IMGS-616-20131 — FOURIER METHODS FOR IMAGING (RIT #11857)

website: *http://www.cis.rit.edu/class/simg616/*

Relevant Published Materials:
Though this list is meant to be fairly comprehensive, I am sure that there are others that should be included – feel free to suggest additions to the list. Library of Congress call numbers are included for books available in the RIT library. The comments are my own gauges of usefulness to this class and to imaging in general. You should spend some time in the library looking over these books! Many of you may know about the open-source website archive.org, which has posted many useful papers. I often go there first when looking for background material.

Text:

1. ***Fourier Methods in Imaging***, Roger L. Easton, Jr., Wiley, 2010, ISBN 978-0-470-68983-7, available for free use online from RIT Library as e-book.

Other (very useful!) Textbooks:

2. ***Foundations of Image Science***, H.H. Barrett & K.D. Myers, Wiley, 2004, ISBN 0-471-15300-1, Catalog number TK8315.B37 2004, (my research advisor and a colleague from graduate school, respectively) considers much of the same material up through optical imaging, though at a more theoretical level and without figures and homework problems. Even with that constraint, you should be aware of this book.
3. ***Linear Systems, Fourier Transforms, and Optics***, Jack D.Gaskill, Wiley, 1978, QC355.2.G37 (formerly text for this class, source of many homework problems)
4. ***Fourier Transforms: Principles and Application*s,** Eric Hansen, Wiley, 2014 (brand new book by a colleague), ISBN: 978-1118479148, description: *explains transform methods and their application to electrical systems from circuits, antennas, and signal processors—ably guiding readers from vector space concepts to the Discrete Fourier Transform (DFT) and the Fourier series.*
5. ***Two-Dimensional Imaging***, R.N. Bracewell, Prentice-Hall, 1995, TA1637.B73 *(good book by author of several classics)*
6. ***Fourier Analysis and Imaging***, R.N. Bracewell, Springer 2004, ISBN 978-030648187
7. ***Digital Image Processing***, K.R. Castleman, Prentice-Hall, 1996 (§1-2,§9-16), *(far more comprehensive than title implies; excellent source for a variety of imaging systems, including optics; demonstrates relationship of linear systems to optical systems, I **really** like this book)*, TA1632.C37

Mathematical Foundations of Linear Systems:

1. For review, the *Schaum's Outline Series* volumes on Calculus, Linear Algebra, Vector Analysis, Matrices, Complex Variables; *(everybody in the sciences knows about (or SHOULD know about) Schaum's Outline Series; each volume includes solved and supplemental problems)*, also *Schaum's Mathematical Handbook (of formulas and concepts)*
2. ***Advanced Mathematical Methods for Engineering and Science Students***, G. Stephenson, P.M.Radmore, Cambridge, 1990 (particularly §2 on special functions and §7 on Fourier transforms)
3. ***Linear Algebra and its Applications*** (3rd Edition), Gilbert Strang, Harcourt, Brace, Jovanovitch, 1988, (Chapters on orthogonal projections, eigenvectors, change of bases)
4. Any of several texts on mathematical physics, e.g., Kreysig and Kreysig, *Advanced Engineering Mathematics*, Arfken, *Mathematical Methods for Physicists*, Byron and Fuller *Mathematics of Classical and Quantum Physics*, etc. (Every scientist probably needs to be familiar with at least one of these). Byron and Fuller is available as a Dover paperback reprint for under $25 (www.doverpublications.com)

Fourier Transforms in Mathematics: (theorems and proofs, perhaps of special interest, but not generally needed)

1. ***The Fourier Integral and Certain of its Applications***, N. Wiener, Dover Publications reprint, 1958 (first published in 1933 – *tediously mathematical*), QA404.W47
2. ***An Introduction to the Theory of Fourier's Series and Integrals***, H.S. Carslaw, Dover Publications reprint, 1950 (first published in 1930 -- *also mathematical, but easier to read than Wiener)* QA404.C32
3. ***A Handbook of Fourier Theorems***, D.C. Champeney, Cambridge, 1987, (*best of the three*) QA403.5.C47

Fourier Transforms in Physics/Engineering:

