

Projects

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This is a three week project. Each project group will turn in one written report and present their results to the class.

Objective To gain hands-on design and measurement experience with real-world applications.

9-1 INTRODUCTION

The last four weeks of the EECS 330 Lab are dedicated to performing a group project. Unlike the Lab Exercises, there will be five different projects to choose from, each one covering a different aspect of electromagnetics. Each of the projects has been carefully designed to not only test your knowledge and understanding of electromagnetics, but to include *other aspects of electrical engineering as well*.

You will work in a group of three to four people. You will be expected to turn in a group report (similar to the one in Lab Exercise 7) and present your project during the last week of class.

9-2 PROJECTS

The projects that you have to choose from are:

- Alarm radar sensor
- Microwave frequency-modulated (FM) communication link
- Optical amplitude-modulated (AM) communication link
- Steerable antenna array
- Fourier Optics

A brief description of each project and what it entails will be presented next. You must fill-out and return the project sign-up sheet to the lab instructor at the start of Lab Exercise 7. An up-to-date version of the signup sheet will be available on the course website (an older version is on page 57). The project assignments will be announced during the start of Lab Exercise 8.

9-2.1 Alarm Radar Sensor

Overall

In this project, your group will be asked to design the processing circuit of an alarm sensor based on the use of Doppler radar. As you have learned from the last Lab Exercise, the motion of an object can induce a Doppler shifted reflection wave that can be detected by a Doppler radar. The signal coming out of the radar unit contains the information about the moving object. By utilizing a sequence of circuit components, we are able to process the signal and recognize the speed of the moving object. Specifically, this project entails:

- Reviewing the concept of the radar sensor (read 10.5 to 10.7, *Fundamentals of Applied Electromagnetics* by Prof. Ulaby)
- Learning or reviewing knowledge of circuits design. Relevant materials can be found in the listed references.
- Determining specifically what goals you want to achieve. For example, determining a threshold either in frequency or amplitude to trigger the alarm.

- Recognizing the required circuits components needed to achieve your goals, and then designing circuits that would realize them.
- Implementing the circuit.
- Testing the limits and capabilities of your circuit.
- Demonstration of a working alarm and its sensitivity.
- Any additional measurements (be creative!)

A simple example of the circuit diagram and its description are given in the next section, so students can get a sense of how to start. This project will help to reenforce (or introduce) a wide range of topics including: radar sensors, Doppler shift, circuit design, signal detection, and noise.

Example

Assume that our objective is to build a sensor that would detect the movement of a human being based on speed discrimination.

Before designing any circuit, we need to know the limit of Doppler radar. From its specifications included in the appendix, the standard Doppler radar can detect a minimum speed of 1 mph and a maximum of 120 mph. We then proceed to determine the desired detecting speed range. The velocity can be converted to the Doppler frequency using the formula given by (10.34) of EECS 330 textbook. For example, if we want to detect any motion between 50 Hz (about half of normal walking) to 600 Hz (fast running), a bandpass filter is needed to let through any signal within this frequency range so it can trigger the alarm or light-up the LED.

After the signal is filtered, its voltage level significantly drops and thus it might not be sufficient to provide enough power to the LED. Therefore, a voltage amplifier is also required after the band pass filter. There are several configurations of amplifiers using op-amp LM741. Related information about circuit design is given in the links in the reference list or see the textbook of EECS 215.

The last problem is the AC condition of the amplified signal, which will cause the LED to blink with certain frequency. By using a full-wave rectifier in series with a suitable capacitor, we can convert the AC signal to almost DC. The example circuit schematic diagram are shown in Fig. 9-1.

