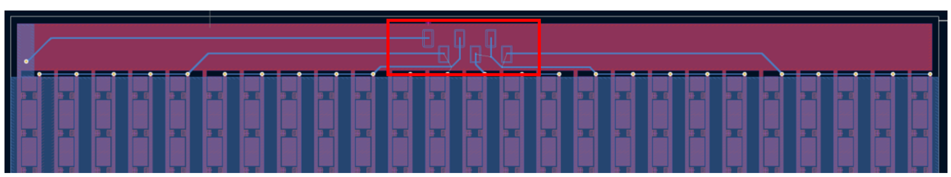

Figure 4: Upper Part of the Metasurface

2.2.2 Transmission Control Algorithm

The control unit contains a Raspberry Pi, a monitor, a bread board and some wires. Ground of 5 signals connect together on bread board. We use Python to control the GPIO components in Raspberry Pi, Python has RPi.GPIO module which is easy to use. As the metasurface features a degree of freedom of 5, it can be in a specific status ranging from 00000 to 11111. With each bit that the Raspberry Pi transmits to the metasurface, it can control five columns on the board. This ultimately results in the metasurface having a total of 32 states. We write some scripts, one of which is to run automatically on 32 states. Every state lasts some seconds to ensure the received signal's stability and differences of each states. Also we write scripts to run only on two states to make sure the states we have found is truly distinguishable.

2.2.3 Decoding Algorithm

After receiving the sampling value, we need to decoding the received signal and transform it into digital signal. We try several decoding strategies and find an optimal one.

1. Using the absolute value of power to decode. Since the value of power of the two states has a apparent difference, we think maybe we can use a range of absolute value to distinguish the two states.

2. Using an average value to divide '0' and '1'. We plan to use one value to distinguish the state '1' and state '0'. The value is the average of the maximum value and minimum value we have sampled. The sigals with a value above that value should be decoded as '1' and others are '0'.

3. Adding calibration codes when encoding. When encoding the image, we add several calibration codes every several bits. Then the bits of image that are closer to calibration code '1' should be decoded as '1' and vice versa. In Figure 5, the red points are calibration codes and the blue points are bits of information we transmit. This will sacrifice some transmission efficiency, but we believe it can improve accuracy.

4. Adding time shifts when we process the received data. Since there is time drift between our sending side and receiving side, resulting the time interval division more and more inaccurate as time goes on, the part of the image data has a strong tendency to be incorrect because wrong calibration codes or data points. We add the time drift constant Eps and let the receiving side to adjust its time clock so that the two system can approximately synchronize during transmitting.

