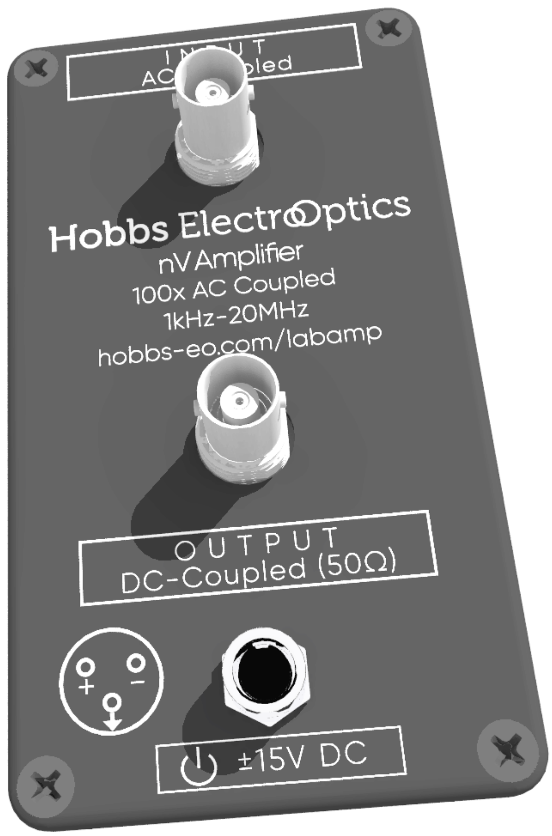
Hobbs ElectroOptics

LA-22 Low Noise Lab Amplifier



User's Guide

Rev. 0.9

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1 Introducing the LA-22 Low Noise Lab Amplifier

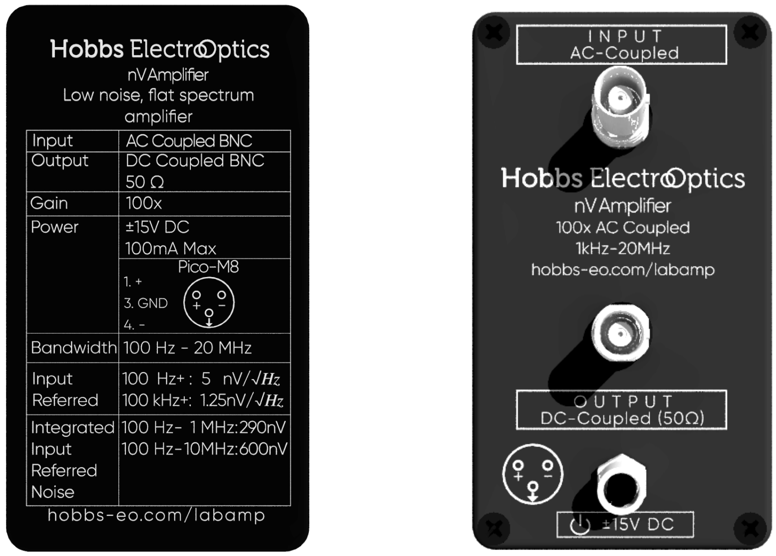

Figure 1.1: The LA-22 Low Noise Lab Amplifier

1.1 Overview

The LA-22 Low Noise Lab Amplifier is intended to make it easy to do low-level measurements using ordinary lab equipment such as oscilloscopes, spectrum analyzers, and data acquisition bricks, which usually have noise levels in the tens of nanovolts per root hertz.

The LA-22 has 1-nV/$\sqrt{\text{Hz}}$ voltage noise, wide bandwidth, FET input, 100× gain, and good manners: in the time domain, 20-ns edges with low overshoot, and in the frequency domain, 500 Hz–20 MHz bandwidth with a smooth rolloff and no high-frequency peaking.

1.2 Design Philosophy

The design philosophy is to minimize surprises, so that you can concentrate on your measurement instead of your apparatus.

Gain of 100±1 Enough that ordinary lab equipment doesn't limit the measurement. That spectrum analyzer's 30-dB noise figure is now 3 dB or better.

AC Coupling Helps protect the sensitive input from damage, and reduces low-frequency hum and other noise.