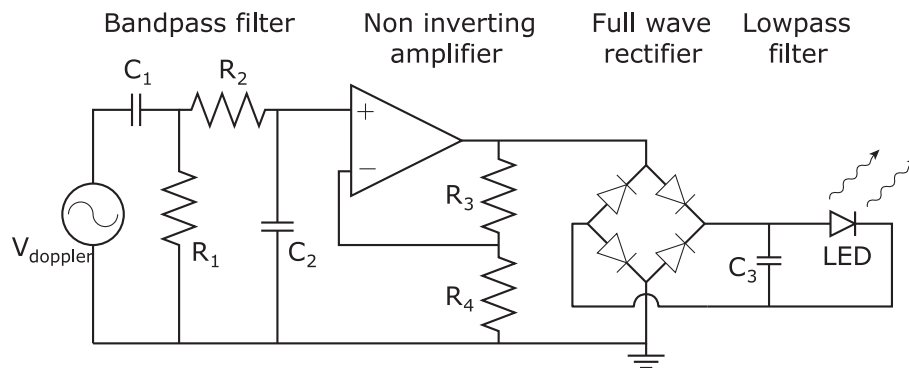


Figure 9-1: Example Doppler radar circuit. This circuit turns on an LED if the Doppler frequency is within the range of the bandpass filter

Alternative project directions and ideas for experiment

- Experiment on the working limits of the band pass filters using the racetrack from Lab 7.
- Building active band pass filters instead of passive filters
- Building a Doppler radar sensor based on object's size instead of its speed
- Experiment on the relation between false alarm probability, detection probability and threshold level to light-up the LED
- Building a radar gun showing the speed " Building a Doppler radar using horn antennas
- The project is wide open, only make sure you use the concept of Doppler frequency shift as the heart of this project

References

- All About Circuits <http://www.allaboutcircuits.com/>
- Filters http://www.allaboutcircuits.com/vol_2/chpt_8/index.html
- Resistor color codes http://www.allaboutcircuits.com/vol_5/chpt_2/1.html
- AC to DC converter <http://www.kpsec.freeuk.com/powersup.htm>
- Rectifier http://www.allaboutcircuits.com/vol_3/chpt_3/4.html
- Common configurations of operational amplifiers <http://www.answers.com/topic/operational-amplifier?method=6>
- LED http://www.allaboutcircuits.com/vol_3/chpt_3/12.html

9-2.2 Microwave FM Communication Link

Overall

In this project, your group will be asked to design a frequency-modulated wireless communication link. The minimum criterion is to demonstrate that the transmission and reception of voice or music are feasible between two parabolic antennas at a carrier frequency of 1.95 GHz. Once your link is established, additional measurements or further modifications to improve the system performance may be required. This project entails:

- Reviewing or learning about FM communication, including modulation and demodulation. Relevant materials can be found in the reference list.
- Studying the working principle of an FM modulator and demodulator and their components such as mixer, phase-lock loop, diode detectors
- Designing the communications link
- Developing a block diagram of the transmitter from the audio source to the antenna
- Developing a block diagram of the receiver from the antenna to the speaker
- Building the link
- Demonstrating a working communication system
- Any additional measurements (be creative!)

A simple example of the block diagram and its description are given in the next section, so students can get a sense of how to start. This project will help to reinforce (introduce) a wide range of topics including: frequency modulation, mixers, parabolic antennas, and phase-lock loops.

Example

Before starting the project, there are several questions to consider.

- What is FM communication?
- What is the audible frequency range of human ears?
- What is the function of a mixer?
- What is the frequency deviation and why is its value important?
- How does a phase lock loop (PLL) work?
- Does AM communication need PLL?

Secondly, you should familiarize yourself with the devices provided in the lab for this project. The following section lists the specifications of RF mixer, parabolic antenna and phase lock loop (PLL.)

Next, we show a generic diagram of a basic FM communication link.