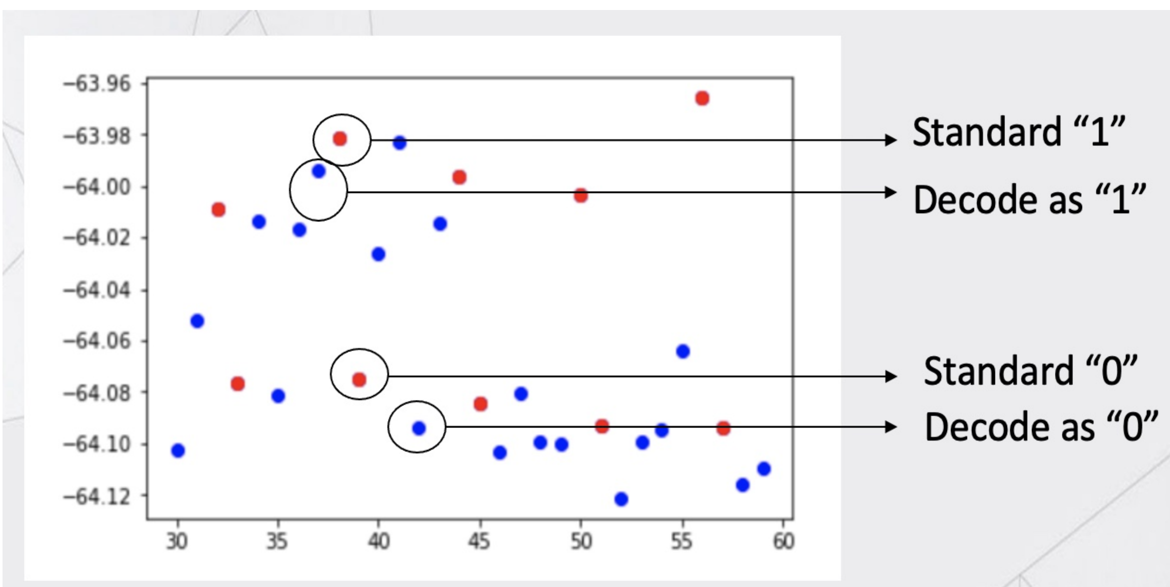

Figure 5: The Decoding Strategy 3

2.2.4 Image Drawing Interface Design

In order to better serve for our testing purpose of the transmission functionality of the system, we develop an image drawing interface for users to draw a 20 * 20 pixels black-white image and transmit via the metasurface. The picture can be drawn by clicking pixels in the chessboard-like interface with mouse at the sending side. The binary data is also saved at the same time and the tranmission control unit can use it to transmit signals for the receiving end to decode back to the original image. The illustraion of this interface is shown in Figure 6.

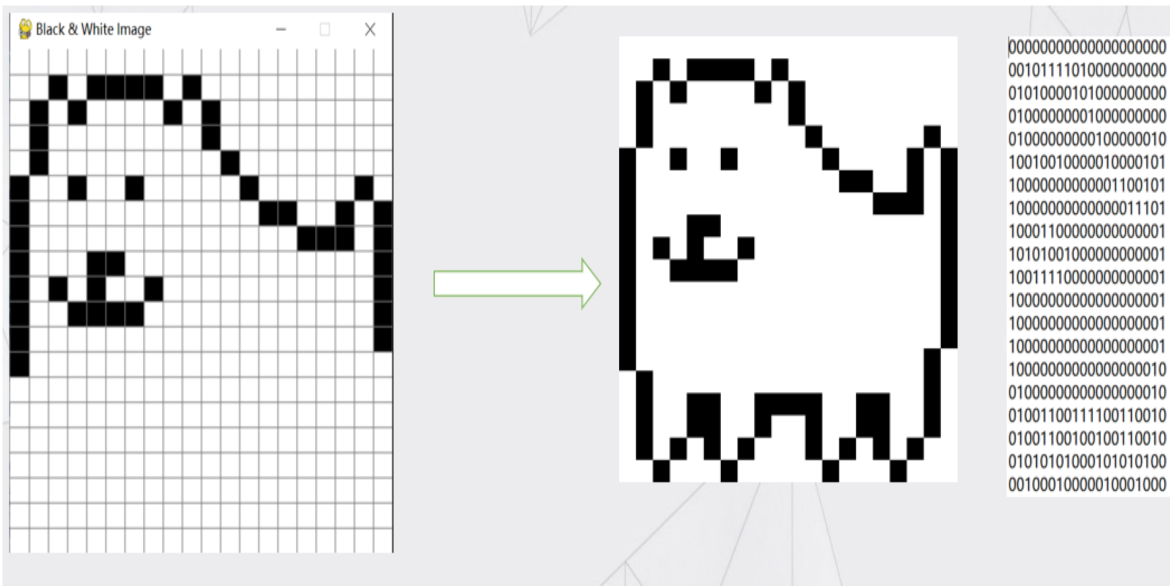

Figure 6: The Interaction Interface and the Data it Generates

3 Verification

Since our system is built with new technology, we think it is necessary for us to test whether our project is applicable, so we first need to do some simulations both on the metasurface and the whole system.

3.1 CST Simulation on Metasurface

After testing on several frequency range, we find some satisfying results. The Figure 7 and 8 shows the result of CST simulation. In Figure 7, we can see that the magnitude is close to 1 in then range of 5.5 to 6 GHz and 7 to 9.5 GHz, which means that the metasurface will reflect wave with strong magnitude and can be detected more easily. This means that the working frequency can be chosen from 5.5 to 6 GHz and 7 to 9.5 GHz. In Figure 8, the result shows that the phase has a difference near to 180 degrees near 6.5GHz or between 7.5GHz to 7.7GHz, this indicates that the difference in different states will be clear to see. So, the working frequency can be chosen near 6.5GHz or between 7.5 to 7.7. The simulation results inspire us to choose 7.5 to 7.7 GHz and we test that 7.5GHz works pretty well in later experiments.