20 MHz Bandwidth Wide enough for most low-noise measurements, and doesn't produce a lot of grass on a scope display.

Flat Frequency Response There's no mystery about what the noise gain is—you can do measurements without worrying about normalization.

Clean Edges With high linearity and less than 1% overshoot, the LA-22 shows you your signal's time dependence accurately.

1 kΩ AC Input Resistance Prevents excessive output noise and possible oscillation when an unterminated cable is attached to the input. The LA-22 has good manners in all sorts of situations.

2 Specifications

LA-22 Low Noise Lab Amplifier

GAIN	$100\times, \pm$ 1%
BANDWIDTH	500 Hz–20 MHz @ -3 dB
INPUT-REFERRED NOISE	$1.1\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$ (short circuit)
INPUT IMPEDANCE	1 kΩ in series with 330 nF
OUTPUT RANGE	Greater than ±10 V
RISE/FALL TIME	21 ns @ 10%–90%
OVERSHOOT	1% typical
POWER SUPPLY	±15 V @ > 150 mA max
CONNECTORS	Solid metal BNCs for signals, M8-3 to color-coded banana plugs for power (Plug-in power supply optional)

2.1 Performance Verification

It's pretty simple to verify these specifications using an oscilloscope plus a signal generator with good amplitude fidelity and pulse shape. For the time-domain plots in this manual, the apparatus consisted of a Tektronix TDS 784A 1-GHz, 4-GS/s oscilloscope, a Highland Technology P400 digital delay generator for the pulses, and an HP 3325A for the swept sine, plus various fixed attenuators and 50-Ω feedthrough terminations.

The frequency-domain plots were made using an HP 89410A spectrum analyzer (DC–10 MHz) and the FFT mode of the TDS 784A. The scope FFTs were made at 250 MS/s to avoid aliasing problems.

