Appendix A
Reference Material

A man loses contact with reality if he is not surrounded by his books.

—François Mitterand[*]

A.1 Good Books

If you're going to build electro-optical systems for a living, you're going to have to change fields a lot. If you're still in school, use the opportunity to broaden your expertise—an experimental physics student should learn signal processing and circuit design, and an electrical engineering student, classical and quantum mechanics. It's well worth devoting an extra semester to, if you can afford it—graduate students usually can. The rest of us need good readable books that don't demand total devotion, and maybe help wangling a sabbatical.

The best way to start learning a new field is to get a good undergraduate-level textbook and read it like a novel. Pay special attention to getting the very basic concepts down perfectly; as we've seen in earlier chapters, our confidence in working in a new area depends entirely on how sure we are of our tools. For example, we've seen that Fourier optics is an approximation, but that the Fourier decomposition of an optical field is exact; in electronics, metal resistors have only Johnson noise and capacitors subtract dc noiselessly. In this class also are the classical techniques of other fields, e.g. the idea of using UHF modulation to suppress mode hopping in diode lasers was first used

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[*] Quoted in *The Times* (London), May 10, 1982

around 1930, in the quench circuits of superregenerative receivers, whose very high gain detectors would otherwise oscillate.

Some fields are harder to learn this way, of course; statistics, mathematics, and mathematical physics are the hardest for most of us. To pick up those, you need to sit down and do the chapter problems too. The books listed here are an unsystematic sampling, consisting of favourite references and textbooks of the present author and his friends.

Multi-author handbooks consist of chapters written by experts in their fields, who quite reasonably think that what they do is the most interesting and useful subfield of them all (even radiometry). Thus they typically suffer from all-inclusiveness, and are not always useful in discriminating between what has been done and what you ought to do. Use them with care.

A.1.1 Electro-Optical Systems Lore

John Lester Miller & Edward Friedman, *Photonics Rules Of Thumb*, McGraw-Hill, New York, 1996, ISBN 0-07-044329-7. A couple of hundred pieces of well-explained wisdom from the military-industrial complex. Lots of stuff about atmospheric propagation, sensors, and management. Some duplication of material with Accetta & Shumaker's *Infrared And Electro-Optical Systems Handbook*.

A.1.2 Interferometry

Pramod K. Rastogi, ed., *Optical Measurement Techniques And Applications*, Artech House, Norwood MA, 1997. A good summary of interferometric and holographic techniques for engineering measurements, especially full-field ones such as optical testing, electronic speckle pattern interferometry (ESPI, also known as TV interferometry), and moiré. Also has some stuff on fibre sensors, lidar, and particle velocimetry.

A.1.3 Building and Testing Systems

Daniel Malacara, ed., *Optical Shop Testing*, 2nd Ed., Wiley, New York, 1992 ISBN 0471522325 This is the book to read before figuring out a test strategy for your latest gizmo. There's a lot of optical testing lore here.

Paul R. Yoder, *Opto-mechanical Systems Design*, Marcel Dekker, 1986 ISBN 0824773470 An excellent and widely used book on designing optomechanical systems, test jigs, and so on. Yoder has immense design experience, and the book repays close attention. A few more worked examples would make it a better self-teaching book, but there's lots of stuff on mechanical engineering available elsewhere.

A.1.4 Instrument Construction

John H. Moore, Christopher C. Davis, and Michael A. Coplan, *Building Scientific Apparatus* 2nd Ed., Addison-Wesley, Redwood City CA, 1989 ISBN 0201131897. A very readable guide to building apparatus. Lots of stuff about basic optics, mechanics, and vacuum, although the charged particle optics stuff is pretty specialized and the electronics part isn't as good as Horowitz and Hill.

A.1.5 Electrodynamics

John D. Jackson, *Classical Electrodynamics* 2nd Ed., Wiley, New York, 1975, ISBN 047143132X. The best graduate E&M textbook of all time. Excellent problems. There is a 3rd edition due soon, which extends the Jacksonian treatment to free electron lasers and optical fibres.

Lev D. Landau, Evgeny M. Lifshitz and Lev P. Pitaevskii, *Electrodynamics of Continuous Media*, Pergamon, Oxford, 1984, ISBN 0080302750. The Landau and Lifshitz *Course of Theoretical Physics* books contain an amazing amount of aptly chosen material on all of physics. This book has an especially accessible discussion of crystal optics.

A.1.6 Statistical Mechanics

Lev D. Landau, Evgeny M. Lifshitz, and Lev P. Pitaevskii, *Statistical Physics, 3rd. Ed.* (2 vols), Pergamon, Oxford, 1980 and 1981, ISBN 0080230725. Especially good on black body radiation and the fluctuation-dissipation theorem, from a theoretical physics point of view.

A.1.7 Classical Optics

Max Born & Emil Wolf, *Principles of Optics*, 6th ed. with corrections, Cambridge University Press, reissued 1998, ISBN 0521639212. The standard work on optical theory: propagation, diffraction, coherence, aberrations, you name it. If you don't have a copy, buy one.

Eugene Hecht and Alfred Zajac, *Optics* 3nd ed., Addison-Wesley, Reading MA, 1997, ISBN 0201838877. Hecht and Zajac, first edition, was the present author's first undergraduate optics text, and the mere fact that it's gone on through three editions says a lot. It's a great book, especially strong on Fourier optics.

Miles V. Klein & Thomas E. Furtak, *Optics* 2nd Ed., Wiley-Interscience, New York, 1986. A good complement to Hecht and Zajac, with more discussion of aberrations.