RF Mixer Specifications

Model No.	ZEM-4300
LO/RF Frequency	300 - 4300 MHz
IF Frequency	DC - 1000 MHz
LO max input power	7 dBm
RF max input power	0 dBm
Conversion Loss	9.5 dBm
LO to RF isolation	20 dBm minimum 15 dBm typical

ZEM-4300MH



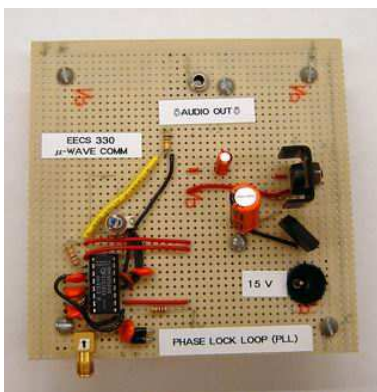
RF Mixer

Parabolic Antenna Specifications

Operating Frequency	1.95 GHz
Diameter	45.72 cm
Wavelength	15.4 cm
Focal length of the dish	11.43 cm
Beam width	$70^\circ \lambda/D$
Gain	756



Parabolic Antenna



Phase Locked

Loop Circuit

Phase Locked Loop Specifications

Model	NE564N
Manufacture	Philips
Lock Frequency	2.3MHz

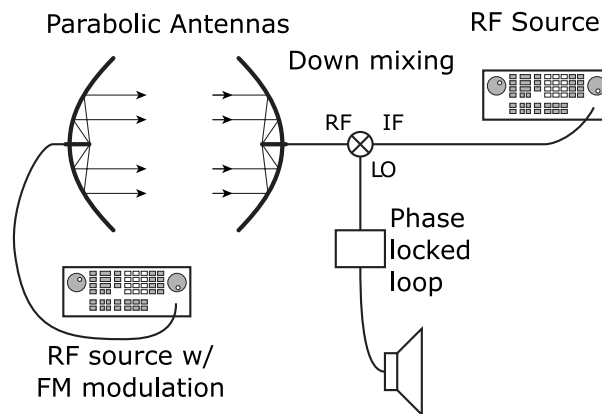


Figure 9-2: FM modulation diagram.

As shown in Fig. 9-2, an FM signal at a carrier frequency of 1.95 GHz is transmitted utilizing a signal generator. Note that in this configuration the modulation work is being done with the signal generator, so one possible direction for this project is to build an FM modulator on your own.

After the antenna receives the EM wave, it should be down-converted to base band so we can hear it. Since PLL works at a frequency of 2.3 MHz, the local oscillator provided to the mixer is at 1947.7 MHz ($=1950 \text{ MHz} - 2.3 \text{ MHz}$) without any modulation. The FM signal can then be demodulated by the PLL and then transmitted to the speaker.

Note that the mixer has three parts: RF (Radio Frequency), IF (Intermediate Frequency) and LO (Local Oscillator.) When wiring the mixer, be sure to follow the connection guide shown in Fig. 9-2.

Warning:

- Do not exceed 7 dBm input power to LO port
- Do not exceed 0 dBm input power into RF port
- Do not allow the external modulation signal into the function generator to exceed 1 Vpp
- Do not touch the dipole and connectors of parabolic antenna. They are very fragile.

Alternative project directions and ideas for experiment

- What is capture range and lock range of PLL?
- How does the power of LO affect the PLL?
- What are the antenna pattern and polarization of the parabolic antenna?
- What is the system bandwidth?
- How does FM radio work? Can we build an FM communication link transmitting multiple channels at the same time?
- Can we build an AM communication system using the same equipment? How would you draw its block diagram?

- Can we build our own FM modulator circuit instead of using a signal generator?

Reference

- Frequency modulation <http://www.answers.com/Frequency%20modulation>

9-2.3 Optical AM Communication Link

Overall

In this project, your group will be asked to design an amplitude-modulated communication channel using the laser source provided to you. You will need to demonstrate the successful transmission and recovery of audio signals in free space with a carrier wave at optical frequencies. Further characterizing of the capability and limit of your communication system is also expected. The project entails:

- Reviewing or learning about AM communication, including modulation and demodulation. Relevant materials can be found in the listed references.
- Studying the working principles of AM demodulator components such as photodiodes or phototransistors.
- Designing of the communications link
- Developing a block diagram of the transmitter from the audio source to the laser
- Developing a block diagram of the receiver from the detector to the speaker
- Building the link
- Demonstrating a working communication system
- Any additional measurements (be creative!)

A simple example of the circuit diagram and its description are given in the next section, so students can get a sense of how to start. This project will help to reinforce (introduce) a wide range of topics including: amplitude modulation, lasers, and optical detectors.

