"I cannot conceal from myself, in spite of your distinguished politeness, that I am becoming intolerably tiresome with my commonplace talk."

"On the contrary," replied Kai Lung, "while listening to your voice I seemed to hear the beating of many gongs of the finest and most polished brass."

—*The Wallet of Kai Lung*, Ernest Bramah

In this appendix, we provide an overview of key concepts in Fourier analysis.

A.1 FOURIER SERIES REPRESENTATION OF PERIODIC SIGNALS

With the aid of a good table of integrals, it is a remarkably simple task to determine the frequency domain nature of many signals. We begin with periodic signals. Any periodic signal can be represented as a sum of sinusoids, known as a Fourier series:[1]

$$x(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty}[A_n \cos(2\pi n f_0 t) + B_n \sin(2\pi n f_0 t)]$$

where f_0 is the reciprocal of the period of the signal ($f_0 = 1/T$). The frequency f_0 is referred to as the **fundamental frequency** or **fundamental harmonic**; integer multiples of f_0 are referred to as **harmonics**. Thus a periodic signal with period T consists of the fundamental frequency $f_0 = 1/T$ plus integer multiples of that frequency. If $A_0 \neq 0$, then $x(t)$ has a **dc component**.

The values of the coefficients are calculated as follows:

$$A_0 = \frac{2}{T}\int_0^T x(t)\,dt$$

$$A_n = \frac{2}{T}\int_0^T x(t)\cos(2\pi n f_0 t)\,dt$$

$$B_n = \frac{2}{T}\int_0^T x(t)\sin(2\pi n f_0 t)\,dt$$

This form of representation, known as the sine-cosine representation, is the easiest form to compute but suffers from the fact that there are two components at each frequency. A more meaningful representation, the amplitude-phase representation, takes the form

$$x(t) = \frac{C_0}{2} + \sum_{n=1}^{\infty} C_n \cos(2\pi n f_0 t + \theta_n)$$

[1]Mathematicians typically write Fourier series and transform expressions using the variable w_0, which has a dimension of radians per second and where $w_0 = 2\pi f_0$. For physics and engineering, the f_0 formulation is preferred; it makes for simpler expressions, and is it intuitively more satisfying to have frequency expressed in Hz rather than radians per second.

This relates to the earlier representation as follows:

$$C_0 = A_0$$

$$C_n = \sqrt{A_n^2 + B_n^2}$$

$$\theta_n = \tan^{-1}\left(\frac{-B_n}{A_n}\right)$$

Examples of the Fourier series for periodic signals are shown in Figure A.1.

A.2 FOURIER TRANSFORM REPRESENTATION OF APERIODIC SIGNALS

For a periodic signal, we have seen that its spectrum consists of discrete frequency components, at the fundamental frequency and its harmonics. For an aperiodic signal, the spectrum consists of a continuum of frequencies. This spectrum can be defined by the Fourier transform. For a signal $x(t)$ with a spectrum $X(f)$, the following relationships hold:

$$x(t) = \int_{-\infty}^{\infty} X(f)e^{j2\pi ft}\,df$$

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}\,dt$$

where $j = \sqrt{-1}$. The presence of an imaginary number in the equations is a matter of convenience. The imaginary component has a physical interpretation having to do with the phase of a waveform, and a discussion of this topic is beyond the scope of this book.

Figure A.2 presents some examples of Fourier transform pairs.

Power Spectral Density and Bandwidth

The absolute bandwidth of any time-limited signal is infinite. In practical terms, however, most of the power in a signal is concentrated in some finite band, and the effective bandwidth consists of that portion of the spectrum that contains most of the power. To make this concept precise, we need to define the power spectral density (PSD). In essence, the PSD describes the power content of a signal as a function of frequency, so that it shows how much power is present over various frequency bands.

