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Direct Digital Modulated Wireless Communication System

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1 Introduction

1.1 Background and overview

Communication system is closely related to our life. We measure communication systems primarily by their effectiveness and reliability. In fact, validity and reliability are a pair of contradictory indicators, and they need a certain compromise. We hope to improve the efficiency of communication system on the basis of guaranteeing the accuracy of communication.

1.2 Basic Solution

The project is to design and implement a kind of communication system for the next generation technology which is much more simplified compared to the systems that existed. The final version of the system should be expected to be able to transmit data like images and videos. Our basic idea is that the information can be send in digital signal form to metasurface, EM waves will be sent to the metasurface and be scattered to space. The information we want to transit will be carried on scattered EM waves. And once the receiver receives the signal it will be decoded into the original information.

Basically, our project is a kind of innovation or re-creation of an existing communication system. The biggest difference between our design and other systems could be the method to process the information. There is a significant component in our future design called metasurface, which could be used to adjust the phase, magnitude, and polarization along with other significant properties of EM waves which can send multi-digit signal at same time.[1]

As for the functionality of our project, we think it could be an interesting trial and we have faith to finish it since everything we need in the project we could find plenty of research materials and reports to look into. Even if the project is not applicable in the end, we believe the application of the metasurface material could be still powerful in communication system.

1.3 Programmable Metasurface and DDM System

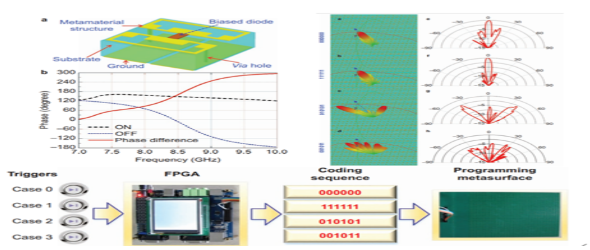

Figure 1: The implement of Metasurface

Metasurface could be used to adjust the phase, magnitude, and polarization along with other significant properties of EM waves.Basicially, it is a board with integration of individual units. These units are setting aline on the board. The structural units, referred to as artificial 'atoms' and 'molecules', can be customized in terms of shape, size, and lattice constant, while interactions between them can be engineered. By manipulating these "atoms" in a certain way, we could let them send out signal with coded information. For example, a group of 5 atoms could be used to represent binary code "00001" since the EM wave coming from the diode in each atom of conducting and cutoff state is different. The figure above is one of our proposed implementation of the metasurface. To program the metasurface we design, we have to attach it with the FPGA board. The FPGA is controlled under the instructions of MCU(Micro Control Unit) and adjusts the digital states of the controllable column of the metasurface.

The second part of our project is the DDM system which is short for the Direct Digital Modulated System. Direct digital modulation is a unique modulation method that eliminates many previously required components from a radio transmitter to create a simple, flexible, cost effective alternative.It contains receiver, where information will be received and decoded, transmitting control unit mainly comprises of a microcontroller unit and an FPGA board,a receiving unit, a feeding antenna and a receiving antenna.The basic working flow of our suggested version is shown below.

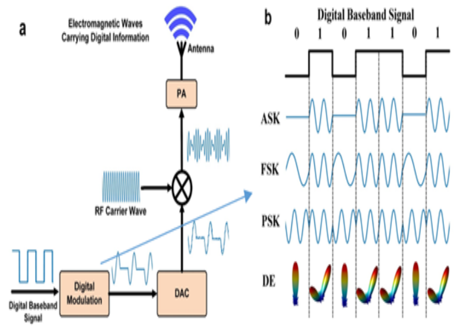

Figure 2: The flow of DDM system

1.4 High-level Requirements

1.Accuracy: The information data we will collect in the receiving end should be accurate. For example, there should not be any misplacement of any pixel for the image we have from the emitting end.
2.Resolution: The picture we get at the receiving end should be at appropriate resolution rate, there shouldn't be too much loss on the colored pixels on the receiving end.
3.Speed: The time spent on the information transmission as well as figure regeneration shouldn't be too long.
4.Safety: All of the equipment involved in the project should be working under their requirements, and radiation should be limited.
5.Low Energy Consumption: The major power source of the system is DC voltage source, the current and voltage should be limited under a threshold.
6.Operability: The human-computer interaction should be enhanced to make sure we don't have to do too much work.
7.Stability: The system should demonstrate ability to get rid of disturbance of outside noise.
8.Adaptiveness: The system should be able to function normally under different environmental conditions.
9.Information Security: The information transmitting in the system should be difficult to encrypt.