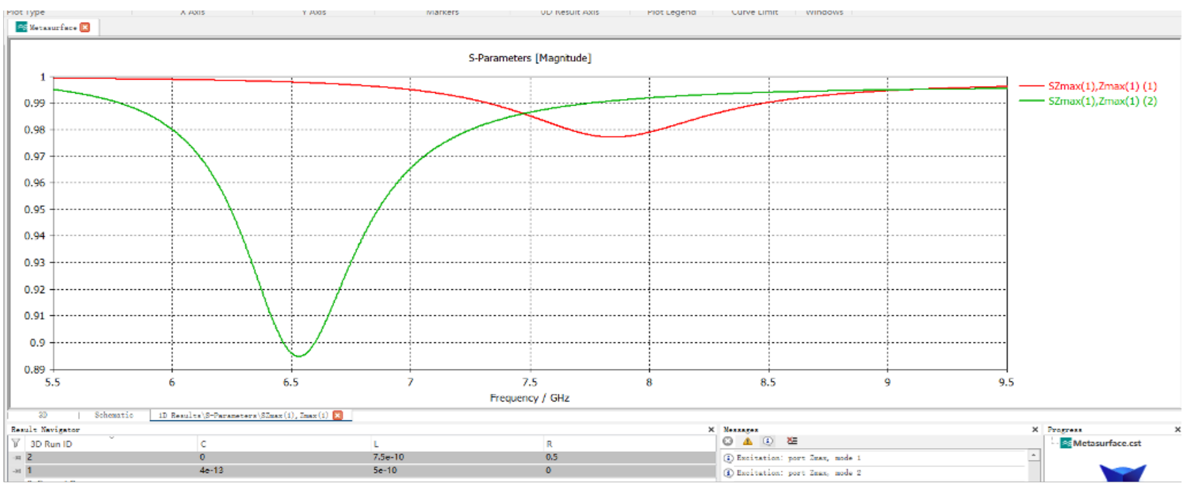

Figure 7: The Magnitude in Terms of Frequency

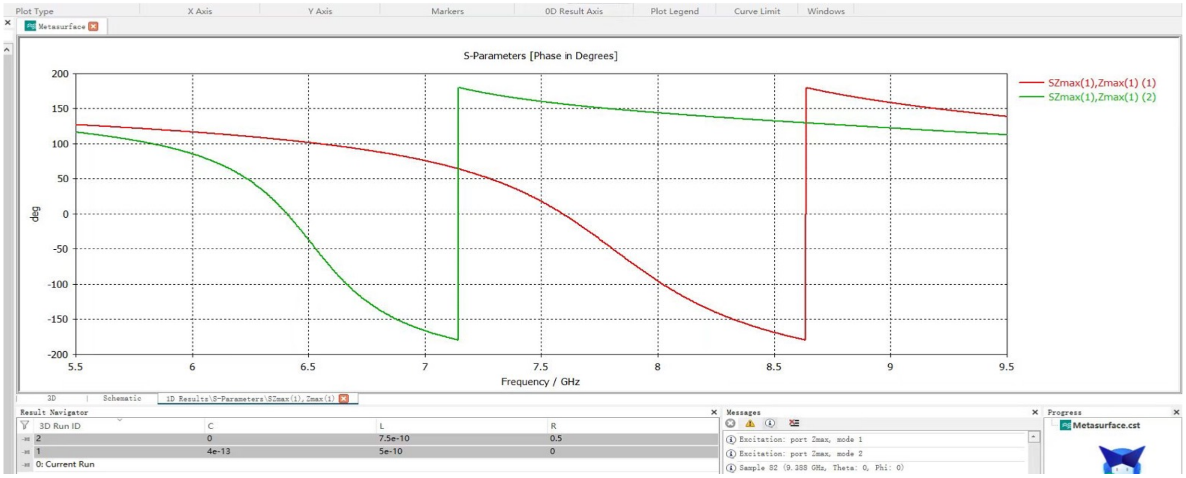

Figure 8: The Phase in Degrees in Terms of Frequency

3.2 System Simulation

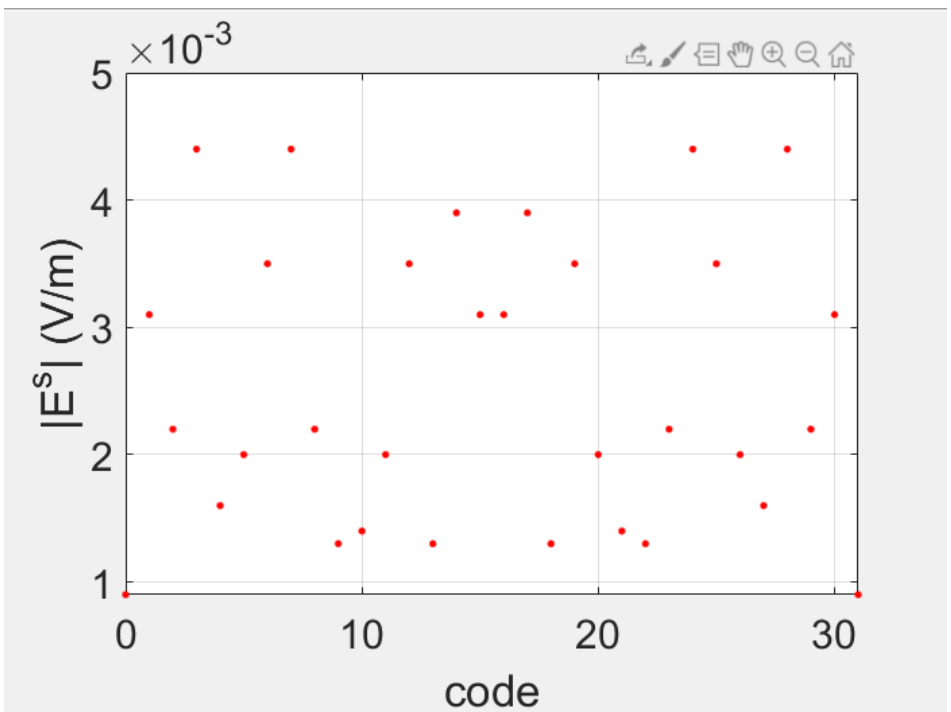

Figure 9: EM Wave Results on θ=45 and ϕ=0

Despite the section being titled "System Simulation", our main focus is indeed on finding suitable states for signal transmission. The principle of signal transmission in our designed metasurface is as follows: When the feeding antenna illuminates the metasurface with an electromagnetic (EM) wave, the metasurface scatters the EM wave. And our simulation is to record the EM wave magnitude in some directions to find the appropriate state. To simulate this process, we employ code that defined the entire space in a spherical coordinate system. The range of theta is set *theta* from 0 degrees to 90 degrees, while the range of *phi* is set from -180 to 180 degrees. We then simulate various characteristics of the metasurface using the code to obtain the final results. Figure 9 shows our simulation results in the direction of θ=45 and ϕ=0.

The horizontal axis of Figure 9 is the sequence from 0 to 31. Since our metasurface has 5 input signal pins, the states on board could vary from 00000 to 11111, which are 0 and 31 respectively in decimal representation. So basically Figure 9 shows the magnitude of the EM wave in the direction of θ=45 and *phi*=0 within the variation of states from 0 to 31. It's easy to notice that not all the states will have different EM magnitudes, there are several points that actually have the same magnitude. Therefore, we have to pick a unique state that provides a unique magnitude in each direction.

The Figure A1 shows the maximum states we find in each *phi* direction as well as the unique state's list. Since our test will be done in far-field conditions, meaning that the change in *theta* direction may not be considered. So we just record the change in the ϕ direction. We can see that the column on the leftmost is the value for ϕ, the middle several columns are the unique states in the specific direction. The "Valid States" column shows the number of unique states that will be used and the "Total States" column records the number of unique state we find.

After finding the unique states in different directions, the next thing to do is to determine the communication protocol. The Figure 10 shows how our communication protocol is determined and a case for the data transmission.