First, we observe the power in the time domain. A function $x(t)$ usually specifies a signal in terms of either voltage or current. In either case, the instantaneous power in the signal is proportional to $|x(t)|^2$. We define the average power of a time-limited signal as

$$P = \frac{1}{t_1 - t_2}\int_{t_1}^{t_2} |x(t)|^2\,dt$$

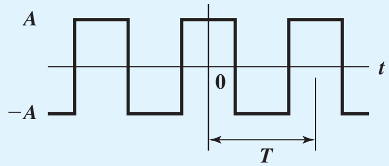
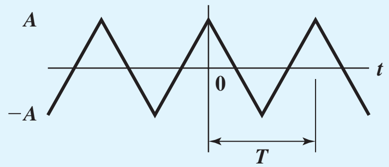
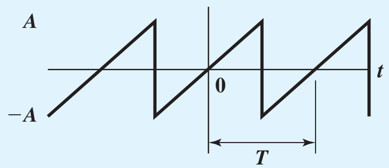
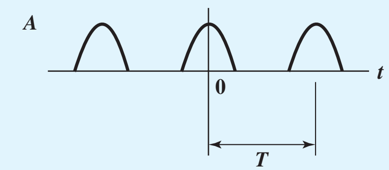
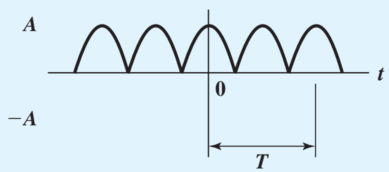
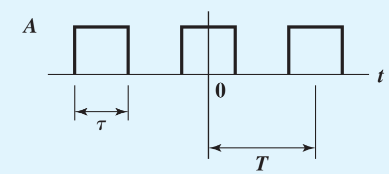
Signal	Fourier Series
Square wave  	$(4A/\pi) \times [\cos(2\pi f_1 t) - (1/3)\cos(2\pi(3f_1)t)$ $+ (1/5)\cos(2\pi(5f_1)t) - (1/7)\cos(2\pi(7f_1)t)$ $+ \ldots]$
Triangular wave  	$C_0 = 0$ $C_n = 0$ for n even $C_n = 8A/(n\pi)^2$ for n odd
Sawtooth wave  	$A_0 = 0$ $A_n = 0$ for n even $B_n = -(-1)^{(n)} \times (2A/\pi n)$
Half-wave rectified cosine  	$C_0 = 2A/\pi$ $C_n = 0$ for n odd $C_n = (2A/\pi) \times (-1)^{(1+n/2)} \times (2/(n^2 - 1))$ for n even
Full-wave rectified cosine  	$C_0 = 4A/\pi$ $C_n = (4A/\pi) \times (-1)^n \times (1/(4n^2 - 1))$
Pulse train  	$C_n = (2A\tau/T) \times \sin(n\pi\tau/T)/(n\pi\tau/T)$

Figure A.1 Some Common Periodic Signals and Their Fourier Series

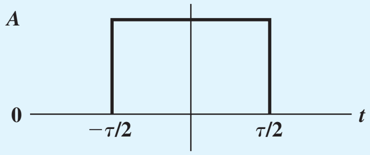
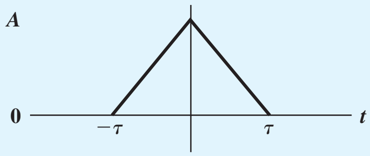
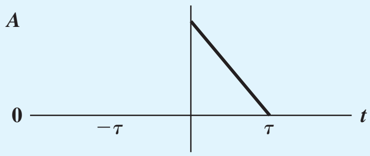
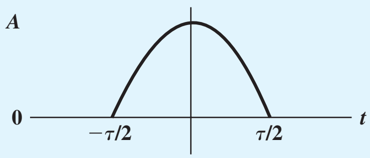
Signal $x(t)$	Fourier Transform $X(f)$
Rectangular pulse 	$A\tau \dfrac{\sin(\pi f \tau)}{\pi f \tau}$
Triangular pulse 	$A\tau \left(\dfrac{\sin(\pi f \tau)}{\pi f \tau}\right)^2$
Sawtooth pulse 	$(jA/2\pi f) \times$ $\{[(\sin \pi f\tau)/\pi f\tau)]\exp(-j\pi f\tau) - 1\}$
Cosine pulse 	$\dfrac{2A\tau}{\pi} \times \dfrac{\cos(\pi f \tau)}{1 - (2f\tau)^2}$