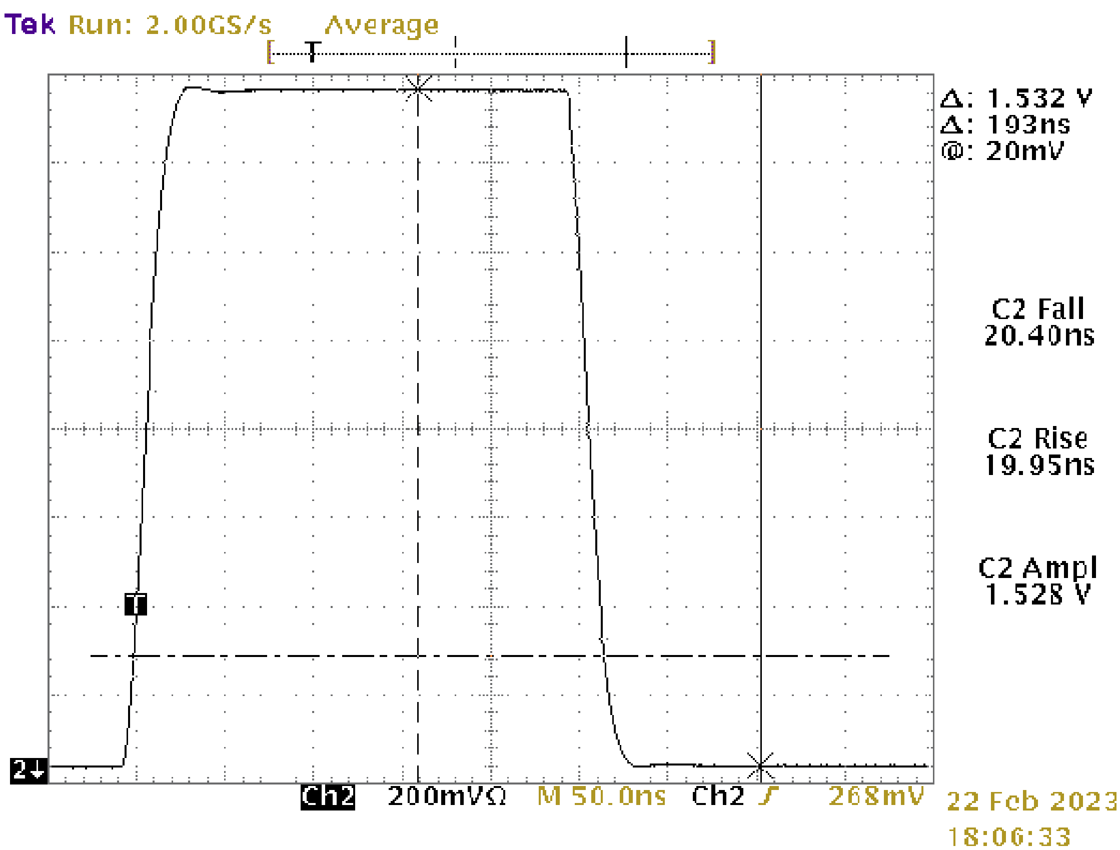

Figure 2.1: Response to a 250-ns, 31 mV pulse, into a 50-ohm oscilloscope input.

Figure 2.2: Output noise, DC-10 MHz with 12.5Ω source resistance R_S (-140 dBV = 1 nV input-referred noise; R_S adds 0.9 dB extra noise). Integrated noise of 368 uV in a bandwidth from 0.25 MHz–10 MHz is 1.1 nV/$\sqrt{\text{Hz}}$ after source noise correction.