J. J. Stamnes, *Waves in Focal Regions*, Adam Hilger, 1986 ISBN 0852744684 A really thorough treatment of wave propagation of all kinds, in situations where diffraction is important; it isn't really as limited as the title would indicate. It's pretty expensive, but maybe your technical library could get one if you ask nicely.

A. Gerrard and J, M. Burch, *Introduction To Matrix Methods In Optics*, Dover, 1994 ISBN 0486680444 A good and very inexpensive presentation of ABCD matrices, Jones matrices, and other matrix topics in optics.

A.1.8 Aberration Theory and lens design

Rudolf Kingslake, *Optical Systems Design*, Academic Press, New York, 1983, ISBN 0124086608., and
Rudolf Kingslake, *Lens Design Fundamentals*, Academic Press, New York, 1978 ISBN 0124086501. These books are classics, reflecting the Conrady tradition of hand calculation in optical design. You can't run a numerical optimizer with a desk calculator, so Kingslake talks a lot about heuristics and intuitive methods, and this is worth the price of the books.

Virendra N. Mahajan, *Aberration Theory Made Simple*, SPIE, Bellingham WA, 1991. A clear and accessible discussion of classical aberration theory in two sections, covering wave and ray

aberrations. As you'd expect from such a split treatment, it's a bit weaker on the connections between the two pictures, e.g. the way distortion and field curvature don't usually come out in a wave analysis, and on the subtle changes in terminology between them.

Robert R. Shannon, *The Art And Science Of Optical Design*, Cambridge University Press, Cambridge (UK), 1997, ISBN 052145414X. A good modern treatment of software-assisted optical design in all its aspects: geometric optics, lens designs, aberrations, image quality, materials, mounts, environmental considerations, the works.

A.1.9 Fourier Optics

Ronald N. Bracewell, *The Fourier Transform and Its Applications*, 2nd Ed., McGraw-Hill, New York, 1986, ISBN 0070070164. A most intuitive and useful Fourier Transforms book, written by a radio astronomer who is expert in both analogue and digital signal processing, and the inventor of the Fast Hartley Transform. The good humoured and accessible style makes it good for self-teaching, too.

Joseph W. Goodman, *Introduction to Fourier Optics, 2nd ed.*, McGraw-Hill, San Francisco, 1986, ISBN 0070242542. A beautifully written textbook on paraxial Fourier optics.

A.1.10 Coherence theory

Joseph W. Goodman, *Statistical Optics*, Wiley-Interscience, New York, 1985 ISBN 0471015024. A very readable, complete and accessible presentation of statistical optics, including speckle, classical and quantum fluctuations, and the complete theory of imaging with partially coherent light. There's a lot of good stuff in here, but you have to be comfortable with fairly advanced statistical reasoning to get the most out of it.

A.1.11 Fibre Sensors

Eric Udd, ed., *Fiber Optic Sensors: An introduction for Engineers and Scientists*, Wiley-Interscience, New York, 1991, ISBN 0-471-83007-0
This one is a bit long in the tooth now, because fibre sensors are a fast moving field (at least for optics), but it contains a fair amount of lore from experts. There is a fair amount of rather partisan boosting of fibre sensors; other alternatives are not really given their due.

A.1.12 Lasers

Anthony E. Siegman, *Lasers*, University Science Books, Mill Valley CA, 1986 ISBN 0935702113. A gigantic tome on all aspects of lasers. Aimed at entering graduate students with an electrical engineering background, but generally accessible; full of good intuitive examples. Due to its age, it's better on gas and solid state lasers than on semiconductor ones.

Motoichi Ohtsu, *Highly coherent semiconductor lasers*, Artech House, Boston, 1992, ISBN 0890064628, and
Motoichi Ohtsu, ed., *Frequency Control of Semiconductor Lasers*, Wiley, New York, 1996, ISBN 0471013412. Design and experimental data on how to stabilize diode lasers, for spectroscopy, frequency standards, and other uses.

A.1.13 Spectroscopy

David S. Kliger, *Ultrasensitive Laser Spectroscopy*, Academic Press, New York, 1983 ISBN 0124149804. This book is now somewhat dated, but remains a very good presentation of the techniques and difficulties encountered doing ultrasensitive optical measurements. Readable and full of lore.

Marc D. Levenson and Satoru S. Kano, *Introduction to Nonlinear Laser Spectroscopy*, revised ed., Academic Press, New York, 1988, ISBN 0-12-444722-8 This is now out of print, but is a really good book for coming up to speed in laser spectroscopy quickly, including chapter problems and lab exercises.

A.1.14 Lidar

Albert V. Jelalian, *Laser Radar Systems*, Artech House, Boston, 1992, ISBN 0-89006-554-3 A pretty comprehensive approach to the problem of detecting objects by bouncing laser beams off them. Jelalian is readable and clear.

A.1.15 Detectors

Ian S. McLean, *Electronic Imaging In Astronomy: Detectors and Instrumentation*, Wiley-Praxis, Chichester, 1997, ISBN 0471969729. A very readable and informative introduction to high performance low light imaging with CCDs.

A.1.16 Electronics

Paul Horowitz and Winfield Hill, *The Art of Electronics* 2nd. Ed., Cambridge University Press, Cambridge, 1989, ISBN 0521370957. The primary and indispensable reference for every circuit designer; getting a bit dated in detail (especially in components and construction practices, since it pre-dates widespread adoption of surface mount and wireless), but still superior to all others. If you so much as wire up an op amp occasionally, you should own this one. It is possible to learn circuit design by merely leaving H&H in the bathroom for a year.

Robert A. Pease, *Troubleshooting Analog Circuits*, Butterworth-Heinemann, Boston, 1991 ISBN 0750691840. An entertaining and readable look at troubleshooting. Full of war stories, and applicable to a lot of other types of systems besides analogue circuits.