Figure A.2 Some Common Aperiodic Signals and Their Fourier Transforms

For a periodic signal the average power in one period is

$$P = \frac{1}{T}\int_0^T |x(t)|^2\, dt$$

We would like to know the distribution of power as a function of frequency. For periodic signals, this is easily expressed in terms of the coefficients of the Fourier series. The power spectral density $S(f)$ obeys

$$S(f) = \sum_{n=-\infty}^{\infty} |C_n|^2 \delta(f - nf_0)$$

where f_0 is the inverse of the period of the signal $(f_0 = 1/T)$, C_n is the coefficient in the amplitude-phase representation of a Fourier series, and $\delta(t)$ is the unit impulse, or delta, function, defined as

$$\delta(t) = \begin{cases} 0 & \text{if } t \neq 0 \\ \infty & \text{if } t = 0 \end{cases}$$

$$\int_{-\infty}^{\infty} \delta(t)\, dt = 1$$

The power spectral density $S(f)$ for aperiodic functions is more difficult to define. In essence, it is obtained by defining a "period" T_0 and allowing T_0 to increase without limit.

For a continuous valued function $S(f)$, the power contained in a band of frequencies, $f_1 < f < f_2$, is

$$P = 2\int_{f_1}^{f_2} S(f)\, df$$

For a periodic waveform, the power through the first j harmonics is

$$P = \frac{1}{4}C_0^2 + \frac{1}{2}\sum_{n=1}^{j} C_n^2$$

With these concepts, we can now define the half-power bandwidth, which is perhaps the most common bandwidth definition. The half-power bandwidth is the interval between frequencies at which $S(f)$ has dropped to half of its maximum value of power, or 3 dB below the peak value.

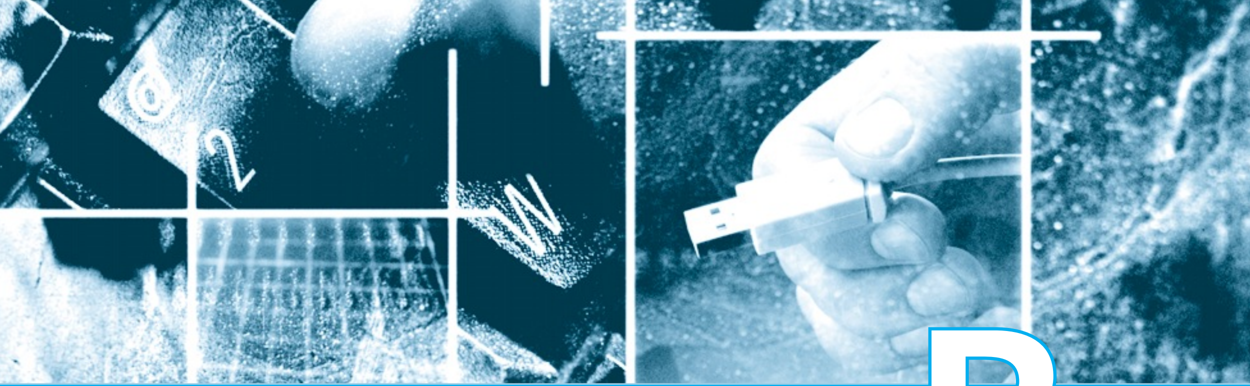
A.3 RECOMMENDED READING

A very accessible treatment of Fourier series and Fourier transforms is [JAME01]. For a thorough understanding of Fourier series and transforms, the book to read is [KAMM00]. [BHAT05] is a useful short introduction to Fourier series.

BHAT05 Bhatia, R. *Fourier Series.* Washington, DC: Mathematical Association of America, 2005.

JAME01 James, J. *A Student's Guide to Fourier Transforms.* Cambridge, England: Cambridge University Press, 2001.

KAMM00 Kammler, D. *A First Course in Fourier Analysis.* Upper Saddle River, NJ: Prentice Hall, 2000.



APPENDIX B

Projects and Other Student Exercises for Teaching Data and Computer Communications

Analysis and observation, theory and experience must never disdain or exclude each other; on the contrary, they support each other.