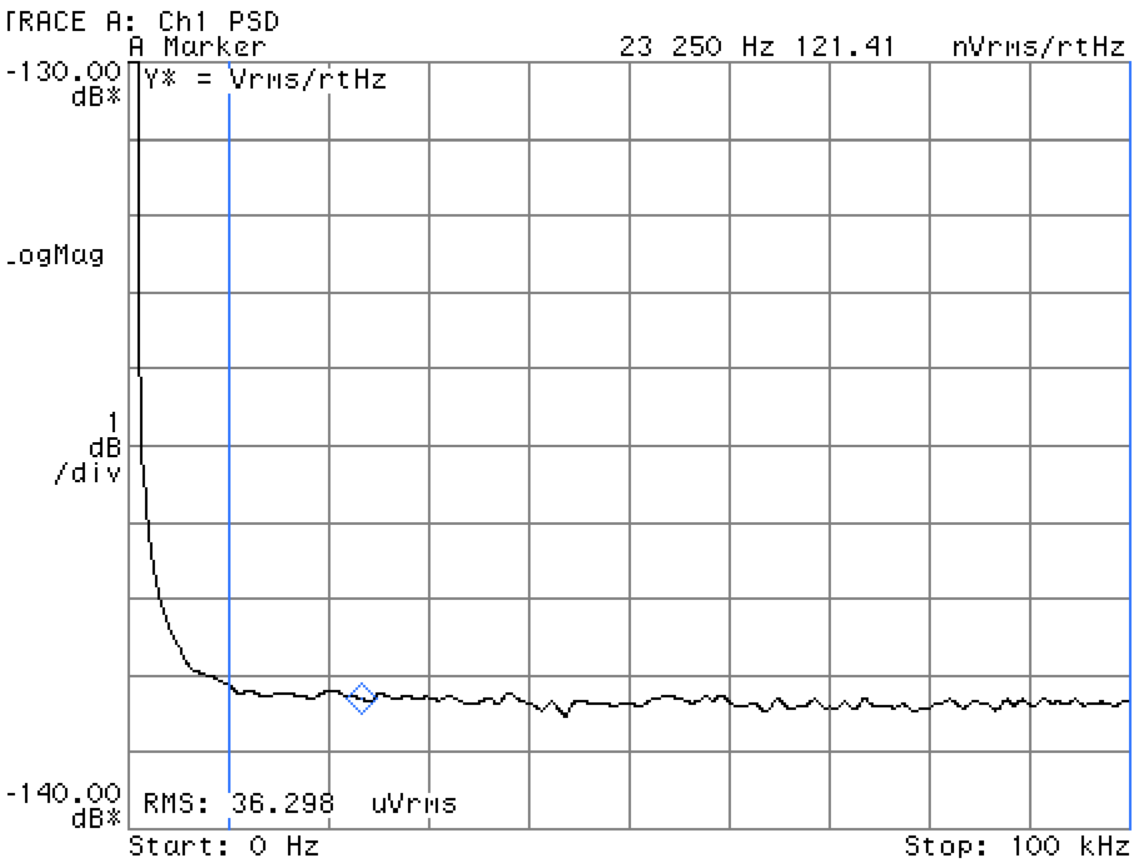

Figure 2.3: Output noise, DC-100 kHz with 12.5Ω source resistance R_S

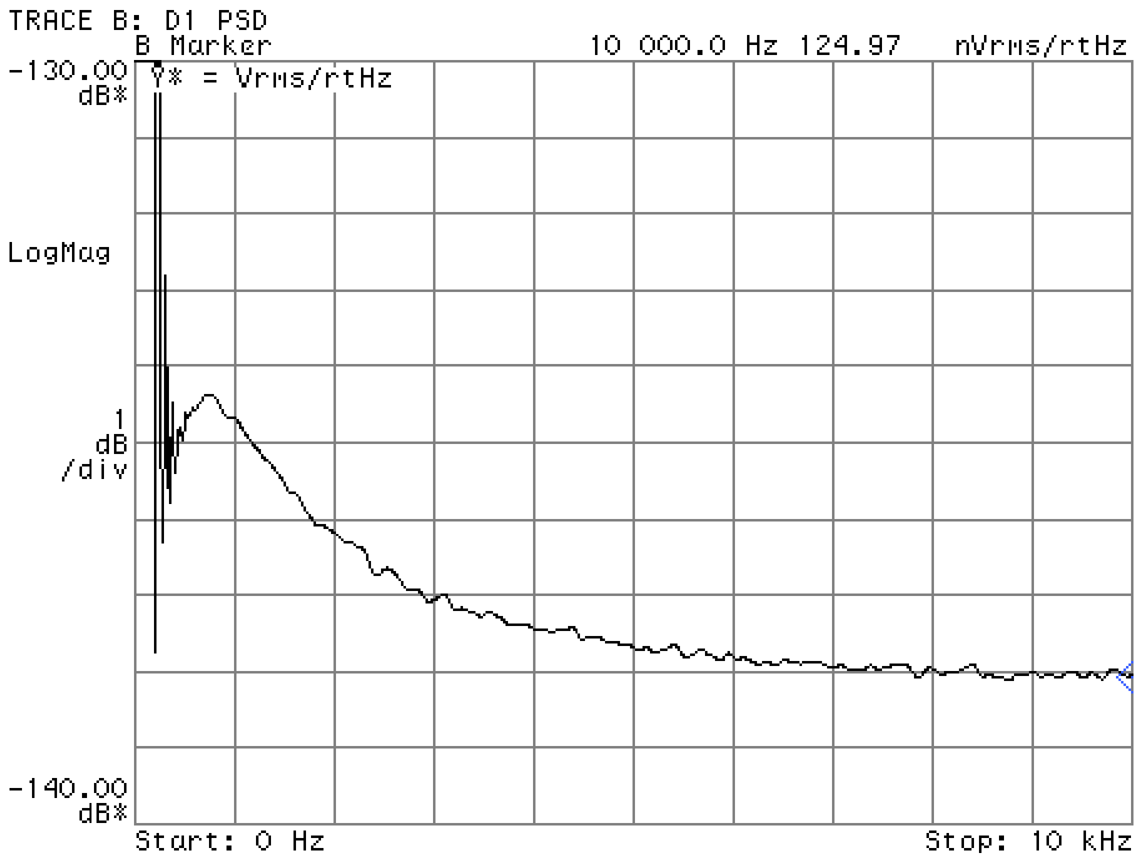

Figure 2.4: Output noise, DC-10 kHz with 12.5Ω source resistance R_S, showing a $1/f$ corner at about 1.5 kHz.