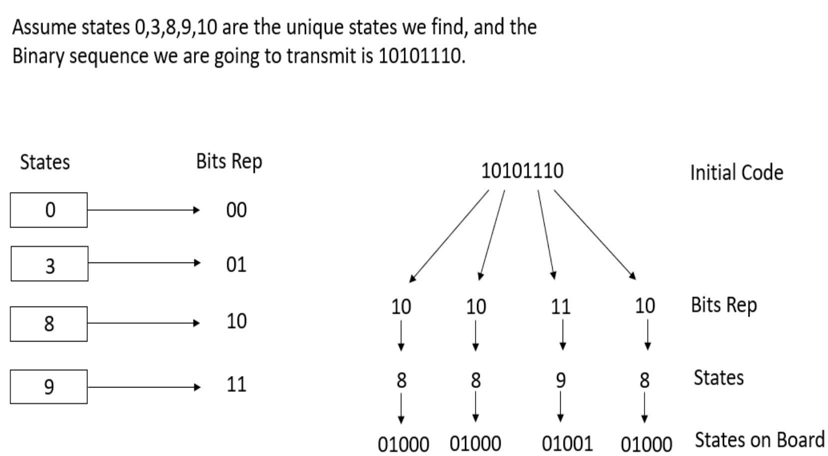

Figure 10: Communication Protocol and A Simple Case

3.3 Requirements & Verification

The high-level of the R & V table is shown in Figure A2. For the first Requirement, accuracy, we have tested on a image generated by our own, and the accuracy is 100 percent. Figure 11 is the comparison of the initial image and the image we receive and decode at the receiving end.

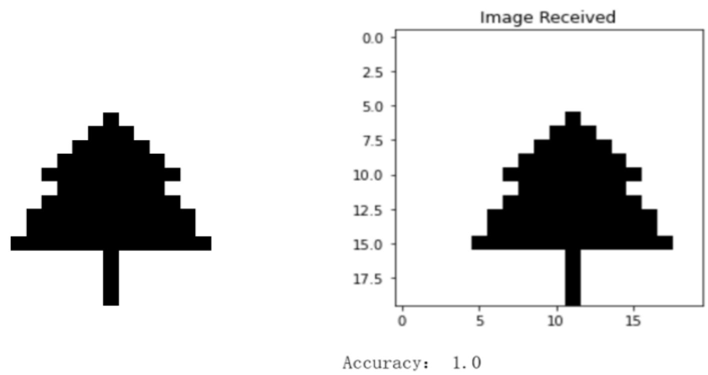

Figure 11: Comparison of Initial Image with Received One

For verifying the stability of our system, as it mentioned in the RV table, we have left many things inside the anechoic chamber which could offer some interference to the system we operated. Figure 12 is the messy environment we set up for the system.

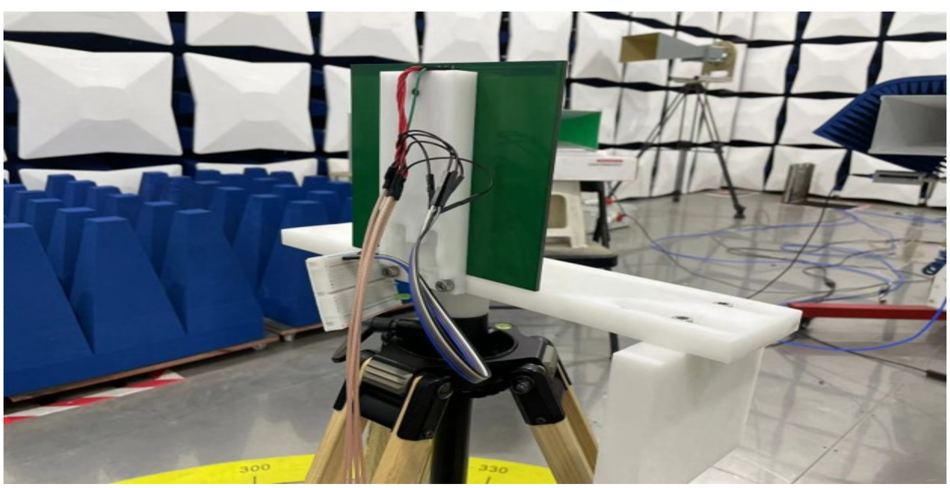

Figure 12: Messy Setup for Verification of Stability

When we test under such circumstances, our result is the same as the previous one, about 100 percent correct, therefore, to conclude that our system is quite stable under messy surroundings is reasonable.