1. ***Fourier Series and Boundary-Value Problem*s**, R.V. Churchill, McGraw-Hill, 4th Edition, 1987, (*classic text with lots of physical applications*), QA404.C6
2. ***A First Course in Fourier Analysis***, D.M. Kammler, Prentice-Hall, 2000, (useful discussions of mathematical and computational aspects), QA403.5.K36
3. ***Fourier Transforms and their Physical Application*s**, D.C. Champeney, Academic Press, 1973, *(excellent book)*, QA403.5.C46
4. ***Fourier methods for mathematicians, scientists, and engineer*s**, M. Cartwright, Ellis Horwood, 1990, *(paperback, introductory, lots of physical applications)*, QA403.5.C37

5. ***The Fourier Transform and Its Applications*** (2nd Edition, Revised), R.N.Bracewell, McGraw-Hill, 1986, *(the standard reference on 1-D Fourier, good discussion of discrete transforms and applications),* QA403.5.B7
6. ***Fourier Transforms, An Introduction for Engineers***, R.M. Gray and J.W. Goodman, Kluwer Academic Publishers, 1995, *(aimed at discrete transform, not as useful as I expected),* TK5102.9.G73
7. ***A student's guide to Fourier transforms, with Applications to Physics and Engineering***, J.F. James, Cambridge, 1996, QC20.7.F67J36, (reissued 2011, *thin, cheap as paperback, useful)*
8. ***The Fourier Integral and its Applications***, A. Papoulis, McGraw-Hill, 1962, *(old, pre-FFT, though good mix of mathematical theory and practical applications),* QA404.P32
9. ***Fourier Transforms***, I.N. Sneddon, Dover Publications, 1995 (first published in 1951), *(similar comments to Papoulis above),* QA404.S53
10. ***Fourier Analysi****s*, T.W. Körner, Cambridge, 1988, *(potpourri of Fourie rtheory from nonconventional point of view -- historically driven),* QA403.5.K67
11. ***Exercises for Fourier Analysis***, T.W. Körner, Cambridge, 1993 *(comment for Körner above ,*QA403.5.K66
12. *I**ntegral Transforms in Science and Engineering***, K.B. Wolf, Plenum, 1979, *(mathematical reference),* QA432.W64
13. ***Probability, Statistical Optics, and Data Testing***, 2nd Ed., B.R. Frieden, Springer-Verlag, 1991 (particularly §4 on Fourier methods – *excellent discussion of applications of statistical principles to many types of imaging problems, not just optics),* QA273.F89
14. ***Statistical Optics***, J.W. Goodman, Wiley, 1985, *(applications of Fourier theory to statistics, particularly in optics),* QC355.2.G66
15. ***The Hartley Transform***, R.N. Bracewell, Oxford, 1986, (*describes a special case of Fourier transform that is real valued for real-valued inputs, a favorite of Bracewell)* QA403.5.B73

Discrete Fourier Transforms: (more relevant to course IMGS-718 *Digital Imaging Mathematics*)

1. ***The FFT, Fundamentals and Concepts***, R.W. Ramirez, Prentice-Hall, 1985, *(graphical introduction to discrete and fast Fourier transform algorithms)* QA403.5.R36
2. ***The Fast Fourier Transform and its Applications***, E.O. Brigham, Prentice-Hall, 1988, *(excellent),* QA403.B75
3. ***Fast Fourier Transforms***, J.S. Walker, 2nd Edition, CRC Press, 1996, *(w/ DOS software ☺),* QA403.W33
4. ***Multidimensional Digital Signal Processing***, D.E. Dudgeon and R.M. Mersereau, Prentice-Hall, 1984 (§1-§2), *(written for EEs, but good discussion of 2-D discrete transform)* TK5102.5.D83
5. **Exact Fourier Spectrum Recovery,** M. Andrecut, Arxiv.org, https://archive.org/details/arxiv-1304.2043
6. **The Fractional Fourier Transform and Applications**, David H. Bailey and Paul N. Swarztrauber, 1990, https://archive.org/details/nasa_techdoc_19970015100

Linear Systems and Optical Imaging:

1. ***Introduction to Fourier Optics,*** J.W. Goodman, (3rd Edition), Roberts and Co., 2005, (updated classic, generally accepted, with good reason, as the BEST book on Fourier transforms in optical imaging), QC355.G65
2. ***Fourier Optics, An Introduction*** (2nd Edition), E.G. Steward, Wiley, 1987, (useful introduction, lower level than Goodman), QC454.F7S83
3. ***Introduction to the Optical Transfer Function***, C.S. Williams and O.A. Becklund, Wiley, 1989, (specialized topic of linear systems in optics), QC367.W55
4. ***Systems and Transforms with Applications in Optics***, A. Papoulis, McGraw-Hill, 1968, (another classic, Papoulis has LOTS of useful things to say!), QC383.P23
5. ***Applications of Optical Fourier Transforms***, H. Stark, ed., Academic Press, 1982, (as implied, discussions of specific applications), TA1632.A68
6. ***Quantitative Coherent Imaging: Theory, Methods, and Some Applications***, J.M. Blackledge, Academic Press, 1989, (nice description, unusual notation/spellings, e.g., "Weiner" vs. "Wiener"), QC476.C6.B553
7. ***The New Physical Optics Notebook***, Reynolds, DeVelis, Parrent, and Thompson, SPIE Press, 1989, *(applications of linear systems to optics/holography; though I am not fond of the notation, this is a very useful book that considers applications of Fourier transforms to optics and imaging), QC395.2.N48*
8. ***Fourier Series and Optical Transform Techniques in Contemporary Optics***, Raymond Wilson, John Wiley & Sons, Inc, 1995. QC454.F7 W55 (ISBN 0-471-30357-7)
9. ***Two-Dimensional Phase Unwrapping, Theory, Algorithms, and Software***, Dennis C. Ghiglia and Mark D. Pratt, Wiley-Interscience, 1998. (not in RIT Library, call number is TK6582.S95G45, ISBN 0-471-24935-1), includes algorithms and code.
10. ***Deconvolution of Images and Spectra*** (Second Edition), Peter A. Jansson (ed.), Academic Press, 1997, QC451.6.F45 (ISBN 0-12-380222-9)
11. ***Analysis and Evaluation of Sampled Imaging Systems,*** Richard H. Vollmerhausen; Donald A. Reago Jr.;

Ronald G. Driggers, SPIE, 2010 (available as e-book from RIT library), *)Advancing technology in detector arrays, flat panel displays, and digital image processing provides new opportunities to expand imaging applications and enhance system performance.)*

12. ***Transformations in Optics,*** Lawrence Mertz, John Wiley & Sons, 1965, ISBN 978-0471596400 *(classic book that discusses on Fourier transform spectrometry theory and practice, Fresnel transforms including the chirp Fourier transform)*
13. ***Basic electro-optics for electrical engineers,*** Glenn D. Boreman, SPIE tutorial text, 1998 (available as e-book from RIT library)
14. ***Computational Fourier Optics: a MATLAB Tutorial***, David G. Voelz, SPIE Library, 2011 (available as e-book from RIT library)
15. ***Modulation Transfer Function in Optical and Electro-Optical Systems,*** Glenn D. Boreman, SPIE tutorial text, 2001 (available as e-book from RIT library)

Image Recovery:

1. ***Image Restoration and Reconstruction***, R.H.T. Bates and M.J. McDonnell, Oxford University Press, 1986, *(application of linear systems to imaging),* TA1632.B36
2. ***Image Recovery, Theory and Application***, (H.Stark, ed.), Academic Press, 1987, *(similar to Bates but more applications, multiple authors, fragmented),* TA1632.I4824

Useful References from Magazines and Journals: (with links to pdf copies)