Jim Williams, ed., *Analog Circuit Design: Art, Science, and Personalities*, Butterworth-Heinemann, Boston, 1991 ISBN 0750691662. The lore of analogue design, told by masters of the art.

Jim Williams, ed., *The Art and Science of Analog Circuit Design*, Butterworth-Heinemann, Boston, 1995, ISBN 0750659056. More analogue design lore, especially about high-impedance, high frequency circuits—very useful in front end design.

Floyd M. Gardner, *Phaselock Techniques* 2nd ed., Wiley, New York, 1979 ISBN 0471042943. A slim but information-rich book primarily about analogue phase-locked loops. Too old to contain much on direct digital synthesis, but for PLL signal detection, telemetry, and Doppler tracking, this is the book to read.

Mac E. Van Valkenburg, ed. *Reference Data For Engineers* 8th ed., Sams, Carmel, Indiana, 1995 ISBN 0672227533. Lots of practical stuff about design of rf, communications, analogue and digital

circuits, and computers. This edition branches out from the previous radio-only focus, but there's still a lot of great rf stuff.

American Radio Relay League, *The ARRL Handbook for the Radio Amateur*, 76th ed. (annual) American Radio Relay League, Newington CT, 1996 ISBN 0872591735. Aimed at radio hobbyists of a wide range of skills, so its sections on modulation, signal processing, and wave propagation contain lots of heuristic arguments. Its relatively low technical level means that there's more lore, but may be frustrating when you're looking for hard information. Old editions (before about 1990) had lots of rf construction lore, but newer ones have much less, reflecting the unfortunate decline in homebuilt amateur equipment.

Anatol Zverev, *Handbook of Filter Synthesis*, Wiley, New York, 1967, ISBN 0471986801. Zverev is the classic reference for continuous time filter design, especially lumped element LC ladder filters. The book is mostly tables, but the plots of filter behaviour for different designs—ripple, group delay, and so on, are easily worth the price. The discussion of how to synthesize a bandpass, bandpass, or bandstop filter from a lowpass prototype is very useful. They don't teach this stuff in school any more. Still in print as of 1998.

Merrill I. Skolnik ed., *Radar Handbook*, 2nd ed., McGraw-Hill, New York, 1990. A good reference for more advanced signal processing. Its sharp targeting to radar applications is not a serious impediment to learning a lot about signal processing subsystems and the tradeoffs involved in designing an instrument. It falls into the trap (usual in well-ploughed fields) of wanting to stick every little effect into one enormous master equation, which tends to obscure what the sources of the problems are.

Jiri Dostal, *Operational Amplifiers*, 2nd. ed., Butterworth-Heinemann, Boston, 1997. An excellent mixture of rigour and arm waving gets across the subtleties of op amps and operational circuits with a minimum of wasted effort and confusion. Well worth reading if you need to design high performance analogue circuits—ADC front ends, say, or charge-sensitive preamps.

Paul A. Gray & Robert G. Meyer, *Analysis and Design of Analog Integrated Circuits*, 2nd ed., Wiley, New York, 1984, ISBN 0471874930. Everyone's favourite book on building and using analogue ICs. This should be on every circuit designer's shelf. The second edition has a great deal on IC MOSFETs, which still reads remarkably well after 15 years.

Howard Johnson and Martin Graham, *High Speed Digital Design*, Prentice-Hall, Upper Saddle River NJ, 1993. Despite the title, this book is mainly about circuit strays, power supply coupling, cable crosstalk, and other ways in which digital is really analogue. The authors give good rational explanations for a lot of odd circuit behaviour, so it is ironically subtitled, *A Handbook of Black Magic*.

Ralph Morrison, *Grounding and Shielding Techniques*, 4th. Ed., Wiley, New York, 1998, ISBN 0471245186. Morrison is great on how to cope with having your sensitive analogue circuit surrounded with a noisy digital and switching circuit environment, and how to design interference out.

Henry W. Ott, *Noise Reduction Techniques In Electronic Systems*, 2nd ed., Wiley, New York, 1988, ISBN 0471-85068-3. A really solid intro to grounding, shielding, decoupling, filtering, and

how to calculate noise and interference. Essential reading for low noise circuit designers, and those whose products have to meet FCC certification (i.e. most of us).

Aldert van der Ziel, *Noise in Solid State Devices and Circuits*, Wiley, New York, 1986. A magisterial presentation of the (surprisingly simple) theory of noise in circuits. If you're doing low noise design, you need a copy. Currently out of print, unfortunately.

T. H. Wilmshurst, *Signal Recovery From Noise In Electronic Instrumentation*, 2nd Ed., Hilger, Boston, 1991, ISBN 0750300590   This is the book on to read on pulling signals out of noise. Wilmshurst covers lock-in detection, signal averaging, and other useful and general techniques.

A.1.17 Mathematical Methods

Carl M. Bender & Steven A. Orszag, *Advanced Mathematical Methods for Scientists and Engineers*, McGraw-Hill, New York, 1978 ISBN 00704452X. This is the present author's favourite applied mathematics book. It has asymptotic methods (e.g. Laplace's method, stationary phase, saddle point method), perturbation theory (e.g. boundary layer theory, WKB theory), difference equations and differential equations. It's full of mathematical lore, with lots of illuminating examples, pictures, and exercises. Bender and Orszag understand that rigour is not always the object of the game, and concentrate on getting correct results using reliable but not guaranteed methods, while gaining insight into the problems.

