Appendix A
Reference Material

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

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

* 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,
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
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.

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
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


A.1.6 Statistical Mechanics

A.1.7 Classical Optics


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.1.8 Aberration Theory and lens design

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.

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.


A.1.9 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.

A.1.13 Spectroscopy


A.1.14 Lidar

A.1.15 Detectors

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.


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.


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*.


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).

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.

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.

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.

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
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.


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.


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.


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 \( J_0(0)=1 \)), and test them carefully against series representations and the high precision values found in Abramowitz and Stegun.


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.

* 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.


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.

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


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. COG 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, 4.7 μF, 10 μF.
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)
14. Voltage regulators: (TO-92 plastic package) LM317LZ, LM337LZ
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: 3.5x6x1.25 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)
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>23.</td>
<td>Stranded, tinned, PVC jacketed hookup wire, 26 gauge, assorted colours</td>
</tr>
<tr>
<td>24.</td>
<td>Assorted heat shrink tubing</td>
</tr>
<tr>
<td>25.</td>
<td>Small heat gun</td>
</tr>
<tr>
<td>26.</td>
<td>Canned compressed air (or a shop air gun, with filtered and dried compressed air)</td>
</tr>
<tr>
<td>27.</td>
<td>Denatured ethanol and an old soft-bristle toothbrush for cleaning boards</td>
</tr>
<tr>
<td>28.</td>
<td>Water in a large squeeze bottle for your soldering iron sponge</td>
</tr>
<tr>
<td>29.</td>
<td>Freeze spray</td>
</tr>
<tr>
<td>30.</td>
<td>Good prototyping vice with rubber padded jaws that open at least 20 cm (8 inches), e.g a wide-jawed Panavise</td>
</tr>
<tr>
<td>31.</td>
<td>Dremel grinder and assorted bits</td>
</tr>
<tr>
<td>32.</td>
<td>Large cordless hand drill (9.6V type)</td>
</tr>
<tr>
<td>33.</td>
<td>Drill Index (complete set of drill bits)</td>
</tr>
<tr>
<td>34.</td>
<td>Really bright articulated desk lamp (100W tungsten + 20W circular fluorescent bulbs)</td>
</tr>
<tr>
<td>35.</td>
<td>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</td>
</tr>
<tr>
<td>36.</td>
<td>Good handheld DVM with capacitance, frequency, and other bells and whistles: Fluke 87</td>
</tr>
<tr>
<td>37.</td>
<td>&gt;500 MHz 4-channel analogue scope with 1 mV/div and 1 ns/div ranges and really good triggering</td>
</tr>
<tr>
<td>38.</td>
<td>Good set of matched ×10 probes with all the little clips and ground doohickeys</td>
</tr>
<tr>
<td>39.</td>
<td>Synthesized sine or sine/function generator, 0-100 MHz at least</td>
</tr>
<tr>
<td>40.</td>
<td>Decent pulse or digital delay generator: Stanford Research DG535</td>
</tr>
</tbody>
</table>

### 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. Iонically 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.

* 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.