2 Design

2.1 Block Diagram

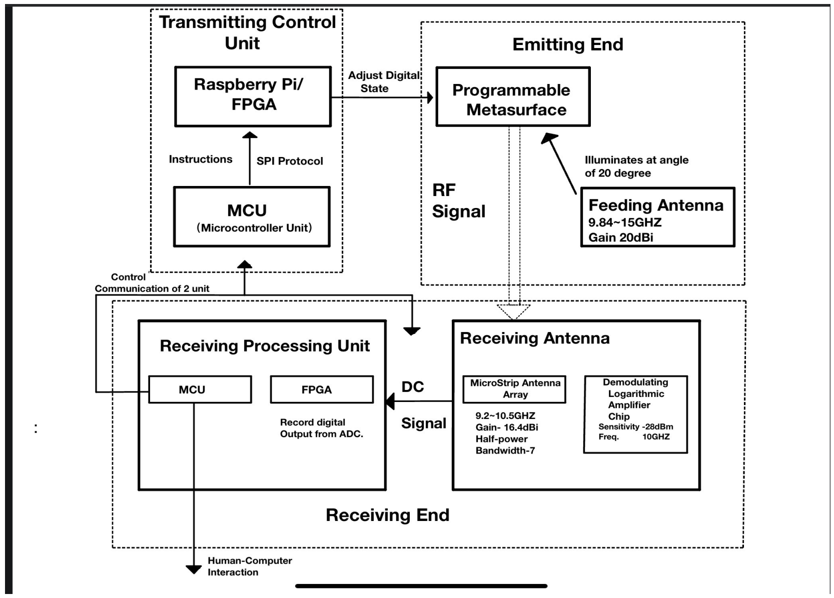

Figure 3: Block Diagram of the System Combined

2.2 Subsystem Overview

2.2.1 Transmitting Control Unit

The transmitting control unit is responsible for controlling the programmable metamaterial through Raspberry Pi and transmitting the data to the receiver through a wireless transceiver module. It includes an STM32F767IGT6 MCU and an NRF24L01 wireless transceiver module, which communicate through the SPI protocol. The transmitting control unit adjusts the digital states of each controllable column on the programmable metamaterial, and interacts with the receiver to determine the available digital states for reliable transmission at a given noise threshold.

Connection with other subsystems:

Connection to emitting end: adjust the digital state.

Table 1: Transmitting Control Unit

Requirement	**Verification**
The transmitting control unit must adjust the digital states of each controllable column on the programmable metamaterial to transmit data	Test that each controllable column can be adjusted to each of the 32 possible digital states
The transmitting control unit must reliably transmit data to the receiver through the wireless transceiver module	Test the transmission of multiple packets of data over different distances and in varying levels of interference
The transmitting control unit must interact with the receiver to determine the available digital states for reliable transmission at a given noise threshold	Test the interaction between the transmitting control unit and receiver to ensure the receiver can identify the available digital states at different noise thresholds

2.2.2 Emitting End

The emitting end includes a feeding antenna;a programmable metamaterial, and is responsible for transmitting data to the receiving end. The feeding antenna operates from 9.84 to 15 GHz with a gain of 20 dBi, and the programmable metamaterial generates 32 digital states from 0 to 31 by biasing its corresponding voltages. The emitting end transmits multiple n-bit-long symbols into free space through the programmable metamaterial.

Connection with other subsystems:

Connection with receiving end through RF wave to transmit information.

Table 2: Emitting End

Requirement	**Verification**
The feeding antenna must operate from 9.84 to 15 GHz with a gain of 20 dBi	Test the feeding antenna across the operating frequency range to ensure consistent performance and measure the gain of the antenna
The programmable metamaterial must generate 32 digital states from 0 to 31 by biasing its corresponding voltages	Test each controllable column to ensure it can be biased to each of the 32 possible voltages
The emitting end must transmit multiple n-bit-long symbols into free space through the programmable metamaterial	Test the transmission of multiple packets of data over different distances and in varying levels of interference

2.2.3 Receiving End

The receiving end includes a receiving antenna, a Demodulating Logarithmic Amplifier Chip, an STM32 MCU, and Raspberry Pi. It is responsible for receiving and processing the data transmitted by the emitting end. The receiving antenna aims at the programmable metamaterial to maximize the intensity of the received RF signal. The Demodulating Logarithmic Amplifier Chip and the receiving processing unit work together to process and optimize the received signals. The receiving processing unit supports a maximum of 8 channels, recovers the original data based on the look-up table, and displays the complete data on the screen.

