1 Purpose

Although the optical portion of the electromagnetic spectrum has always been the most ubiquitous spectral region when it comes to transmission and reception of the kind of visual information of which we are most cognizant, the use of optical hardware in high data rate transmission along with sensitive detection and techniques for complete information extraction in reception are of more recent origin than Paul Revere’s signal light or the wave of one caveman to another as a greeting. Communications theory is a rather mature field but one that was originally developed using a knowledge base that progressed from the experience of radio frequency engineers. There are more than simple scaling differences in increasing the transmission frequency from one that lies well below that where the terrestrial environment dictates that an electromagnetic stream is a continuum to one at which reception statistics can be dominated by the discrete nature of detection events. The basic nature of light (versus radio frequency waves) leads to detection, generation, propagation and reception distinctions which are neither primarily advantageous or disadvantageous, but are different. These differences need to be understood in order that one can optimally optical communications technology.

The global communications network is only the most ubiquitous example in an ever growing array of application areas which use the techniques of optical communications, areas which include communications, sensing, and information processing. The principles that lie behind successful implementation of these applications are just those of conventional communications theory as that theory applies to the optical portion of the spectrum, taking into account all of the nuances that are involved in this reworking of the theory. The purpose of this course is to elucidate the principles of optical communications theory through first seeing how the nature of light affects the mechanics of communications theory analysis and then applying this “new” theory to analog, digital and coherent systems transmission systems. Topics may include applications of the technique to optimizing optical sensing and/or of implementing quantum computation with light.

The analytical techniques employed in the course will include linear systems, probability and some techniques related to wave propagation. Other techniques will be introduced as necessary. Some discussion will be given to simulation techniques and communication system architecture, although the focus of this course is on the understanding of optical communications theory rather than application of any specific techniques.

2 Objectives

The general objective of this course is to present optical communications theory and show how it applies to some real systems. A more specific objective is to bring out the generality of the communications theory approach, and show how one can treat any system (including sensing as well as information processing systems) in terms of a communications theory model in which someone at a receiver tries to decode as much information as possible about a process at a different location, whether that location lies at a discrete transmission point or whether the process is either located or distributed along a transmission path. A more
practical aspect of the course will be embodied by a course project which will involve carrying out a rather rudimentary simulation.

3 The text and the prerequisites

There will be no text for the course although a manuscript, Alan Mickelson, Theory of Optical Communications, will serve as a text. Options for distribution will be sale of copies of chapters (at copying cost) probably through the CU Bookstore, distribution of copies via email or posting of pdf copy versions on the web. The level of the text is that of a senior or first year graduate text and requires no special background other than that generally possessed by those in engineering or physics at the senior of first year graduate level. The analysis is based primarily on linear systems techniques and classical probability theory although some understanding of wave propagation is desirable.

Although optical systems in general and optical communications systems in particular are rapidly evolving, the practise of applying communications theoretical techniques to the optical portion of the spectrum is a sufficiently mature practise such that there is some consistency in the details of its application. Because the field of optical communications has been in flux for some period, many of the available texts emphasize analysis of specific hardware and specific system configurations that were popular at the time of publication of the text. This text is designed to cover basics and then to attempt to generalize them. Reference to specific configurations are made only in examples. The goal is to abstract away from specifics which rely on details which will soon may become obsolete. Copious references to the literature and other texts will be made throughout the course however.

4 Topics covered

The (roughly) 40 lecture periods of the course (1 of the 44 lectures to be presented will be devoted to an in-class midterm and perhaps 3 to guest lectures or project presentations) will be split roughly equally among four different topics:

1. A general communications system model

2. Filling in the pieces of the general model with photodetectors, (noise in) sources (and amplifiers), (propagation in) channels and receivers

3. Analog, digital and coherent systems

4. special topics

In the following paragraphs, some more specific discussion of each of the above enumerated topics will be given.

1. A general systems model As we have mentioned numerous times above, communications theory is a rather mature subject. It is natural then to begin an optical communications course by going through an overview of some relevant portions of communications theory. A main goal of the exposition of this portion of the course is to introduce the origins of the ubiquitous gaussian models of detection, generation, amplification, and reception along with the concepts of additive versus signal dependent noise.

2. The pieces of an optical communications system model A block diagram of a communications system may be composed of various different blocks. Four of those blocks, the detector, the source (and/or amplifier), the channel and the receiver blocks are different for optical communications systems than they are for communications systems employing different frequency carriers. In this section of the course each of these blocks will be discussed in some detail.

3. Analog, digital and coherent systems Although the systems that transmit the information that allow for the worldwide net to operate are digital systems, one should not belittle the need for analog
systems for a plethora of lower sales volume applications nor the present day applications and tremendous promise for future applications of coherent transmission systems.

4. **Special topics** The communication system framework is quite general and the same model that is used to optimize a digital system can also be used to optimize a detection system or a processing system. Depending on the interests of the people in the class and the time available, it is possible that a more exotic topic such as quantum optical information processing may be taken up here.

5  **A class calendar**

Given the class starting date of January 13, 2003, that Martin Luther King Day this year falls on January 20, 2003, spring break lasts from March 24-28, 2003, and that the last day for classes is May 2, 2003 leaves 8 lectures in January, 12 in February, 10 in March, 13 in April and 1 in May. With March 3 reserved for an in class midterm, that leaves 43 lectures. The plan is that part I of the course will occupy 8 lectures, up through January 31, part II will occupy the 12 lectures of February before the midterm on March 3 and the 5 lectures in March following the midterm, Part III, the section on systems, the 13 lectures from March 17 through April 21, and part IV, the special topics, will be the 5 lectures beginning the second lecture of the week of April 21 through the final lecture of the course on Friday May 2. Table 1 summarizes these considerations.

6  **Work load**

Problems will be assigned with due dates of roughly every other week. There will be a project, which will involve some sort of system simulation.
7 Grading

The grade will be determined in roughly equal parts from performance on the homework (20%), midterm(25%), final(25%) and project(30%).

8 Something on supplementary references

Below, in the section entitled References, I have included a markedly incomplete list of books that might prove useful. A number of these references are included simply because they were the books I originally studied some of these topics from. Do note before reading further that I have placed none of these books on reserve in any of the CU libraries. There are so many good references that I have failed to list because I wasn’t aware of or wasn’t sufficiently familiar with them that it should be easy for anyone in the class to find a secondary source if she/he has a mind to. Hopefully, students in the class already have in hand a certain number of favorite references for things they have already studied. Hopefully, also, students who are keenly interested in the material here (or at least some part of it) will find new references during the semester that they will use for future reference.

The references are identified in complexity by the color of their reference number in the following reference list. Blue references are elementary, green ones are more on the level of this course, whereas red ones are more specialized.

References