—*On War*, Carl Von Clausewitz

Many instructors believe that research or implementation projects are crucial to the clear understanding of the concepts of data and computer communications. Without projects, it may be difficult for students to grasp some of the basic concepts and interactions among components. Projects reinforce the concepts introduced in the book, give the student a greater appreciation of the how protocols and transmission schemes work, and can motivate students and give them confidence that they have mastered the material.

In this text, I have tried to present the concepts as clearly as possible and have provided nearly 400 homework problems to reinforce those concepts. Many instructors will wish to supplement this material with projects. This appendix provides some guidance in that regard and describes support material available in the instructor's supplement. The support material covers nine types of projects and other student exercises:

- Practical exercises
- Sockets programming projects
- Ethereal projects
- Simulation projects
- Performance modeling projects
- Research projects
- Reading/report assignments
- Writing assignments
- Discussion topics

B.1 PRACTICAL EXERCISES

The instructor's supplement includes Web pages that provide a set of practical exercises for an introduction to the use of IP over a local area network (LAN). The exercises naturally follow one another and build on the experience of the previous exercises. They do not however need to be attempted one after another. The four exercises may more easily be done on four separate occasions. The practical exercises are designed to help the student understand the operation of an Ethernet LAN and an IP network. The exercises involve using simple network commands available on most computers. About an hour is needed to perform all four exercises. The exercises cover the following topics: your own network connection, computers on your LAN, computers on remote networks, and the Internet.

B.2 SOCKETS PROJECTS

The concept of sockets and sockets programming was developed in the 1980s in the UNIX environment as the Berkeley Sockets Interface. In essence, a socket enables communications between a client and server process and may be either connection oriented or connectionless. A socket can be considered an endpoint in a communication. A client socket in one computer uses an address to call a server socket on another computer. Once the appropriate sockets are engaged, the two computers can exchange data.

Typically, computers with server sockets keep a TCP or UDP port open, ready for unscheduled incoming calls. The client typically determines the socket identification of the desired server by finding it in a Domain Name System (DNS) database. Once a connection is made, the server switches the dialogue to a different port number to free up the main port number for additional incoming calls.

Internet applications, such as TELNET and remote login (rlogin) make use of sockets, with the details hidden from the user. However, sockets can be constructed from within a program (in a language such as C or Java), enabling the programmer to easily support networking functions and applications. The sockets programming mechanism includes sufficient semantics to permit unrelated processes on different hosts to communicate.

The Berkeley Sockets Interface is the de facto standard application programming interface (API) for developing networking applications, spanning a wide range of operating systems. The sockets API provides generic access to interprocess communications services. Thus, the sockets capability is ideally suited for students to learn the principles of protocols and distributed applications by hands-on program development.

The Web site for this course includes an overview of sockets programming prepared especially for this book plus links to sites with more information on the subject. In addition, the instructor's supplement includes a set of programming projects.

B.3 ETHEREAL PROJECTS

Ethereal is used by network professionals around the world for troubleshooting, analysis, software and protocol development, and education. It has all of the standard features you would expect in a protocol analyzer, and several features not seen in any other product. Its open source license allows talented experts in the networking community to add enhancements. It runs on all popular computing platforms, including UNIX, Linux, and Windows.

Ethereal is ideal for allowing students to study the behavior of protocols not only because of its many features and multiplatform capability but also because students may subsequently use Ethereal in their professional life.

The instructor's supplement includes a Student User's Manual and a set of project assignments for Ethereal created specifically for use with *Data and Computer Communications*.

B.4 SIMULATION AND MODELING PROJECTS

An excellent way to obtain a grasp of the operation of communication protocols and network configurations, and to study and appreciate some of the design tradeoffs and performance implications, is by simulating key elements. A tool that is useful for this purpose is *cnet*.

Compared to actual hardware/software implementation, simulation provides two advantages for both research and educational use:

- With simulation, it is easy to modify various elements of a network configuration or various features of a protocol, to vary the performance characteristics of various components and then to analyze the effects of such modifications.
- Simulation provides for detailed performance statistics collection, which can be used to understand performance tradeoffs.