Connection with other subsystems:

Connection with Transmitting Control Unit: control communication of 2 unit.

Table 3: Receiving End

Requirement	**Verification**
The receiving antenna must maximize the intensity of the received RF signal	Test the receiving antenna to ensure it can maximize the signal intensity by pointing it at different positions of the programmable metamaterial
The Demodulating Logarithmic Amplifier Chip and receiving processing unit must work together to process and optimize the received signals	Test the processing of received signals by feeding known test signals and measuring the output signal quality
The receiving processing unit must recover the original data based on the look-up table and display the complete data on the screen	Test the recovery of data for multiple packets with different data and noise levels and verify that the correct data is displayed on the screen

The changes made were adding double backslashes at the end of each row to indicate a new line and adding vertical bars in each table cell to create a table border.

2.3 Subsystem Requirements

2.3.1 Transmitting Control Unit

The transmitting control unit must be able to communicate with the receiver through the NRF24L01 wireless transceiver module and control the programmable metamaterial through the Raspberry Pi under the instructions of the STM32F767IGT6 MCU. It must adjust the digital states of each controllable column on the programmable metamaterial and interact with the receiver to determine the available digital states for reliable transmission at a given noise threshold. The requirements for the transmitting control unit include:

The MCU must be an STM32F767IGT6. The wireless transceiver module must be an NRF24L01 from Nordic. Both cores must communicate through the SPI protocol. The transmitting control unit must be able to adjust the digital states of each controllable column on the programmable metamaterial. The transmitting control unit must be able to interact with the receiver to determine the available digital states that can be used for reliable transmission at a given noise threshold.

2.3.2 Emitting End

The emitting end must include a feeding antenna and a programmable metamaterial, and be able to transmit multiple n-bit-long symbols into free space through the programmable metamaterial. The feeding antenna must operate from 9.84 to 15 GHz with a gain of 20 dBi. The programmable metamaterial must generate 32 digital states from 0 to 31 by biasing its corresponding voltages. The requirements for the emitting end include:

The feeding antenna must work from 9.84 to 15 GHz with a gain of 20 dBi. The programmable metamaterial must be able to bias its corresponding voltages to generate 32 digital states from 0 to 31. The emitting end must be able to transmit multiple n-bit-long symbols into free space through the programmable metamaterial.

2.3.3 Receiving End

The Receiving End subsystem is responsible for receiving and processing the signals transmitted by the Emitting End subsystem. It includes a receiving antenna, a demodulating logarithmic amplifier chip, an STM32 MCU, and Raspberry Pi.

Receiving Antenna: The Receiving Antenna should be able to aim at the programmable metamaterial to maximize the intensity of the received RF signal. It should have a gain of at least 20 dBi and work from 9.84 to 15 GHz. Any degradation in the gain or frequency range would result in a weaker signal being received, which could lead to erroneous data processing.

Demodulating Logarithmic Amplifier Chip: The Demodulating Logarithmic Amplifier Chip should be able to process the received signals and convert them into voltage signals with logarithmic amplification. The chip should have a wide dynamic range, at least 70 dB. Any degradation in the dynamic range would result in the chip being unable to process signals outside its range, leading to erroneous data processing.

STM32 MCU: The STM32 MCU should be able to work with Raspberry Pi to process and optimize the received signals. It should be an STM32F767IGT6 and should communicate with the FPGA through the SPI protocol. Any failure in the communication or processing capability of the MCU would result in erroneous data processing.

Processing Unit: The Receiving End subsystem should be able to support a maximum of 8 channels. The processing unit should be able to recover the original data based on the look-up table and display the complete data on the screen by repeating Steps 1 and 2 at a certain rate. The processing unit should have a processing delay of no more than 10ms. Any failure in the processing capability or delay would result in erroneous data processing.

2.4 Tolerance Analysis

The metasurface in the system did not reach 180 degrees of phase at the time of design or fabrication, resulting in too much distortion of the transmitted signal to restore the original image. In this case, it is difficult to compensate algorithmically and may required to redesign or remake the metasurface. The quality of the algorithm is also very important for this project. In the case that the algorithm is not good enough, in order to avoid electromagnetic noise interference in the environment, the signal that the system can transmit at the same time needs to be significantly reduced, which may not reflect the superiority of this wireless communication mode.