Example

Questions to consider:

- What is AM communication?
- What are the advantages and disadvantages of optical communication?
- How does a nonlinear device such as diode or phototransistor work?

Secondly, the specification of the laser source provided in the lab is listed below.

Diode laser input range	
Digital Signal	0 - 5 V
Analog Signal	1.8 - 3.2

An important consideration for the diode laser is the analog voltage range. The laser's output intensity has an S shaped response to the modulation signal. Low input signal voltage suffer from distortion and high input voltages saturate the laser and can possibly damage the control electronics inside the laser housing. Fortunately, the laser has a roughly linear response curve in the input range of 1.8 - 3.2 V. Therefore, any zero-mean signal will need to be biased to 2.5V in addition to any amplification or attenuation. When we add them together, the total input voltage should fall in the linear range of the laser in order simplify the receiving circuit. The adding, amplifying, or attenuating circuit can be easily achieved by an op-amp LM741CN or LM 324N.

As to the receiving circuit, we utilize a photodiode to extract the information from the carrier wave. The interesting question of why a nonlinear device, e.g. a diode, could perform the demodulation function is left to your group to examine and should be included in the project report. The simple circuit is composed of a photodiode in series with a resistor and is shown below. Once the signal is recovered, the other remaining steps should be attended to include filtering and amplification.

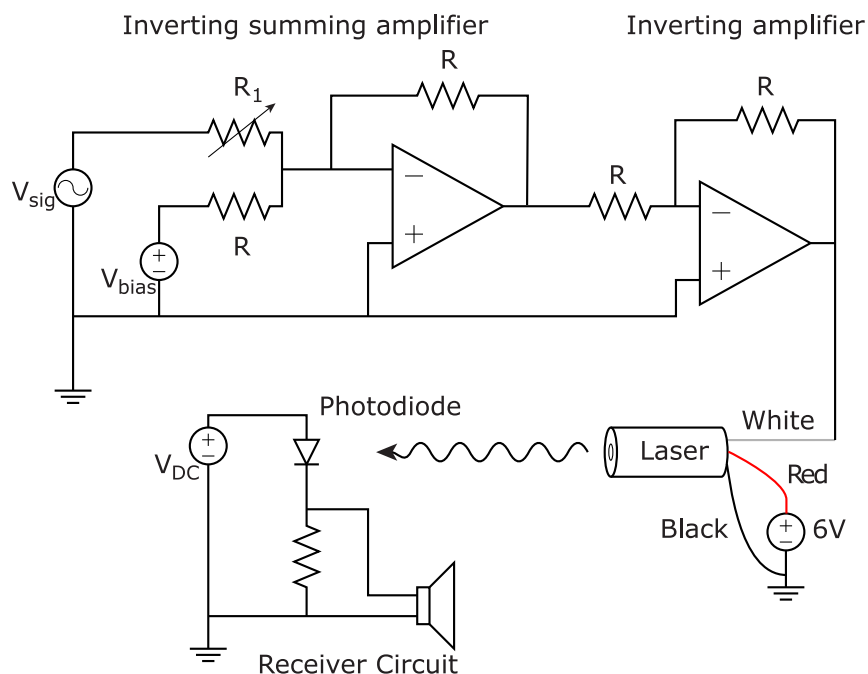


Figure 9-3: Example AM modulation circuit. A zero-mean signal is biased to the linear range of the diode laser

Alternative project directions and ideas for experiment

- Building processing circuits to improve the quality of the communication system
- Experiment on the polarization properties of the laser light
- Experiment on the frequency response and bandwidth of the system
- Experiment on the bias voltage value and resulting performance

- Experiment on range dependence.