For the last one, the security of information, it could be much more instinctive and we don't even need to test on it. If we just touch the receiving antenna and make a slight displacement of the receiving antenna, the EM wave magnitude could be completely different and our communication manual will be completely wrong, which means that even ourselves could not figure out what the initial image would be. It's also the reason why our project is called "direct".

4 Costs

4.1 Cost Estimation

Before our calculation about the total cost we have on the materials we need, we first need to compute the cost on the group members in our group. As it mentioned in the Design Document, we agree to set the cost of each person should be about 30 CNY/h, and it we will have 12 hours each week to research on the project. Besides, the total time we need for the whole project is about 8 weeks.Therefore, our total cost for the human resources should be as following:

$$4x30x12x8=11520 \text{ CNY}$$

And for all the costs we have to make for the senior design project, they are listed below in Table1.

Components	Quantity	Cost/Unit (CNY)	Total Cost (CNY)
25x25 Programmable Metasurface	1	4883	4883
Raspberry Pi	1	628	628
Microwave Anechoic Chamber	22 Hour	1000	22000
Coaxial Cable	12	28	336
Radio Detector	1	1960	1960
Sum Cost			29807

Table 1: Costs on Materials

For the 25x25 programmable Metasurface, we contacted a factory which is capable of printing our PCB design on the board. The total cost we have here in the table is the cost on the raw materials of the board and processing of the metasurface schematic.

For the Raspberry Pi, we bought the board on the internet.We double confirmed the parameters we require for the Raspberry Pi after we successfully fabricated the Metasurface and configured the coding sequences. The cost listed on the table above is the price we need for the Raspberry Pi.

For the Microwave Anechoic Chamber, we make appointment with the Laboratory Administration Office of International Campus Zhejiang University. The cost is given by the Laboratory Assistant. And the costs for the Anechoic Chamber are not paid by ourselves. The professor did help us to solve the problem.

For the coaxial cable, we bought them from Taobao too. There are two pins on the metasurface so theoretically we just need 6 cables. However, since the lab didn't have the transfer plug for the Raspberry Pi, we have to buy another 6 cables to deal with it.

For the Radio Detector, we bought it from Taobao and intended to sample the EM wave. however, the trick didn't work out so we have to left the detector in the box.

4.2 Schedule

Week	Task	Responsibility
3/13/23	Project proposals due and reading reletive paper	All
3*3/20/23	Draw matesurface with KiCAD	Bingsheng Hua
	Run the simulation to determine the coding pattern of the metasurface	Luyi Shen
	Try to simulation electromagnetic properties and function of the metasurface with CST	Qingyang Chen & Dingkun Wang
2*3/27/23	Fabricate the programable metasurface	Bingsheng Hua & Luyi Shen
	Run the simulation to check whether the pattern we designed is well-functional	Qingyang Chen & Dingkun Wang
2*4/3/23	Print our design programable metasurface on the actual board and test it with FPGA	Bingsheng Hua & Luyi Shen
	Finish the simulation of the metasurface data transmitting	Qingyang Chen & Dingkun Wang
2*4/10/23	Build the transmitting control unit	Bingsheng Hua & Luyi Shen
	Build the receiving process unit	Qingyang Chen & Dingkun Wang
4/17/23	Merge the whole system together and test it	All
4/24/23	Design the algorthm to recognize the signal matesurface transmit and do more test	All
2*5/1/23	2*Finish final paper and presentation	2*All

Table 2: Schedule for the Design

5 Conclusions

5.1 Discussions On Improvement

5.1.1 Problem Analysis

Although our wireless transmission system achieves a relatively high level of accuracy in terms of the final image received, it is important to acknowledge that our design still harbors several inherent issues and challenges. One critical aspect that necessitates improvement in our wireless transmission system pertains to the issue of transmission speed. At the receiver's end, we have employed the transmission of data from the EMI receiver to the computer for analysis via its remote control port. However, a significant concern arises due to the inherent limitations of the EMI receiver's sampling rate. Primarily, the scanning time of the EMI receiver is subject to the selected resolution bandwidth. And augmenting the resolution bandwidth indiscriminately to minimize scanning time yields substantial errors in the received power values. Thus, a judicious trade-off compelled us to confine the scanning time within the range of 12.46 ms. Nonetheless, scanning time alone does not singularly determine the transmission speed. The data interchange between the EMI receiver and the computer necessitates the execution of a script, thereby introducing additional processing time.Consequently, an appreciable temporal disparity of 80 ms is somehow unavoidable.