3 Cost and Schedule

3.1 Cost Analysis

Before our estimation about the total cost we may have on the materials we need, we first need to estimate the cost on the group members in our group. First, 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, according to our estimation, the total time we need for the whole project should be about 8 weeks.Therefore, our total cost for the human resources should be as following:

4x30x12x8=11520 CNY

Components	Quantity	Cost/Unit (CNY)	Total Cost (CNY)
25x25 Programmable Metasurface	1	6000	6000
Raspberry Pi	1	300	300
Microwave Anechoic Chamber	10 Hour	100	1000
Receiving Antenna	2	1000	2000
Sum Cost			9300

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

For the Raspberry Pi, we intend to buy the board on the internet.We will double confirm the parameter we require for the Raspberry Pi after we successfully fabricating the Metasurface and configure the coding sequences. The cost listed on the table above is the average price we need for the common Raspberry Pi.

For the Microwave Anechoic Chamber, we will make appointment with the Laboratory Administration Office of International Campus Zhejiang University. The cost is given by the Laboratory Assistant.

For the receiving Antenna, we will just order a set of antennas from Taobao. The price of the antenna is given by the owner of the e-shop we contacted.

Week	Task	Responsibility
3/13/23	Project proposals due and reading reletive paper	All
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
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
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
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
5/1/23	Finish final paper and presentation	All

3.2 Schedule

4 Ethics and Safety

4.1 Ethics

First of all, we promise to obey the ethics of IEEE code of ethics[2]and ACM code of ethics[3].In our project, the most important thing is to guarantee that all of the design should be made by our own. We will not copy other research group's work or even get their prototype to pretend to finish our project. There could be technical communication with team members who are pioneers in this field, but we will do all the design and test assignment by our own, and we will cite all the work that is motivated by others idea.[2, 3] The only thing that could not be made directly by us is the printing process of the Metasurface, which we have no choice but to request some factories to help us with it.

Secondly, we promise that the materials we use in our project is safe and we will keep the RF radiation in an appropriate level. Our use of laboratory will be monitored by the laboratory staff and we will obey the basic rules in the lab.[2, 3]

Finally, we will not make up simulation or experiment data in order to meet the requirement of our project. We will make sure every result we get from the experiment or simulation could be repeatedly realized by our design and equipment's setup.[2, 3]

4.2 Safety

4.2.1 Electronic Devices

When designing our project, safety is our top priority for there is no other ethical problem involved in our project. Firstly, most of components in our system are electrical components like FPGA or microcontroller unit. So there is a potential risk of electrical shock. It is important to make sure only touch insulation part when connecting wires. The IEEE and ACM Code of Ethics emphasizes the importance of protecting human safety, and this applies to the design of such systems[2].
Moreover, the receiving antennas are tall and easy to be pushed down if we don't take extra care on them. The antennas being knock down could intimidate both lab equipment and research members.

4.2.2 Electromagnetic Wave Radiation

Another problem is avoid RF signal damage human health. The magnitude of RF signal in the system need to be smaller than 10 μW/cm^2 and people should avoid long-term exposure to RF signal. By taking appropriate precautions, we can minimize the risk of accidents or injuries and conduct our tests in a safe and responsible manner.[4]

4.2.3 Information Security

During our experiment of testing of our prototype, we may try to transmit image as one of the goals. The data transmission should not be easy to be encrypt by others even though the information we are going to transmit is not confidential. Our communication system should be able to handle sort of cases when there is outside antenna receiving our signals.

References

[1] T. J. Cui, M. Q. Qi, X. Wan, J. Zhao, and Q. Cheng, “Coding metamaterials, digital metamaterials and programmable metamaterials,” Light: Science and Applications, vol. 3, no. 10, pp. e218–e218, Oct. 2014, doi: https://doi.org/10.1038/lsa.2014.99.

[2] IEEE, ”IEEE Code of Ethics,” June 2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed 4 March 2021].

[3] The code affirms an obligation of computing professionals to use their skills for the benefit of society. Code of Ethics. (n.d.). Retrieved March 21, 2023, from https://www.acm.org/code-of-ethics

[4] RF safety highlighted releases. Federal Communications Commission. (2020, March 5). Retrieved March 22, 2023, from https://www.fcc.gov/engineering-technology/electromagnetic-compatibility-division/radio-frequency-safety/general/rf