Reference

- Amplitude modulation <http://www.answers.com/amplitude%20modulation>
- Free Space Optics (FSO) <http://www.free-space-optics.org/index.php>

9-2.4 Steerable Antenna Array

Overall

In this project, your group will be asked to design a steerable antenna array. Students will need to demonstrate that the beam properties of a linear one-dimensional antenna array are controlled by the magnitudes and phases of in the signals fed into the array elements. Comparison of experimental results with theoretical values and further characterization of your system are also required. The project entails:

- Familiarizing yourself with the theory of antennas and antenna arrays. Read *Radiation and Antennas*, Chapter 9 of *Fundamentals of Applied Electromagnetics* by Prof. Ulaby. Relevant materials can be found in the listed references.
- Familiarizing yourself with the Image Method (Section 4-12 of *Fundamentals of Applied Electromagnetics*).
- Determining proper antenna length (its working frequency), the number of elements in the array, and the spacing between the elements
- Determining the method to achieve relative amplitudes and phase shifts of signals feeding the array elements
- Building and demonstration of a working antenna array
- Verifying your data with theory and indicating possible error sources
- Any additional measurements (be creative!)

A simple example of an antenna array is given in the next section, so students can get a sense of how to start. This project will help to reinforce (introduce) a wide range of topics including: phase shift, antenna arrays, monopole antennas, yagi-uda antennas, and image theory.

Example

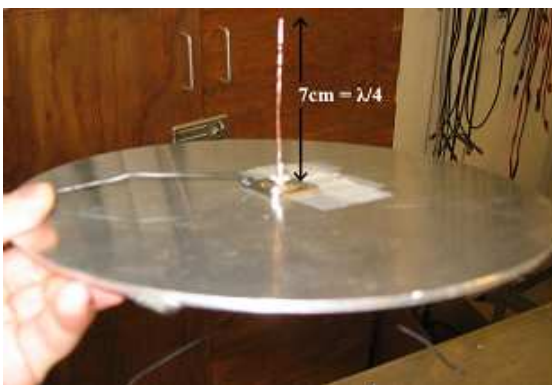
Before starting the project, several questions should be considered:

- What is an array factor? How do you compute it?
- What is the pattern multiplication principle and its mathematical equation?
- What is the far-field approximation? Is it related to pattern multiplication principle?

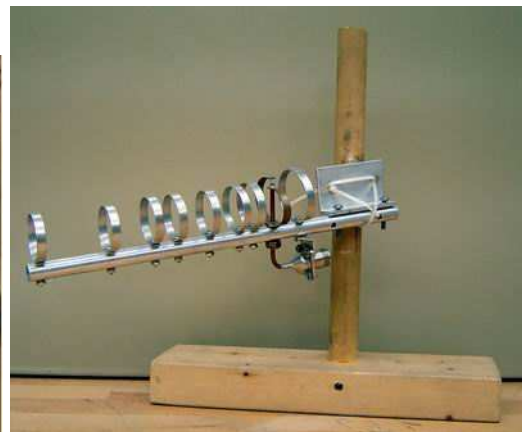
- How would the number of array elements and their spacing affect the 3-dB bandwidth and shape of the radiation pattern?
- How would the length of coaxial cables feeding the radiators affect the directivity of the beam?

In the lab, the antennas provided are monopole antennas or Yagi-Uda antennas. A large conducting table and a small conducting plate serve as the ground plane. Their photos are shown on Fig. 9-4

(a)



(b)



(c)

Figure 9-4: Antenna array components. 9.5(a) Large conducting table and transmitter monopole antennas. 9.5(b) Receiver monopole antenna 9.5(b) Yagi-Uda antenna

If we purposely design the length of a monopole antenna to be a quarter of wavelength and put it on a large ground plane, it will exhibit the same radiation pattern as a half-wave dipole antenna placed in free space. We can verify this by placing only one monopole antenna on the large conducting plane and use another monopole on a conducting plate (dipole eventually) to receive the radiation power. We can then compare the measured data with the theoretical values.

In addition, we can measure the directivity, 3-dB bandwidth and radiation pattern of variable monopole antenna elements or variable radiator spacing. Students can come up with their own array configuration and verify it. An example set-up of the project is shown in Fig. 9-5.