Meanwhile, we could not just shift two states on metasurface after 80ms because we can see from the Figure 12 that the differences between the maximum magnitude and the minimum magnitude is so small, approximately 0.16dBm differences. Therefore, we could just pick two states to form our communication protocol,which is greatly less than my simulation result.

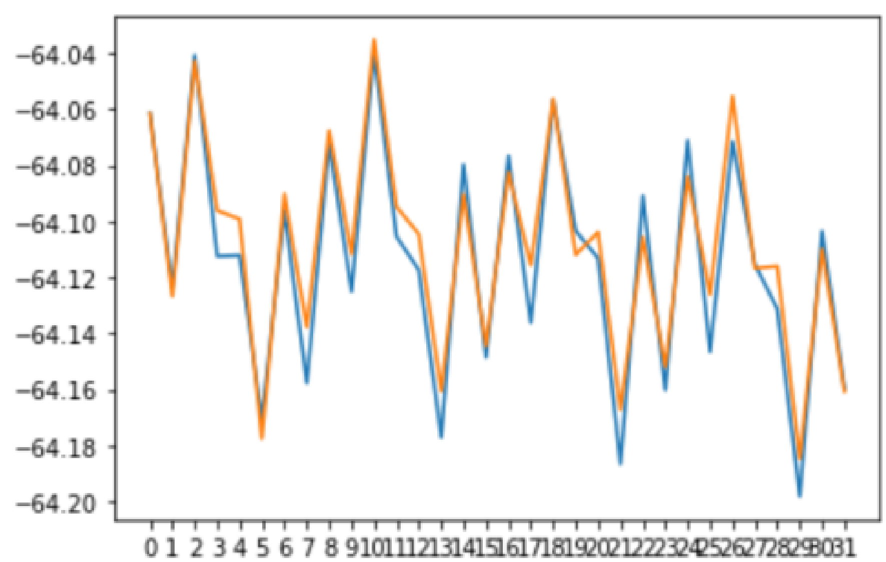

Figure 13: Power Magnitude for 0-32 States

Although the magnitude difference is quite unnoticeable, the fluctuation of the magnitude we received is quite huge. For example, if the state 20 is expected to fluctuate from the -64.12 dBm to -64.14 dBm, the real experiment may find that the magnitude could vary form -64.04 to -64.24. So in order to neutralize the impact of those extreme values, we have to set the time between each states to 500 ms to collect 6 values of the states and compute their average value to represent the magnitude of the state.

5.1.2 Possible Solutions

We can see that the problem of low transmission speed could be mainly blamed on the EMI receiver, so one of the methods, which could be the simplest and most possible method to improve the transmission speed is to find an alternative for the EMI receiver. For example, although we find that the radio detector may not be an appropriate solution for our project, we could still find a way to make it applicable. The major reason for denying the radio detector is that the Raspberry Pi will filter the DC signal from the Microphone port. So if we could find another way to deal with the DC signal from the radio detector, it could be an ideal alternative since it will become the real-time sampling for the EM wave and the time latency could be much lower than the communication between the EMI receiver and the computer, which is our current method.

Another thing that could be fixed is the signal generator. Although theoretically, the signal generator should output the EM wave in a fixed magnitude. But unfortunately, if we shut down all the connections with the metasurface and let the receiving antenna directly face the feeding antenna, the EM magnitude we got from the EMI receiver is still fluctuating. So in order to make the signal more steady, we may try to find other reliable signal resources.

5.2 Conclusion of our Works

Although there is room for improvement in our design, we believe that our project prototype has achieved the basic functionalities required for a wireless communication system. This successful implementation validates the feasibility of using programmable metasurfaces to construct a digital modulated system. With the gradual maturation of metasurface-related technologies, it holds the potential to become the core of future next-generation communication technologies.

The design experience of this project has also made us acutely aware of the significant gap between theory and experimentation. While our DDM system is relatively simple in theory, we inevitably encountered numerous challenges and issues during the experimental process. At times, these experimental results even had a disruptive impact on our previously established design approach.

