Chapter F

Online Appendix: Outfitting Your Lab

F.1 Uses for This List

We know it's hard to know where to begin, in outfitting a home shop or a course lab. Our list, describing equipment that we have liked, may be helpful, at least as a starting point. Within a few years after publication of this book, surely additional good alternatives will have appeared. So we know that we are not saying the last word on this subject. Note, by the way, that our prices are what we find listed online. You may well get a better price, especially if you are buying for a university.

Figure F.1: A student station in our lab in late-2023.

F.2 Oscilloscope

This is the most important piece of equipment in our lab, and the most expensive. For 30-odd years we have used mostly Tektronix scopes. We tried a scope made by HP (later called Agilent, now Keysight); we tried a Hameg and a LeCroy. We always returned to Tektronix. Most of our analog scopes were 2213s (2-channel, 60MHz); our digital scopes – which we continued to use until recently – were TDS3014s (4-channel, 100MHz).

Both these models now have gone out of production. Feeling that our TDS3014s were getting a bit long in the tooth (for some reason students had trouble coming up with 3.5in floppy disks to store their results to <g>), we joined with Paul Horowitz in a scope "shootout" to compare second tier, 4-channel scopes from Tektronix (TBS2104B), Rigol (MSO5104) and Siglent (SDS2104X Plus). At 100MHz, these are in the mid-$1000 range, except the Tek, which is about $1000 more.

After the shootout, we decided to replace our old scopes with the 200MHz Siglent DSD2204X Plus (with the function generator option, MSO upgrade and digital probe). The Siglent has a much better front end (lower noise and full bandwidth at max gain) than the Tek or Rigol. It also includes SPI, UART and I2C decoding at no extra charge. The Rigol and Tektronix do not have an external trigger, something we use in the Lock-in Lab. Siglent and Rigol have touchscreen control while the Tek does not, but we found that plugging a mouse into one of the USB ports of the Siglent is the easiest way to use it.

The Siglent does not have a video out, you have to use ethernet and a web browser to display on a big screen (which does not automate well), while the Rigol includes an HDMI output. The Tektronix is designed for classroom use and has remote control and lesson software available. It also has fewer features than the Siglent or Rigol, which might be an advantage for neophyte use. (We bought the Tektronix 2074B for the introductory undergraduate Physics electronic lab.)

The Siglent Bode plot function, which works with either the optional built in function generator or an external Siglent AWG, makes nice automated plots for our filter labs: see Fig F.2.

F.2.1 Digital scopes

In addition to the mid-level scopes discussed above, there are a number of entry-level models that can be had for about $250 (2-channel) to $400 (4-channel). These usually are a bit lacking in features and/or ease of use but are incredible bargains compared to low-end scopes of yesteryear.

Siglent SDS1104X-E 100 MHz, 4-channel. Includes serial bus decoding and triggering, low noise 500μV input range. $499. A 200MHz, 2-channel version is $379, while the 200MHz, 4-channel model is $775.

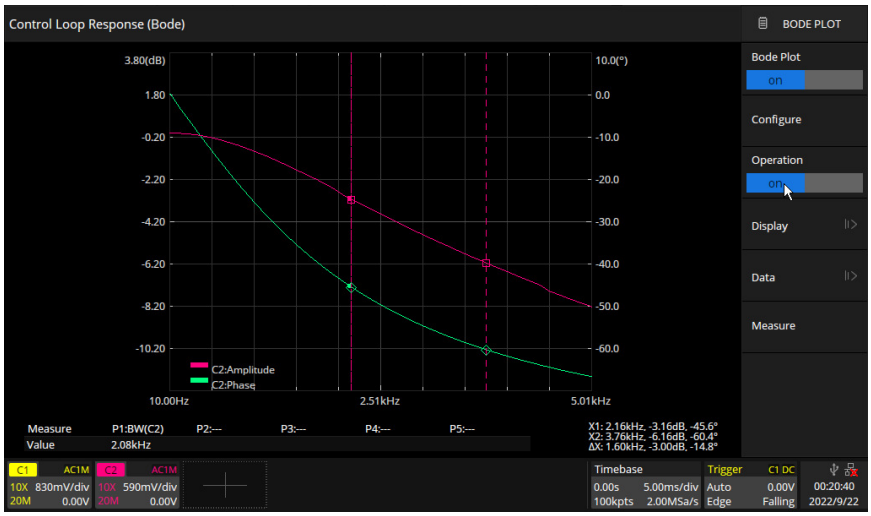

Figure F.2: Automated Bode plot measurement created with Siglent SDS2204X Plus ocilloscope.

Rigol DS1054Z 50MHz, 4-channel. Often has promotions that include serial decoding. Really good value at $349 list price. The DS1074Z Plus is 70MHz, costs $110 more and supports 16 digital channels with the purchase of a $199 digital probe.