George B. Arfken and Hans-Jurgen Weber, *Mathematical Methods for Physicists*, 4th ed., Academic, New York, 1995, ISBN 0120598159. Good undergraduate book on classical analysis as applied to physics, with the usual physicist's mathematical permissiveness; especially good on the calculus of complex variables applied to physical problems. The new edition has a bunch of trendier stuff too.

Athanasius Papoulis, *Probability, Statistics, and Stochastic Processes, 3rd ed.*, McGraw-Hill, 1991, ISBN 0070484775. Papoulis is readable and full of useful examples touching on statistical signal processing, e.g. Wiener and Kalman filters, maximum entropy estimation, maximum likelihood tests, Monte Carlo methods, and signals in noise.

Roger A. Horn & Charles R. Johnson, *Matrix Analysis*, Cambridge University Press, Cambridge, 1987. A clear presentation of advanced linear algebra topics, such as singular value decomposition, condition numbers, and so on. It's a math book, all right, but they state the results in algorithmically useful forms if not explicit algorithms.

I. M. Gelfand and S. V. Fomin, *Calculus of Variations*, Richard A. Silverman (tr.), Prentice-Hall, Englewood Cliffs NJ, 1963. Gelfand and Fomin have packed a really lucid and powerful exposition of the calculus of variations into 226 pages. There are enough problems for self-teaching, and anybody doing optical theory really ought to have a good grounding in this subject; many optical problems are easier this way, and the variational principles often furnish convenient numerical algorithms, free.

Izrail S. Gradshteyn and Iosif M. Ryzhik, *Tables of Integrals, Series, and Products*, 4th Ed. (Alan Jeffrey tr.) Academic Press, Boston, 1980 (reprinted 1994), ISBN 012294755X
The most gigantic analytical math tables in existence. G&R is reliable, complete, and well

organized; although you will probably have to go through a change of variables or two to get your integral into a standard form, you'll be able to find it when you do (providing the solution is known analytically). An unscientific sampling suggests that it contains remarkably few errors.

Daniel Zwillinger, ed., *CRC Standard Mathematical Tables and Formulae (30th Ed)* Chemical Rubber Company, Boca Raton, FL, 1996, ISBN 0849324793. Much smaller than G&R, and so easier to find things in, providing they're there: it's more like a pocket dictionary vs. the unabridged Oxford English Dictionary.

Milton Abramowitz and Irene A. Stegun, *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*, US National Bureau of Standards Applied Mathematics Series vol 55 (AMS-55), U.S. Government Printing Office, Washington DC, 1964. The best book available on practical uses of special functions. Tables are useful for checking mathematical routines, and the polynomial approximations are good for most single-precision computations.

A.1.18 Software

William H. Press, Brian P. Flannery, Saul A. Teukolsky, and Steven Vetterling, *Numerical Recipes in C* 2nd ed., Cambridge University Press, Cambridge, 1992, ISBN 0521431085. The standard work on numerical analysis, with lots of good code you can use right away. NR has more routines than lots of commercial libraries, and almost none are black boxes. If you use their code for prototyping, their write-ups give you enough information to write your own routines to avoid copyright problems.

Richard W. Hamming, *Digital Filters*, Prentice-Hall, Englewood Cliffs NJ, 1989, ISBN 0132128128. A good elementary introduction to finite impulse response (nonrecursive) digital filters, from an intuitive point of view. It's at the advanced undergraduate level, which makes it good for coming up to speed rapidly. Currently out of print, alas.

E. Oran Brigham,*The Fast Fourier Transform*, Prentice-Hall, Englewood Cliffs NJ, 1974 ISBN 0-13-307496-X An undergraduate level presentation of the ins and outs of the FFT algorithms known at that time. A good readable book, and very worthwhile if you have to code your own signal processing software or analyze it for roundoff and error propagation.

Forman Acton, *Numerical Methods That Work*, Mathematical Association of America, Washington DC, 1990 ISBN 0-88385-450-3. A salty, opinionated, and very lucid book on numerical analysis with a decidedly practical outlook. Full of lore, including a lovely section on what not to compute. This book was originally published in 1970, but is so relevant still (and so loved) that the MAA republished a minimally revised version in 1990.

Alan V. Oppenheim & Ronald W. Shafer *Digital Signal Processing*, Prentice-Hall, Englewood Cliffs NJ, 1975 ISBN 0-13214-635-5. Old but good; fairly heavily theoretical.

L. R. Rabiner & B. Gold, *Theory and Application of Digital Signal Processing*, Prentice-Hall, Englewood Cliffs NJ, 1974. The advanced course following on after Oppenheim and Shafer. It is less relentlessly mathematical, with a fair amount of lore and good insights on when you'd want to use the different algorithms; the sections on special-purpose hardware are of historical interest only at this point.

Philip J. Davis & Philip Rabinowitz, *Methods of Numerical Integration*, Academic Press, New York, 1975, ISBN 0-12206-350-3. A really good book on all sorts of numerical integration. One of the few books that can give you a command of the literature in the whole field. The topic is somewhat peripheral to instrument building, but the hundreds of short discussions of the algorithmic ingenuity involved shed a lot of light on numerical mathematics generally, and hence on digital signal processing. Now unfortunately out of print.

Anthony Ralston & Philip Rabinowitz, *A First Course in Numerical Analysis*, 2nd Ed., McGraw-Hill, New York, 1978, ISBN 0-07-0551158-6. A good undergraduate book on numerical analysis, that spends no time on techniques that are mathematically neat but numerically useless. R&R is a suitable book for self-teaching, with good examples, especially on error analysis.