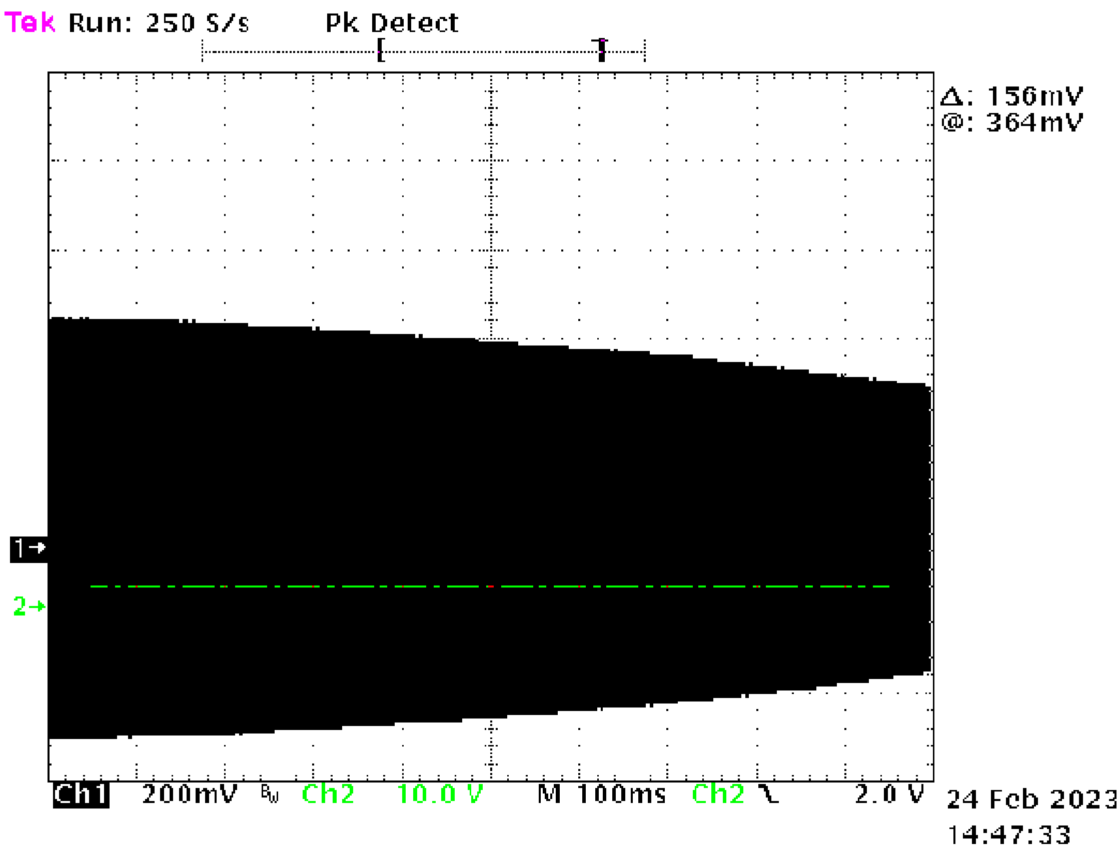

Figure 2.5: Swept-sine measurement of frequency response, DC-20 MHz (2 MHz/division). The p-p voltage decreases smoothly from 520 mV at low frequency to 364 mV (-3 dB) at 20 MHz.