1. "The Fourier Transform," R.N. Bracewell, in ***Scientific American****,* June 1989, pp. 86-95
2. "Numerical Transforms," R.N. Bracewell, in ***Science***, **v.248**, 11 May 1990, pp. 697-704
3. "Fourier Analysis Using a Spreadsheet," R.A. Dory and J.H. Harris, in ***Computers in Physics***, **Vol. 2,** Nov.-Dec. 1988, pp. 83-86
4. "A Plain Man's *(sic)* Guide to the FFT," P. Kraniauskas, in ***IEEE Signal Processing Magazine***, v.**11**, April 1994, pp. 24-35
5. "Tom, Dick, and Mary Discover the DFT," J.R. Deller, Jr., in ***IEEE Signal Processing Magazine***, v.**11** April 1994, pp. 36-50
6. "SIGNALS, Interactive Software for One-Dimensional Signal Processing," R.L. Easton, Jr., in ***Computer Applications in Engineering Education***, v.**1**, December 1993, pp. 489-501
7. "Fast Fourier Transforms for Fun and Profit," W.M. Gentleman and G. Sande, in *Proceedings - Fall Joint Computer Conference*, 1966, pp. 563-578
8. The Theory and Design of Chirp Radars, J.R. Klauder, A.C. Price, S. Darlington, and W.J. Albersheim, **BSTJ, 39**, 745-808. (available from https://archive.org/details/bstj39-4-745); *(classic paper about chirp radar that is also relevant to optical imaging, John Klauder was by all accounts a brilliant contributor to many areas of science, from math radar to quantum theory to radar).*

Other books containing useful discussions of imaging subjects:

1. ***Principles of Digital Image Synthesis***, Andrew Glassner, Morgan-Kauffman, 1995 (two volumes), *(very nice discussion of broad range of imaging topics, relevant material in §4-5,§8-10*), T385.G585
2. ***Image Reconstruction in Radiology,*** J. Anthony Parker, CRC Press, 1990, (*excellent book of much more general application than title implies; written for medical students and radiologists, does not require a "high" level of mathematical knowledge, useful intuitive discussions of imaging principles and linear algebra*) RC78.7.D53 P36
3. ***Radiological Imaging***, H.H. Barrett and W.Swindell, Academic Press, 1981, *(terrific book, also much more general than indicated by its title),* (§2, §4 on Linear Systems, §3 on Random Processes, §7 on Computed Tomography) RC78.B337

Computing Resources:

Many computational software packages are available that are helpful when learning the material in this class. CIS uses ***IDL™*** from ITT Exelis (*http://www.exelisinc.com/*) as its "standard" package. It is installed on the *UNIX* workstations in the Center, and also is available for purchase at a substantial student discount from CIS. Other packages exist, including ***Mathematica™*** (available on RIT VAX), ***MathCad™***, ***Matlab™***, and ***Scientific Workplace™***, and **ENVI®**. All these packages allow computations involving most aspects of matrix algebra and complex analysis to be evaluated quickly and (more or less) painlessly. They also have graphing routines which may assist in visualizing concepts. In my opinion, most of the packages have a fairly steep learning curve – you cannot do much that is useful "out of the box." The programs also have their respective advantages and disadvantages, *e.g.*, my opinion is that the interfaces to ***Mathematica™*** and ***MathCAD™*** are not very intuitive, which means that new users have to travel the learning curve. Conversely, experienced users are rewarded by quicker answers.

I suggest exploring some of the freeware alternatives to the big expensive programs, the Python-based software Sage Math (http://www.sagemath.org) or Geogebra (http://www.geogebra.org) – of course, you can guess that a free package likely is more difficult to learn and use. The Wolfram demonstrations project includes a range of possibly useful stuff (http://demonstrations.wolfram.com/), such as Fourier transform pairs, but most demos are not flexible.

Signals Software:

For demonstrations in lectures, I shall often use my (ancient, but still serviceable) program "***SIGNALS***" (which was written before many, if not all, of you were born!). It is keystroke driven from menus, so it is typically much faster to use in class than other available software tools, such as MATLAB. It may be downloaded from the CIS website:

http://www.cis.rit.edu/people/faculty/easton/signals/signals.zip.

A "User Manual" is posted at: http://www.cis.rit.edu/resources/software/sig_manual/index.html.

"*SIGNALS*" was written to run in the antediluvian PC Disk Operating System ("DOS") and therefore cannot be used directly on "modern" PC operating systems (any after Windows 98). Fortunately, it runs quite well on a wide range of computer platforms including all flavors of Windows (95, 98, XP, Vista, Win7, and Win8), the Macintosh OS, and Linux by using the free DOS emulator "*DOSBox*" (available at http://www.dosbox.com/). In *DOSBox*, the graphics display appears in a window, which is a significant advantage over the old full-screen DOS display. For example, it now is possible to run several independent sessions of *Signals* by starting different sessions of *DOSBox*.