J. F. Hart, E. W. Cheney, C. L. Lawson, H. J. Maehly, C. K. Mesztenyi, J. R. Rice, H. G. Thacher, Jr., and C. Witzgall, *Computer Approximations*, R. E. Krieger, Malabar, FL 1968 (recently reprinted), ISBN 0882756427. Full of excellent rational function approximations to both elementary and special functions, in a wide variety of precision from 2 digits to 30. All these approximations have been tested extensively, and the coefficients were printed directly from the computer output, with no transcription, so few or no errors are expected[*]. These approximations are widely used and liked. You build them into C functions, with appropriate care to get special values right (e.g. $\cos(\pi/2)=0$, and $J0(0)=1$), and test them carefully against series representations and the high precision values found in Abramowitz and Stegun.

Steve Maguire, *Writing Solid Code*, Microsoft Press, Redmond WA, 1993 ISBN 1556155514. Maguire tells lots of good war stories about writing C programs that work and can be maintained.

John J. Barton and Lee R. Nackman, *Scientific and Engineering C++*, Addison-Wesley, Reading, MA, 1994, ISBN 0-201-53393-6. A good, accessible presentation of object-oriented software design for instrument control. The C++-only paradigm is getting less compelling for communications and user interfaces, but is still the way to go for control code, especially if you have a range of similar devices and components.

A.1.19 Laser Safety
David Sliney and Myron Wolbarsht, *Safety With Lasers and Other Optical Sources*, Plenum, 1980 ISBN 0306404346. A weighty tome which lives up to its subtitle, "A Comprehensive Handbook". You can find what you need to protect your eyesight in here, but it takes a bit of work; they have lots of tables and graphs, plus step-by-step instructions on how to use them, and lots of background material on the origin and character of laser hazards.

A.1.20 Reference
Michael Bass, ed., *Handbook of Optics*, 2nd Ed. (2 vols), Optical Society of America, McGraw-Hill, New York, 1995. An excellent handbook, with a good deal of depth in a very broad range of topics. This one is better than most, and is entertaining and readable.

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[*] The third alternative, i.e. many, many errors due to some software bug, seems to be excluded by testing and the wide use of these routines by others.

William L. Wolfe and George J. Zissis, *The Infrared Handbook*, revised ed., Environmental Research Institute of Michigan, 1985. A somewhat dated but complete presentation of the state of the infrared art about 1982; the things it leaves out are mostly the newest solid state detectors, arrays, and tracking systems.

J. S. Accetta and David L. Shumaker, eds., *The Infrared and Electro-Optical Systems Handbook* (8 vols), Infrared Information, Ann Arbor, 1993 (reprinted 1996), ISBN 0819410721. The follow-on to the *Infrared Handbook*. This is a really readable collection, not nearly as handbooky as the first two.

Edward D. Palik and Gorachand Ghosh, eds., *Handbook of Optical Constants of Solids*, 2nd ed., Academic, New York, 1997 ISBN 012544415X, and
Edward D. Palik, ed., *Handbook of Optical Constants of Solids II*, Academic, New York, 1991 ISBN 0125444222. These are very expensive but very necessary if you need to know the minute details of the properties of materials, e.g. if you're building semiconductor inspection tools. For mundane use, the current edition of the *CRC Handbook of Chemistry and Physics* has most of what you'll need.

G. W. C. Kaye & T. H. Laby, *Handbook of Physical and Chemical Constants and Some Mathematical Functions*, Longman, London, 1986. This is a real instrument-builder's idea of a handbook. K&L is very useful when you have to choose materials, or calculate heat transfer—it has things like the specific heat and thermal conductivity of tantalum wire.

C. W. Allen, *Astrophysical Quantities, 3rd ed.* Athlone, 1985, ISBN 0485111500
Where else can you find out that there are about 0.1 naked-eye visible stars (6th magnitude or brighter) per square degree in the night sky?

Chemical Rubber Company, *CRC Handbook of Chemistry and Physics* (annual), CRC Press, Boca Raton FL. The "rubber Bible" used to be a huge list of indifferently edited tables culled from ancient scientific and engineering literature, but recent editions are much better. If you have an old one, consider chucking it and getting a new one. There are extensive tables of optical properties of materials now, for example. It is indispensable for anyone building mixed-technology systems like optical instruments. Its editors deserve our thanks for their fortitude; the amount of duplicated effort they have saved people over the years is very large indeed.

A.1.21 Mechanical Engineering
Eugene A. Avallone and Theodore Baumeister III, eds., *Marks' Standard Handbook for Mechanical Engineers, 10th ed.* McGraw-Hill, 1996 ISBN 0070049971. Mechanical engineers love this one. Covers the whole field, including incineration and power generation, but the depth of detail and choice of material is excellent.

Erik V. Oberg and Christopher J. McCauley, eds., *Machinery's Handbook*, 25th ed., Industrial Press, New York, 1996, ISBN 0831125756. Full of good stuff about machine shop practice.

Stephen P. Timoshenko, *Theory of Plates and Shells*, 2nd Ed., McGraw-Hill, New York, 1959 (recently reprinted). A wonderful mixture of explanation and cookbook formulas on deflection, resonance, buckling, and deformation of structures. If you're designing mechanical parts that have

to be stiff and light, you need a copy of this one.

A.2 Catalogues and Trade Journals

This section is bound to get out of date pretty rapidly, so we'll stick to manufacturers who have a long established history of offering good catalogues. If you subscribe to trade journals such as *Photonics Spectra*, *Laser Focus World,* which are both free, and *Optics And Photonics News*, which you get from the Optical Society of America, you'll be kept up on all the newest commercial stuff and the latest fads, together with a lot of useful background material. In mechanical engineering, look at *Design News*.