Tektronix TBS1000C 50MHz oscilloscope, 2-channel scope for $563

F.2.2 Analog scopes

We have not tried this one. It appears B & K Precision may be the last company still manufacturing an analog scope:

B & K Precision 2120C 30MHz, 2-channels $799

You'll notice that this costs more than a very capable digital scope like the Rigol or Siglent mentioned above, so you'll surely not be tempted to make a new analog oscilloscope your only scope. But it's worth recalling that discontinued analog scopes are available *used*, and can cost very little. (A quick search on eBay for "analog scope" listed a number of relatively modern options for $50 to $200). These can be especially appealing to a hobbyist.

F.3 Function generator

For many decades we have used the Krohn-Hite 1400 and 1600 series function generators in our lab. These old-style analog devices had the advantage of separate controls for each function and a large frequency dial that covered three decades in one turn. The evolution of modern function generators has not suited us. Most generators now use keypad or pushbutton frequency selection, which we find much less friendly than the Krohn-Hite's knob and the single keypad of the modern device does multi-duty in an inconvenient modal

scheme where you select the function then turn the knob or enter the value. Even when a knob to adjust frequency is available, they annoyingly drop to a lower digit as you decrement through zero decreasing the adjustment rate. All in all, we find these user interface "improvements" tedious and unwelcome.

The analog B & K Precision Model 4017A, 10MHz, with linear/log sweep and digital readout, comes close to the old style that we like but at a list price of $615 it is hard to justify.

Newer, digital arbitrary waveform generators (AWGs) offer capabilities not available from the old analog models, including multiple independent or coupled outputs and arbitrary waveform synthesis. We recently conducted a shootout of three digital $\approx 25\mathrm{MHz}$ AWGs: the Tektronix AFG1022 ($1,120), the Rogol DG1000Z ($539) and the Siglent SDX1032X ($359). All feature two independent outputs, arbitrary waveform generation, a plethora of built-in internal waveforms, sweep and modulation capabilities, digital displays and both keypad and knob input. We put the two channels to good use in our Lock-in Lab where one channel supplies the sinewave sent to the amplifier and the second channel provides an identical frequency square wave used in the demodulator. We adjust the phase difference between the channels to obtain the maximum output, eliminating the need to to build the phase shift circuit described in the notes.

The Siglent was the clear winner. Not only was it the cheapest of the three, it excelled in many ways. Each channel is fully independent, capable of normal waveform, sweep or modulation. The other two only allow sweep and modulation on channel one. Both the Rigol and Siglent include a trigger out, a necessity for triggering a scope on a sweep output; the Tek does not. The Siglent has a DC output mode, allowing it to be used to supply precision voltages to a circuit under test. This is handy since it means you don't have to set up a potentiometer to test a circuit with a DC input. The Siglent allows you to set the rise and fall times of a pulse waveform; the other two do not. We outfitted our lab with new Siglent SDX1032Xs, although we kept the Khron-Hites at each bench as well.

F.3.1 Doing without a dedicated function generator

Get a scope which includes a function generator: Some scopes, including the Rigol DS1000Z and the Siglent SDS2000XP Plus mentioned above, offer an optional internal arbitrary waveform generator. On the Rigol, the 25MHz, dual output arbitrary waveform generator adds $200 to the price (the "-S" models). For the Siglent, the single output, 50Mhz waveform generator activation is $229. However, sharing a front panel with the oscilloscope is less convenient than using a separate generator. In addition, the scope function generators are very limited in output voltage. The Rigol outputs a maximum of $5\mathrm{V}$ peak-to-peak into a high impedance load; the Siglent $\pm 3.3\mathrm{V}$. The maximum output voltage is halved into 50Ω. Given the low price of external function generators, it is hard to recommend paying for the internal version – but you should certainly take it if offered in a promotion.

Rely on the powered breadboard's built-in function generator: A hobbyist planning to buy a powered breadboard like the PB-503 (see just below) could get by using the not-so-versatile function generator that is built into the PB-503. It lacks DC-offset variation, its waveforms are less perfect than those from a standalone generator, and its maximum frequency is only 100kHz.[1] But it could be adequate.

F.4 Powered breadboard

A unified breadboard with power supply, like the Global Specialties PB-503, now replaced by the PB-503A ($609), that we have been using for decades, is very convenient. For our full course, it seems nearly indispensable.

For an individual hobbyist, a cheaper alternative would be to buy a triple power supply (+5V, ±15V) and individual breadboard strips, or a mounted set of at least three strips as in Global's PB-105 ($122.75), Adafruit's 443 ($19.95), or this one from Circuit Specialists ($26.10). You would need to improvise other functions of the PB-503 that we find convenient:

- A simple function generator. We seldom use the one provided by the PB-503 but when we want a second signal, it's handy.[2]
- Debounced switches
- Two potentiometers
- LEDs

None of those improvisations would be difficult.