Any version of *DOSBox* may be optimized for "Signals" by editing the configuration file (see instructions on the *DOSBox* website or go to "*Start* → *Programs* → *DOSBox* → *Configuration* → *Edit Configuration*" in Windows; then go to the bottom of the file to the section labeled [autoexec] and insert the lines listed below after "**Lines in this section will be run at startup**:"

#Lines in this section will be run at startup

mount … *(insert location of the directory where the executable program for Signals resides, e.g., "mount z c:\2d", which creates an alias labeled "z" for the directory "c:\2d")*

z: *(switches to the drive letter defined in the previous "mount" command)*

cycles=50000 *(you may want to experiment with this value – faster computers can make use of larger numbers to speed up processing)*

signals /c *(starts the program with the "color" display switch)*

When you start "DosBox," "Signals" should start in a command window. Note that you may read or save files in text format and save them in spreadsheet format, which is sometimes useful as it allows the files to be entered into other software (such as Excel) for graphing. There also is an output format that allows the file to be dropped directly into *Kaleidagraph* from Synergy Software (http://www.synergy.com) for graphing; the graphs in the book were created in exactly this manner.

SignalShow:

A Java counterpart called ***SignalShow*** was written by CIS undergraduate Juliet Bernstein a few years back. Its capability includes illustration of the 2-D case, but is not as fast to use. It also has some problems with saving files and I often seem to be able to overload the program to the point where it becomes unresponsive. The beta releases of *SignalShow* for the three primary computing platforms (Windows, Macintosh OSX, and Linux) are available at from her grad-school website: http://homes.cs.washington.edu/%7Ejuliet/photography/SignalShow.jar. A video introduction is available at http://www.youtube.com/watch?v=yDNipwKTMXM and the JAVA source code is available on Dropbox at https://www.dropbox.com/sh/h3c07v15kf1ptao/PQ1_7n8nEa. Besides being helpful in this course, you may find this program to be helpful in your quest to visualize the concepts in "Digital Imaging Processing," and in "Optics for Imaging."

Other Software Tools

Other programs are available that are helpful in this course and the followup IMGS-618 "Digital Imaging Mathematics."

- *ImageJ* is a freely available open-source program Windows, Linux and Mac OS X that has evolved from former versions *NIHImage* and *ScionImage*. Written in Java, the basic program and "plugins" for more advanced routines are available from the website http://rsbweb.nih.gov/ij/. Plugins are available for advanced processing relevant to this and subsequent courses, including the Radon transform and statistical analysis. My primary gripe with *ImageJ* is the limited documentation for the plugins and the fact that the routines often are not very intuitive, which is not surprising since they were written for specific applications by users.
- *IDL / ENVI* are available on many computers in the Carlson Center
- *Matlab* is available from RIT for faculty and staff at reduced cost, but this offer does NOT extend to students (don't ask me why, because I don't know)
- *Mathematica*, also available from RIT.
- Some symbolic math packages with similar capabilities to Mathematica are available for FREE: the Python-based software *Sage Math* (http://www.sagemath.org), *Maxima* (maxima.sourceforge.net), and *Geogebra* (http://www.geogebra.org) – of course, it often is true that free packages may be more difficult to learn and use, but they are free and you can use them for life.
- The Wolfram demonstrations project (http://demonstrations.wolfram.com/) includes a range of possibly useful stuff, such as Fourier transform pairs, but the demos are typically not very flexible, i.e., you can only demonstrate the specific examples generated by the author(s).
- *Graphing Software*, which may be simple (such as spreadsheet graphing in Excel) or more sophisticated (such as *Kaleidagraph*).

I think of graphing software as a tool for insight and not as a crutch; you need to be able to do sketching without the aid of graphing software, so it is useful to understand the methods for accurate sketches, such as of sinusoidal functions multiplied by bipolar modulations, e.g., $f[x] = \cos[2\pi x] \times SINC[0.25x]$. In this case, the sinusoid oscillates between fixed limits ± 1, so the excursions along the vertical axis are constrained by the *SINC* function. You sketch the function by filling in the oscillating cosine between the limits $\pm SINC[x/4]$

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