Instrument design is a bit of a ghetto as far as publication is concerned, as Feynman pointed out in the quotation on the flyleaf, but you can find some good optical instrumentation papers in *Optical Engineering*, *Applied Optics*, and (somewhat less often) in the *Review Of Scientific Instruments*, *Journal of Physics E*, and the *Journal of Applied Physics*. If you don't mind non-refereed publications, many of the canary yellow SPIE Proceedings books have a lot of instrument stuff in them. They're good for finding out what's going on, and to mine for ideas.

The following sampling consists only of resources that the present author has used himself, and so is neither complete nor entirely based on merit. The Optical Society of America and SPIE have good web sites that have lots of commercial links, so you can find much more there.

A.2.1 National Semiconductor data books

National writes great data books, even though they aren't as much fun as they used to be, when the Audio Handbook had a chapter called "Floobydust" and one part's official name, printed on the data sheet, was the "LH0063 Damn Fast Buffer Amplifier" (it was, too—6000 V/μs and zilch input current was absolutely unique in 1975). The best thing about National is that the designers write the data sheets and many of the application notes, so that you get the real story, not some marketroid's half-understood hype; and *they print the internal schematic of the ICs* so that you can figure out how they work and what their limitations are likely to be. These books are well worth buying, if you haven't got a tame manufacturer's rep to send them to you free; if you go over the circuit designs in the application notes carefully, you can get a pretty complete education in low frequency analogue design.

A.2.2 Other Analogue Electronics Data Books

Philips data books have a fair amount of lore in them too; they have the very nice feature that the relevant application notes are printed along with the data sheet, which makes for big but very useful books. Maxim has a lot of great special parts, and decent data sheets from an applications point of view, but they give few details about the internal workings of the chips, which puts you at the mercy of their applications engineers. Maxim's lead times are often irregular, so buy well ahead if you use Maxim stuff. Linear Technology's are good too, but their application notes tend to cluster around fairly idiosyncratic applications like linearizing RTDs. Analog Devices books are pretty good too, and their rf and data converter technology is becoming very impressive. Burr-Brown's data books have improved enormously in the last few years, and are now well worth getting. BB has reinvented itself as a very credible supplier, with some unique products at competitive prices.

The huge Mini-Circuits catalogue of RF signal processing components is very unusual in that it

contains hundreds of pages of actual measured performance data on everything, which is absolutely wonderful for doing frequency plans and distortion budgets—the confidence that comes from that is worth a lot. Other suppliers' catalogues seem skimpy by comparison.

Other good RF parts catalogues are Alpha Industries, California Eastern Labs (NEC), and Watkins-Johnson.

A.2.3 Electronic Distributors' Catalogues
Newark Electronics, Mouser, Allied Electronics, and Digi-Key have good hard copy catalogues, and take phone orders for small quantities happily. Good places to go for hard-to-find rf parts are Penstock, Mouser, and Richardson Electronics.

A.2.4 Mechanical and Motion Control
You can find good optomechanical and motion control parts from: Mondo-Tronics (http://www.robotstore.com), Small Parts, Inc., Maxon Motor, Mabuchi Motor, Nidec Motor, Burleigh, Newport, Spindler & Hoyer, New Focus, and Thor Labs. Thor Labs especially has a nice series of optomechanical mounts that are relatively inexpensive, make a nice finished-looking job, and interoperate with Spindler & Hoyer's Microbench series.

A.2.5 Buyer's Guides
Buyers guides are usually published by trade magazines. They can be very useful, because they bring together information about companies that want your business, which means they usually have some clue about the requirements of your field. In optics, there are the *Laser Focus World Buyers Guide*, the *Photonics Directory*, and the *Physics Today Buyer's Guide*. For mechanics and motion, look at the *Design News Buyer's Guide*.

An hour with a buyer's guide and a telephone can save you a day and a half's Web browsing.

A.2.6 Optics Catalogues
For historical as well as practical reasons, you should have the *Schott Optical Glass Catalogue*—now available only on floppy disc, more's the pity. The old paper one is a thing of great beauty, and the cruddy Windows program they give you now is pretty limited—there's no way to get at the data tables except by a zillion mouse clicks. If you look on the disc, there's a flat file containing summary optical data on each glass type, with n_d and V, which is helpful but not enough.

To this out-of-print gem we should add the Schott Color Filter Glass Catalogue, Hoya Filter Glass catalogue, and the 3M and Corning optical fibre catalogues.

Some optics catalogues are mini-encyclopedias of optical theory and practice, e.g. Newport Research and Melles Griot. You should have those, as well as New Focus, Dover, Line Tool Co., New Focus, Oriel, Edmund Scientific, Ealing, Spindler & Hoyer, Optics For Research, and Thor Labs. Philips and Hamamatsu have very good applications books for their PMTs, loosely based on the old RCA PMT book of fond memory. Somewhat unusually for a Japanese electronics manufacturer, Hamamatsu has first-class manuals, which are well worth getting. Princeton Instruments has a wonderful book on applications of CCD cameras.

A.2.7 Thermal control and measurement

Omega Engineering has an enormous 3-volume set on measuring temperature, pressure, and other industrial-type quantities. Among many other things, they sell platinum RTDs, thermocouples, heaters, thermistors, temperature controllers, pressure gauges, ice point calibrators, and instruments.

Minco makes polyimide thin film heaters, which they'll build in custom patterns for you to match the local heat input to the local heat loss; in good circumstances that will equalize your temperature profile pretty accurately.

Marlow Industries, Ferrotec, Melcor, and Tellurex make thermoelectric coolers. The Ferrotec and Tellurex catalogues are especially good.