Another alternative is a simple powered breadboard like this kit: Circuit Specialists PBB-272C.

Recently we split our course into the analog chapters and the digital chapters. For the analog course we use a 3M 922336 solderless breadboard mounted on a custom inclined stand with a standalone power supply and function generator: see Fig. F.3.[3] We continue to use the PB-503 for the digital course, as we need the logic switches and indicator LEDs in the labs.

[1] Another way to do without buying a function generator is to buy a fancier oscilloscope that includes a multiple lab instruments, including a function generator. The Tektronix MDO3014 offers this (plus a spectrum analyzer), but at almost $7000 list, it probably is useful neither to a hobbyist nor to someone setting up an electronics lab.

[2] Most often, we use the built-in generator as a source of logic-level square waves. In §5L.1.4 we used it as a second sinewave source, where we feed two signals to a differential amplifier, before we got the dual output Siglent AWGs.

[3] More information on our custom analog breadboard design is available in Online Chapter 1O.

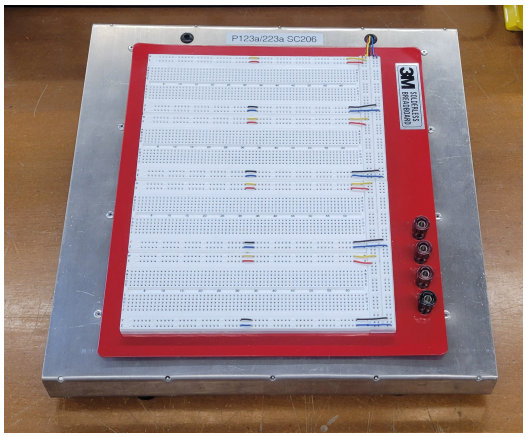

Figure F.3: Stand alone breadboard used in our analog only course.

F.5 Meters, VOM and DVM

F.5.1 VOM (analog multimeter)

The ≈ $500 analog "Simpson meter" that we use only occasionally in our course (Simpson 260-8) is a luxury one can do without. We introduce it on Day 1 because we prefer that students know how to use the instrument (which requires more thought than a DVM does). But in the ordinary case, we all reach for a DVM, not a VOM. The VOM beats the DVM only in the exceptional instance where you would like a quick graphical indication of a slow trend – like the falling off of current in §4L.4 transistor current source, as the circuit slips into *saturation* (and some DVMs include a bar graph indication of the current measurement which serves the same purpose).

Hobbyists can happily skip the analog VOM, or could choose a small and inexpensive model like the Tenma 72-8170, $27.45 (Newark) or the Gardner Bender GMT-319 on Amazon ($22.79).

F.5.2 DVM (digital multimeter)

A great variety of DVMs is available. We need nothing fancy.

B & K Precision 2704C: Very simple. 3 1/2 digit DVM with transistor beta test, capacitance, frequency $78
We like this very inexpensive device. Its frequency counter and transistor tester are nice features, not often found in an low end meter.

Amprobe 37XR-A: Better, and more expensive. 4 1/2 digit DVM: true RMS, capacitance, inductance, frequency. $289

WH5000A: Bargain DVM. We have recently been equipping our lab with this inexpensive import multimeter. It features 6000 counts, true RMS, transistor beta testing,

temperature, capacitance and frequency measurement. The WH5000A is available from multiple sources on Amazon for $30 and up. They all appear to be the same device under different brand labels (AstroAI, ETEPON, Kuman, etc.).

F.6 Power supply

Keysight (formerly HP) E3630A triple output power supply, 35W $1,099

Rigol DP832 triple output, 195W, 0 to $\pm$30V @3A, 0 to 5V @3A $473

Rigol DP831 triple output, 160W, 0 to $\pm$30V @2A, 0 to 8V @5A $473

We have used the HP 6236B triple output lab supply for decades. We like them very much, they are linear with no fan – so very clean and quiet – and have simple controls. Unfortunately, the current version of it, sold by Keysight, is now priced in the stratosphere. We have found used 6236Bs and its sister, the 6237B, on eBay for reasonable prices. Currently, we have equipped our lab with the Rigol DP832. These are a bit more complicated to use and do have a fan but have the advantage of displaying the voltage and current of all three channels simultaneously. In addition, you can turn the outputs on or off independently without having to turn off the entire supply.[4]

F.7 Logic probe

B & K Precision DP-21 discontinued but possibly available used $39

B & K Precision DP-52 combined logic probe and pulser, detects 10ns pulse, switchable TTL vs. CMOS levels $52

RSR Logic Probe $28 (Amazon)

Over the years, we have used logic probes from multiple manufacturers. Recently we were purchasing the B&K DP-21 but it was discontinued in 2022. They now offer a more expensive replacement, the DP-52. We have not tried the RSR probe, but it looks similar to others we have used. The audio indication of logic level is a nice feature.