The *cnet* network simulator [MCDO91] enables experimentation with various data link layer, network layer, routing and transport layer protocols, and with various network configurations. It has been specifically designed for undergraduate computer networking courses and used worldwide by thousands of students since 1991.

The *cnet* simulator was developed by Professor Chris McDonald at the University of Western Australia. Professor McDonald has developed a Student User's Manual and a set of project assignments specifically for use with *Data and Computer Communications* and available to professors on request.

The *cnet* simulator runs under a variety of UNIX and LINUX platforms. The software can be downloaded from the *cnet* Web site. It is available at no cost for noncommercial use.

B.5 PERFORMANCE MODELING

An alternative to simulation for assessing the performance of a communications system or networking protocol is analytic modeling. As used here, analytic modeling refers to tools for doing queuing analysis, as well as tools for doing simple statistical tests on network traffic data and tools for generating time series for analysis.

A powerful and easy-to-use set of tools has been developed by Professor Kenneth Christensen at the University of South Florida. His *tools page* contains downloadable tools primarily related to performance evaluation of computer networks and to TCP/IP sockets programming. Each tool is written in ANSI C. The format for each tool is the same, with the program header describing tool purpose, general notes, sample input, sample output, build instructions, execution instructions, and author/contact information. The code is documented with extensive inline comments and header blocks for all functions. The goal for each tool is that it can serve as a teaching tool for the concept implemented by the tool (and as a model for good programming practices). Thus, the emphasis is on simplicity and clarity. It is assumed that the student will have access to a C compiler and have at least moderate experience in C programming.

Professor Christensen has developed a Student User's Manual and a set of project assignments specifically for use with *Data and Computer Communications* and available to professors on request. The software can be downloaded from the *tools* Web site. It is available at no cost for noncommercial use.

In addition, OPNET, a professional modeling tool for networking configurations, is provided. An academic version is available and a student lab manual prepared for this book is available from Prentice Hall.

B.6 RESEARCH PROJECTS

An effective way of reinforcing basic concepts from the course and for teaching students research skills is to assign a research project. Such a project could involve a literature search as well as a Web search of vendor products, research lab activities, and standardization efforts. Projects could be assigned to teams or, for smaller projects, to individuals. In any case, it is best to require some sort of project proposal early in the term, giving the instructor time to evaluate the proposal for appropriate topic and appropriate level of effort. Student handouts for research projects should include

- A format for the proposal
- A format for the final report
- A schedule with intermediate and final deadlines
- A list of possible project topics

The students can select one of the listed topics or devise their own comparable project. The instructor's supplement includes a suggested format for the proposal and final report plus a list of possible research topics.

B.7 READING/REPORT ASSIGNMENTS

Another excellent way to reinforce concepts from the course and to give students research experience is to assign papers from the literature to be read and analyzed. The instructor's supplement includes a suggested list of papers to be assigned. All of the papers are readily available either via the Internet or in any good college technical library. The manual also includes a suggested assignment wording.

B.8 WRITING ASSIGNMENTS

Writing assignments can have a powerful multiplier effect in the learning process in a technical discipline such as cryptography and network security. Adherents of the Writing Across the Curriculum (WAC) movement (**http://wac.colostate.edu/**) report substantial benefits of writing assignments in facilitating learning. Writing assignments lead to more detailed and complete thinking about a particular topic. In addition, writing assignments help to overcome the tendency of students to pursue a subject with a minimum of personal engagement, just learning facts and problem-solving techniques without obtaining a deep understanding of the subject matter.

The instructor's supplement contains a number of suggested writing assignments, organized by chapter. Instructors may ultimately find that this is the most important part of their approach to teaching the material. I would greatly appreciate any feedback on this area and any suggestions for additional writing assignments.

B.9 DISCUSSION TOPICS

One way to provide a collaborative experience is discussion topics, a number of which are included in the instructor's supplement. Each topic relates to material in the book. The instructor can set it up so that students can discuss a topic either in a class setting, an online chat room, or a message board. Again, I would greatly appreciate any feedback on this area and any suggestions for additional writing assignments.