A.3 Parts And Equipment

Table 16: Basic Electronic Components

1. 1/10W 1% Metal Film Resistors (RN55C style), 50 pieces each, in values spaced about 10% apart, e.g. 10.0 Ω, 11.0 Ω, 12.1 Ω, 13.0 Ω, 14.0 Ω, 15.0 Ω, 16.2 Ω, 18.2 Ω, 20 Ω, 22.1 Ω, 24.9 Ω, 27.4 Ω, 30.1 Ω, 33.2 Ω, 36.5 Ω, 40.2 Ω, 43.2 Ω, 47.5 Ω, 49.9 Ω, 56.2 Ω, 60.4 Ω, 68.1 Ω, 75.0 Ω, 82.5 Ω, 90.9 Ω, and so on in each decade up to 1M Ω.
2. Miniature cermet trim pots, single turn: 1 MΩ, 100 kΩ, 50 kΩ, 20 kΩ, 10 kΩ, 5 kΩ, 2 kΩ, 1 kΩ, 500 Ω, 200Ω
3. Conductive plastic panel mount pots, linear taper: 100 kΩ, 1 kΩ
4. C0G or NPO Monolithic Ceramic Capacitors: 2.2 pF, 3.3 pF, 4.7 pF, 6.8 pF, 8.2 pF, 10 pF (and so on in each decade up to 1 nF)
5. Stacked Mylar film capacitors, same values from 2.2 nF to 0.22 μF
6. X7R Monolithic Ceramic Capacitors, 10 nF, 47 nF, 100 nF, 220 nF, 470 nF, 1 μF
7. 50V Low ESR Aluminum Electrolytic Capacitors; 10 μF, 47 μF, 100 μF, 220 μF, 470 μF, 1000 μF.
8. 25V Dipped Solid Tantalum Capacitors, 1 μF, 4.7μF, 10μF.
9. Surface Mount Capacitor Prototyping Kit (1206 size), 2.2 pF to 0.1 μF
10. Surface Mount Resistor Prototyping Kit (0805 or 1206 size).
11. Surface Mount Inductor Prototyping Kit (10nH-33μH)
12. Surface Mount Trimmer Capacitor Kit (from 1-4pF to 18-60 pF)
13. Op Amps (plastic DIP packages). Linear Technology LT1028A, National LF356AN, LF347AN, LM6361, CLC402, and LMC6484N, Burr-Brown OPA-111, Motorola MC33079P
14. Voltage regulators: (TO-92 plastic package) LM317LZ, LM337LZ
15. Other Linear ICs: (plastic DIP, cheap grade) LM6321 buffer, LM339A, LM311A, and Maxim MAX-900 comparators, Analog Devices MAT-04 transistor array, LMC555C CMOS timer/oscillator
16. Transistors: 2N3904, 2N3906, MPSA14, MPSA64, Toyo-Rohm 2SD786, Philips BFG25A/X, and a few nice power FETs
17. Diodes: 1N4148, 1N4005, Motorola MBD301, Harris CA3039 matched quad
18. Logic ICs: 74HC00 NAND gate, 02 NOR gate, 04 inverter, 08 AND gate, 14 Schmitt

       inverter, 32 OR gate, 74 D flip-flop, 112 J-K flip-flop, 163 synchronous binary counter, 390 dual decade counter, 374 octal register, 4020 ripple counter, 4049 hex buffer, 4316 analogue transmission gate, 4352 analogue multiplexer

19.   Programmable logic: AMD PALCE22V10Z-20 Programmable Array Logic
20.   Signal Processing Components: mixers, power splitters, and 20 dB directional couplers from Mini Circuits in your frequency range
21.   Packaged RF amplifiers: 20 and 40 dB gain, at least +10dBm output power, low noise.
22.   1, 2, 3, 5, 6, 10, 15, 20, 30, and 40 dB BNC attenuators, 50 Ω.
23.   T1¾ LEDs, high efficiency red, green, and amber
24.   Cheap Photodiodes, Siemens BPW-34,
25.   Boxes: 3.5×6×1.25 die-cast aluminum ones from Bud
26.   12 inch square, 2 oz., double side copper clad FR-4 board from Kepro
27.   Board: Vero 002857H ground perf board with pads and ground plane, Eurocard layout
28.   Miniature DPDT panel switches, 250V, 1A.
29.   BNC female bulkhead connectors (the ones that mount in a single 3/8 inch hole)
30.   BNC patch cords: RG-58A/U for general purpose
31.   BNC barrel and T connectors, 50 Ω
32.   BNC-banana and BNC-clip lead adapters
33.   9 and 25 pin D shell connectors for power and slow signals

Table 17: Prototyping and lab equipment

1.   60W temperature controlled soldering iron
2.   750°F (400°C) conical tips, fat and narrow, iron plated
3.   Second small iron for melting the other end of SMT chip components
4.   100-150W soldering iron for soldering ground planes
5.   60/40 rosin core solder, 0.020 inch diameter
6.   Soldering station, with iron holder and wet cellulose sponge for cleaning iron
7.   3 gauges of Solder Wick
8.   Good quality solder sucker with Teflon tip
9.   2x, 3x, 4x eye loupes
10.   Scalpel with straight and curved blades
11.   Really good quality stainless steel tweezers with long, curved, sharp blades
12.   Large and small flush-cutting diagonal cutting pliers
13.   Large and 2 sizes of small long nose pliers
14.   Gas pliers
15.   Bench vice for blacksmithing
16.   Combination wrenches
17.   Screwdrivers
18.   Nutdrivers
19.   Small, bright penlight, e.g. MagLite
20.   Rare earth magnets: SmCo or NdFeB, 7 mm and 20mm diameter, for holding SOICs during soldering and for tweaking inductors during tuning
21.   Set of non-metallic tuning tools
22.   Straight-cutting, compound-action sheet metal shears (Wiss)