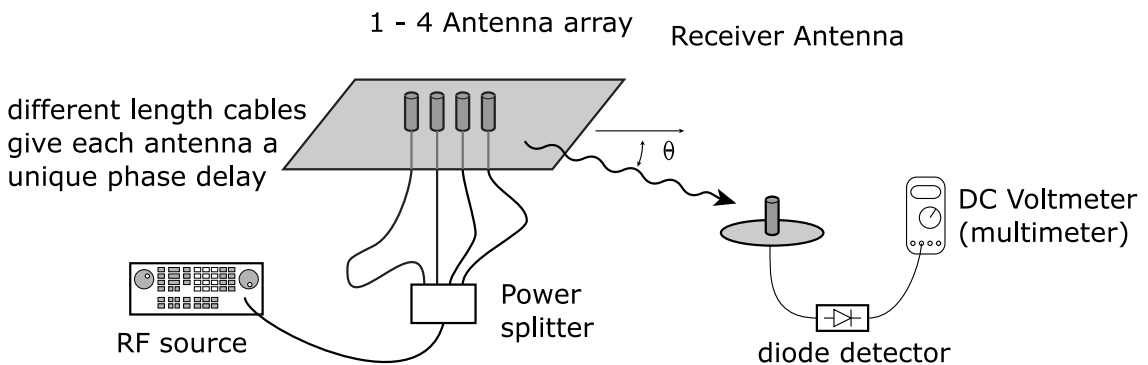


Figure 9-5: Example antenna array setup

Alternative project directions and ideas for experiment

- Use Yagi-Uda antennas instead of quarter-wave monopole antennas
- Change the length and the operating frequency of monopole
- Introduce phase shifts by using subsequent incremental cable lengths
- Introduce the power amplitudes difference by using attenuators or amplifiers

Reference

- *Radiation and antennas*, Chapter 9 of *Fundamentals of Applied Electromagnetics* by Prof. Ulaby.
- EM waves and antennas <http://www.ece.rutgers.edu/~orfanidi/ewa/>

9-2.5 Fourier Optics

Overall

In this project, you will be asked to design an optical image filtering and reconstruction system. In contrast to the temporal Fourier transformation in Michelson Interferometer, the electrical field of the laser light transmitted through an object is Fourier transformed spatially by lenses onto its image plane. Students will need to demonstrate that by using

suitable optical diaphragms placed at appropriate positions, the optical signals can be filtered and thus the image can be recovered. The project entails:

- Reviewing or learning about the mathematics of Fourier transform
- Studying Fraunhofer diffraction theory and its relation to the optical 2-D Fourier transform. Read Chapter 4 and especially 4.4 of Fundamentals of Photonics by Saleh and Teich
- Determining the basic configuration of the imaging system
- Determining the filtering effect you want and make the optical filters using transparency
- Demonstration of the imaging and reconstructing ability of the system
- Any additional measurements (be creative!)

A simple example and its description are given in the next section, so students can get a sense of how to start. This project will help to reinforce (introduce) a wide range of topics including: Fourier transform, lenses, Fraunhofer diffraction, Huygen's principle.

Example

Before starting the project, several questions to consider include:

- What is Fourier transform?
- What is the relation between spatial Fourier transform and lens?
- What is Fraunhofer diffraction theory? How does it apply to our optical system?

There are several different configurations that can be used to realize this imaging and reconstruction operation. Here the most straightforward setup called "4f" arrangement is given below. The specifications of the optical components used in Fig. 9-6 are listed below.

M1, M2, M3, M4	Planar mirror	$f = \infty$
L ₁	plano-concave lens,	$f = -2.5$ cm
L ₂	plano-convex lens,	$f = 35$ cm
L ₃ , L ₄	plano-convex lens,	$f = 10$ cm
He-Ne Laser	output wavelength	633 nm
	output power	10 mW
	polarization	linear