[4] Siglent offers a $300 triple output supply but the third supply is not continuously variable and does not have an adjustable current limit. In addition, the display only shows voltage and current for two of the three outputs. Their more expensive ($400) model has a nicer display but similar limitations.

F.8 Resistor substitution box

We like the one that offers fewer values, because it makes changing values easy. But occasionally the 1Ω resolution of the other is useful. For a course, perhaps many of the RS-400 and one of the RS-500.

Elenco RS-400/K-37 24 values, 10Ω through 1MΩ $27 (Newark in kit form). Also available at Amazon. Possibly discontinued.

Elenco RS-500 1Ω increments, 0 to 11MΩ $30.53 (Amazon)

Programmable Resistor Board lower cost but less convenient $17 (Amazon)

Coppersound Substitution Boxes available for resistance, capacitance, diodes and transistors (both BJT and FET) $59 each

F.9 Hand tools

Figure F.4: Hand tools we use in our course.

F.9.1 Pliers

We like small "chain nose" or "long nose" pliers. The these are approx 5 inches long and spring to their open position. We like the feel of the C & K, but they no longer appear to be available. We have moved to the less expensive Excelta or a generic.

C&K 3772D chain nose $52

Excelta 2644 smooth-surface chain nose $19.44 (Jensen)

Excelta 2644D serrated-surface chain nose $26.80 (Jensen)

Mini needle nose pliers generic	$6.25 (Amazon)
SparkFun generic	$3.50 (SparkFun)
Pittsburgh 4 3/4 inch long nose pliers	$2.99 (Harbor Freight)

F.9.2 Wire cutters

Techspray 170 flush cutters	$7.49 (Digikey)
Xcelite (Apex) 170M	$14.00 (SparkFun)
KAIHAOWIN 170 pack of 10	$19.99 (Amazon)

F.9.3 Wire strippers

Ideal 45-125 22 to 30 AWG wire gauge	$23.26 (Newark)
SparkFun generic	$13.95 (SparkFun)
Seeed Technologies TU-5023 20 to 30 AWG wire gauge	$5 (Digikey)

F.9.4 IC extractor

Jonard Tools S-340 avoids bending the leads	$4.85 (Amazon)
Aries T-90	$9.31 (Digikey)

F.9.5 Screwdriver

Xcelite R3324 slotted head, 0.1” blade, 6.25” length “green tweeker”	$6 (Newark)
Mini pocket screwdriver dual head, 5.3” length	$15 for 10 pack (Amazon)

F.10 Wire

22 AWG solid hookup wire, insulated:

- Alpha: 3051/1 BK005, solid 22 ga., l00-foot spool (8 colors; black color indicated here by “BK;” see other codes, e.g., “RD005” for red) (Digikey $32.06)
- SparkFun: Hook-Up Wire Kit, solid 22 ga., six assorted colors, 25 foot spool of each: Digikey 1568-1358-ND ($25.38) or SparkFun PRT-11367 ($21.50). Adafruit has similar kits.

Figure F.5: Insulated #22 solid wire kit.

Take care not to order 22 gauge *stranded* wire. It won't work with the solderless breadboards.

Banana hookup cables: banana-to-banana, 18 inch. We cut some of these at midpoint and solder on solid leads, to make banana-to-wire cables, convenient for plugging into breadboards.

- Pomona: B-18-0 (black) and B-18-2 (red) ($7.17 Digikey). Generic versions are available in bulk on Amazon.
- Sumnacon: banana-to-banana plug cables in different colors. We use these to connect our bench supply to the stand alone breadboard used in the analog course. ($14 for five cables in different colors Amazon)

Other useful cables: We keep several other types of cables that often prove useful. The list below is of representative examples. They are available from many manufactures and sources.

- Elenco TL-3: BNC-to-minihook ($10 Amazon)
- Tetra-Teknica TMA006: Banana-to-Minigrabber ($9 for set of four at Amazon)
- ANVISION: BNC-to-BNC ($11 for set of four at Amazon)
- Dahszhi: minihook-to-minihook ($8 for set of five at Amazon)
- Micro USB cable for WebFPGA and Segger JLINK ($11 for set of six at Amazon)

F.11 If you need more...

Another list of tools and test equipment for electronic design is available on reddit at `https://old.reddit.com/r/PrintedCircuitBoard/wiki/tools`.
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