In practice, the issues we faced include, but are not limited to, inconsistencies between the performance of metasurface elements and theoretical expectations, noise interference during signal transmission, and the propagation and attenuation effects of electromagnetic waves. Addressing these issues required us to iteratively adjust and optimize our experimental approaches to ensure the stability and reliability of the system's performance.

At the same time, through the implementation of this project, we have come to recognize the close connection between a sound theoretical model and precise experimental testing. The translation from theory to practice necessitates continuous iterations, adjustments, and validations to enable the system to achieve its intended functionalities in real-world environments.

In conclusion, despite encountering some challenges in the design process, our project prototype has successfully realized the basic functionalities of a wireless communication system. This achievement validates the potential application of programmable metasurfaces in digital modulated systems and provides robust support for the development of future communication technologies. However, we must also acknowledge the problems and gaps that arose during the experimental process, which will motivate us to further research and improve upon them to drive the advancement of this field.

5.3 Ethics

In order to ensure that our project is conducted with the highest level of integrity, we have made a commitment to uphold the IEEE code of ethics [2] and the ACM code of ethics [3]. Our primary objective is to ensure that all design work is original and conducted by our team members. We will not engage in any form of plagiarism or misrepresent others' work as our own. While we may communicate with experts in the field for technical guidance, all design and testing assignments will be completed solely by our team, and any ideas or concepts inspired by external sources will be properly cited [2, 3].

Furthermore, we recognize the importance of safety in our project, particularly with respect to the materials we use and the levels of RF radiation produced. We are committed to ensuring that all materials used are safe and pose no threat to the health of individuals involved in the project or the wider community. We will also take measures to keep RF radiation at an appropriate level, in accordance with established safety guidelines. To this end, we will closely follow the laboratory safety regulations and guidelines set forth by the relevant authorities, such as the laboratory staff and other regulatory bodies. [2, 3, 4].

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A Appendix

Phi													Total States	Valid States	Thita
-180	10	1	0	5	11	3	2	14	9	4	6	0	11	8	13.5
-162	14	0	3	10	8	2	1	6	11	5	4	9	12	8	18
-144	10	6	9	14	5	4	2	3	1	0	0	0	10	8	4.5
-126	10	6	9	14	5	3	4	2	1	15	0	0	11	8	4.5
-108	10	6	9	14	5	3	4	2	1	0	0	0	10	8	4.5
-90	3	1	0	0	0	0	0	0	0	0	0	0	3	2	0
-72	10	6	9	14	5	3	4	2	1	0	0	0	10	8	4.5
-54	10	6	9	14	5	3	4	2	1	15	0	0	11	8	4.5
-36	10	6	9	14	5	4	2	3	1	0	0	0	10	8	4.5
-18	14	0	3	10	8	2	1	6	11	5	4	9	12	8	18
0	10	1	0	5	11	3	2	14	9	4	6	0	11	8	13.5
18	14	0	3	10	8	2	1	6	11	5	4	9	12	8	18
36	10	6	9	14	5	4	2	3	1	0	0	0	10	8	4.5
54	10	6	9	14	5	3	4	2	1	15	0	0	11	8	4.5
72	10	6	9	14	5	3	4	2	1	0	0	0	10	8	4.5
90	3	1	0	0	0	0	0	0	0	0	0	0	3	2	0
108	10	6	9	14	5	3	4	2	1	0	0	0	10	8	4.5
126	10	6	9	14	5	3	4	2	1	15	0	0	11	8	4.5
144	10	6	9	14	5	4	2	3	1	0	0	0	10	8	4.5
162	14	0	3	10	8	2	1	6	11	5	4	9	12	8	18
180	10	1	0	5	11	3	2	14	9	4	6	0	11	8	13.5

Figure A1: Maximum States in Each ϕ Direction

Requirement:	***Verification:***
1.Accuracy. Our system should be able to transmit string or even pictures within accuracy more than 90%.	**1.**We draw the same picture in the receiving end and compare it with the initial one.
2.Stability. Our system should be able to work in an environment with obstacles and other interference inside the chamber.	**2.** We have left many things and instruments in the Anechoic Chamber to simulate the case where obstacles exist.
3.Info Security. The data we transmitted shouldn't be compromised in other directions.	**3.**We use the same communication protocol and adjust the position of the receiving antenna, the result is completely different from the initial picture.

Figure A2: R & V Chart