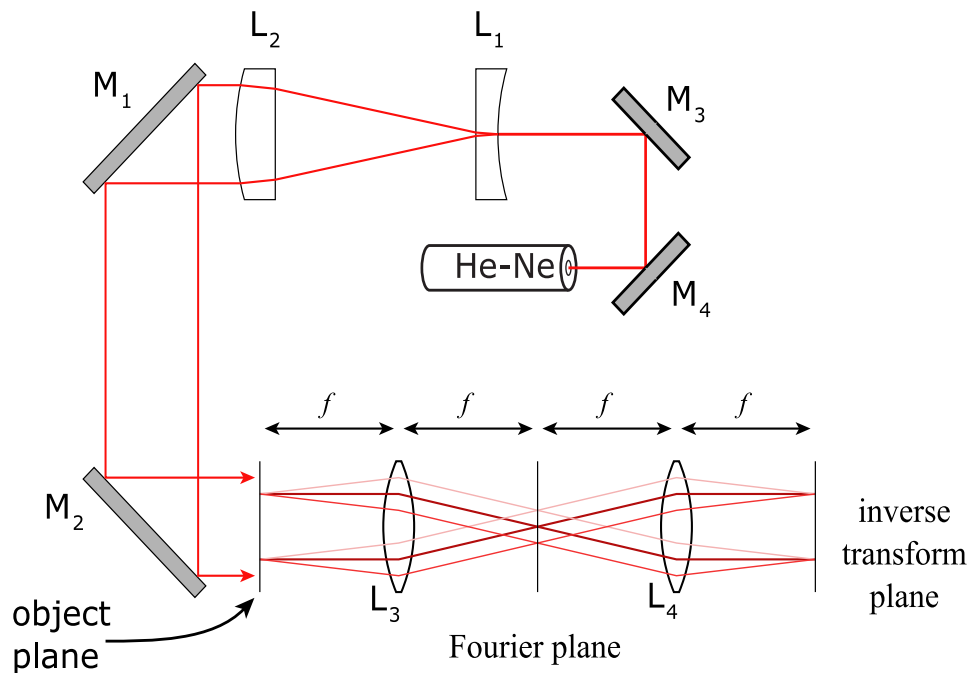


Figure 9-6: Fourier optics setup

In figure 9-6, we expand the coherent laser beam with a concave lens L1, and a convex lens L2, so the light can be uniformly projected onto the transparency placed on the object plane. After passing through the convex lens L3, the optical field is Fourier transformed to spatial frequency domain at the back focal plane of L3. By placing appropriate filters on this plane, we can manipulate the image, which is retrieved on the focal plane behind L4.

Alternative project directions and ideas for experiment

- Different configuration of lens set-up
- Use different kinds of filters and verify their effects with theory

Reference

- Chapter 4 and especially 4.4 of Fundamentals of Photonics by Saleh and Teich
- Examples of Fraunhofer diffraction patterns, 4.4 of Introduction of Fourier Optics by Joseph W. Goodman
- Coherent optical information processing systems, 8.3 of Introduction of Fourier Optics by Joseph W. Goodman
- Fraunhofer Diffraction, 10.2 of Optics by Eugene Hecht

9-3 COMMENTS

The projects have been purposefully designed to be very open ended. This allows your group to experience the process of designing an experiment, a task that is as rewarding

as performing the experiment. Each project carries with it a minimum requirement that a working system be demonstrated. If your group chooses only to build the system and demonstrate that it works, you will receive at most a B for the project. To receive a grade of an A, you must go one or two steps further and design your own experiments, either to better characterize your system, or to find the source of your errors. Where possible, compare the obtained results with what was predicted by theory.

The grade is a group grade and is based on whether you were able to meet your goal, how well you worked as a team, the quality of your written and oral reports, and how much initiative you took (content).

9-4 SIGN-UP FORM

Return the sign-up form (1 per group) to your instructor at the start of Lab Exercise 7.

EECS 330 Project Sign-up	
Section: _____	
Station: _____	
Members	Email
_____	_____
_____	_____
_____	_____
_____	_____
<p>Project Choices Please indicate your lab groups project of choice by ranking the projects from 1 to 4 (1 = first choice, 4 = last choice).</p>	
Alarm Radar Sensor _____	
Microwave FM Communication Link _____	
Optical AM Communication Link _____	
Steerable Antenna Array _____	