23.   Stranded, tinned, PVC jacketed hookup wire, 26 gauge, assorted colours

24.   Assorted heat shrink tubing

25.   Small heat gun

26.   Canned compressed air (or a shop air gun, with filtered and dried compressed air)

27.   Denatured ethanol and an old soft-bristle toothbrush for cleaning boards

28.   Water in a large squeeze bottle for your soldering iron sponge

29.   Freeze spray

30.   Good prototyping vice with rubber padded jaws that open at least 20 cm (8 inches), e.g a wide-jawed Panavise

31.   Dremel grinder and assorted bits

32.   Large cordless hand drill (9.6V type)

33.   Drill Index (complete set of drill bits)

34.   Really bright articulated desk lamp (100W tungsten + 20W circular fluorescent bulbs)

35.   Quiet linear bench power supply: +-30V @ 2A, +5V@ 10A, with separately adjustable voltage and current limits (besides the regular adjustment knobs) and ripple less than 100μV

36.   Good handheld DVM with capacitance, frequency, and other bells and whistles: Fluke 87

37.   >500 MHz 4-channel analogue scope with 1 mV/div and 1 ns/div ranges and *really good* triggering

38.   Good set of matched ×10 probes with all the little clips and ground doohickeys

39.   Synthesized sine or sine/function generator, 0-100 MHz at least

40.   Decent pulse or digital delay generator: Stanford Research DG535

A.4 Laser Safety

It is appalling how many laser people are slapdash about safety. The US Food and Drug Administration runs a Center for Devices and Radiological Health (CDRH) that publishes safety standards for lasers. Elsewhere, the International Electrotechnical Commission rules are commonly applied. Your gizmo has these hoops to jump through before you can sell it in most places.

The quality of laser safety laws in different jurisdictions varies from sketchy through useful to paranoid (Britain's and New York State's are in the paranoid class, for example—the author is legally required to notify the state upon moving a He-Ne into the lab next door, and if he lived in Texas, he'd be liable to state inspections like a North Korean nuclear plant). You may need expert assistance if you engage in international trade in laser-based products. This section is intended as a heads-up and does not pretend to be complete.

It's hard to hurt yourself with lasers below 1 mW (visible), 125 μW (infrared), or milliwatt-level ones beyond 1400 nm, so you can use them without concern. These fall below the 2 mW Class 2 limit for visible lasers, and the far more complicated Class 1 limit for invisible ones; the humours of the eye become essentially opaque from 1400 μm on, so it's mainly a corneal burn hazard. For lasers more powerful than that, or any UV laser whatsoever, take a laser safety course. The eye is peculiarly vulnerable to laser radiation, because it's designed for thermal light, whose radiance is relatively low. It takes some seconds of staring directly into the sun to permanently damage the

retina, and the severe pain of doing so even briefly provides protection[*].

A laser beam is much more dangerous. Its high radiance means that the image it forms on the retina has a huge flux density; a 10 μm spot on the retina has around 20,000 times the flux density that the cornea sees. It's like burning ants, only inside your eyeball. Your pupil is a small target, fortunately, but not that small; a direct hit from a Class 3b or 4 laser can permanently blind you in milliseconds.

The usual reason for not using laser goggles is that they are a nuisance. Uncomfortable, strongly coloured, and sweat-inducing, they prevent you from seeing the beam you're trying to align and make lab work harder. Your laser safety officer, if any, will usually issue you goggles good enough to protect your eyes from anything short of nuclear weapons, which (while safe) compounds the beam viewing problem. You really only need goggles strong enough to attenuate the full beam of whatever lasers you're using to a few times below the Class 1 (invisible) or Class 2 (visible) limits. Goggles for IR lasers are usually no problem, because most of them are not strongly coloured.

For example, if you're using a 1 W Ar^+ laser, then goggles with an optical density of 4.0 will get you well below the 2 mW Class 2 limit, but allow easy viewing of the beam. Aligning a 0.5 mW He-Ne beam is easy, and it's way below the Class 2 limit, but for a 5 mW one you need goggles with OD 1.5 to OD 2.5. The catch is that such goggles may not be easily available; ask. The author at one time used goggles intended for 694 nm ruby light for He-Ne, where they were a comfortable OD 2.5. If you play this sort of game, do get the safety officer's blessing—it saves hassles later, and he may have some good words about it. For example, argon laser goggles need only absorb in the green, blue, and UV, but very similar looking green frequency-doubled, diode-pumped Nd:YAG lasers need high absorption at 800 nm and 1.06μm as well, since significant amounts of pump and fundamental light will accompany the green. You may not think of this, but a competent safety officer will consult his references and find it out.

Beware of using ordinary goggles for high power lasers, e.g. *Q*-switched YAGs, because they can shatter, bleach, or melt, none of which is healthy for you. For the same reason, don't put your head right in the beam, even with goggles on. Ionically coloured glass is very resistant to bleaching, but may let through enough out of band radiation (e.g. strong thermal UV from an argon plasma) to toast your retina. Colloidally-coloured glass and dye-loaded plastic are far less robust. Although you could probably torture-test them yourself, it's a great deal safer to use a CCD camera for aligning beams, and it works OK too, so it isn't worth the risk.

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[*] Small parts of the solar disc visible during a partial solar eclipse do not cause the same amount of pain, but since their image radiance is the same as the whole disc's, they can still cause retinal burns (*eclipse blindness*). That makes them much more dangerous than the uneclipsed sun.