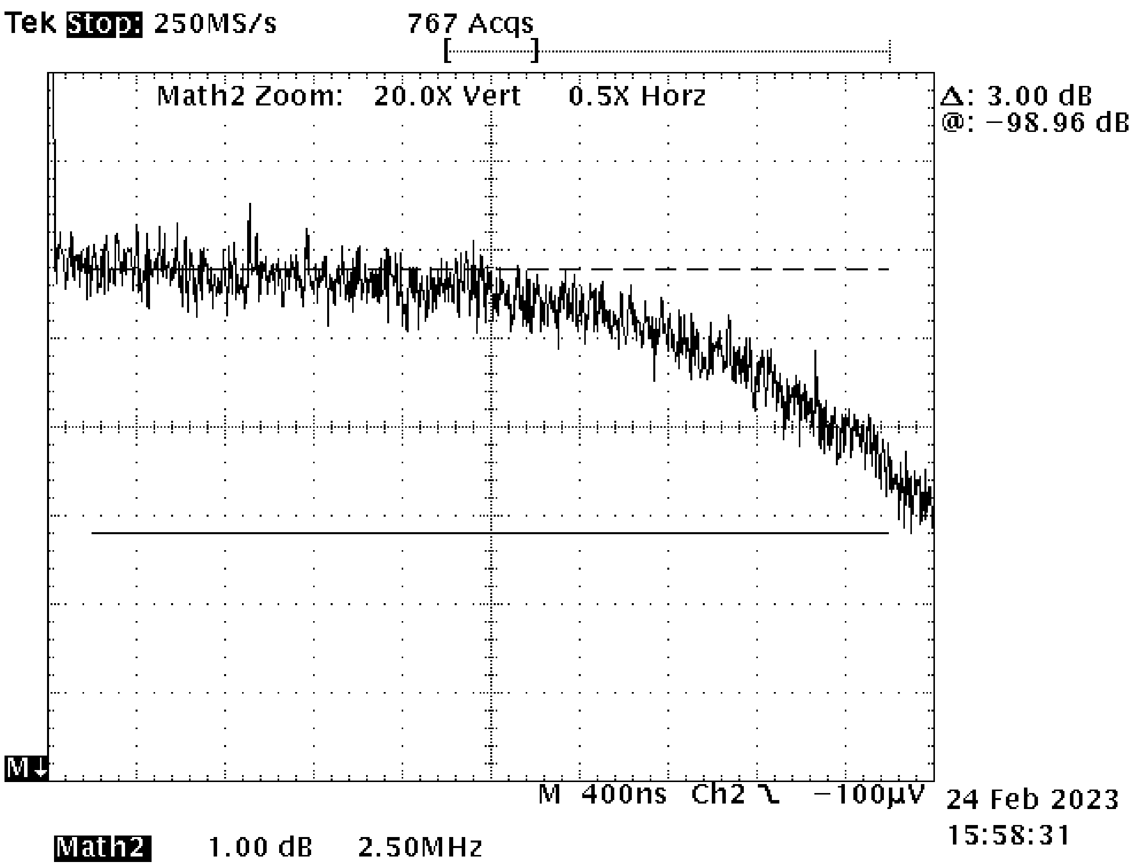

Figure 2.6: Output noise, DC-25 MHz with 12.5Ω source resistance R_S (R_S adds 0.9 dB extra noise). Scope FFT at 15 000 samples at 250 MS/s, Hamming window, 767 averages. Vertical scale is dBV in 16.7 kHz bandwidth (250 MS/s / 15 000 samples, rectangle window function).

3 Measurement Notes

3.1 General Principle

The LA-22 Lab Amplifier uses ultralow noise JFET inputs and a fast-slewing output amplifier capable of driving 50 ohm loads.

The input stage is a bootstrapped differential pair with current-source drive, making the step response clean and predictable. The pair is fast (∼500 MHz), and has differential outputs, so the input stage gain and bandwidth can be set accurately with a simple *RC* across them.

The output stage has very high common-mode rejection and a 1600 V/ μs slew rate, greatly reducing transient intermodulation distortion (TIM).

3.2 Usage Notes

The LA-22 Lab Amplifier is designed to be easy to use. Generally you just wire it up and turn it on. You can kill it with a large overvoltage or a sufficiently-juicy ESD event, but otherwise it'll just work. Here are a few notes about the finer points of low-level measurements with the LA-22.

Source Impedance The LA-22's noise floor of 1.1 $\mathrm{nV}/\sqrt{\mathrm{Hz}}$ is equivalent to the Johnson noise of a 73-ohm resistor at 300 K. At room temperature, low noise voltage measurements have to be done at low impedance. The LA-22 has a 1 kΩ input resistance at AC, which limits the maximum input noise and ensures stability with weird source impedances such as an unterminated cable. At higher source impedances, this needs to be taken into account in order to get accurate gain values.

Cable Reflections The amp's output is series-terminated with 50 ohms, so apart from voltage divider action, the output waveform doesn't depend much on the load impedance.

Bad cable reflections can cause minor distortions of pulses, because the output amplifier's output resistance isn't zero. If you see any artifacts, try using a shorter cable.

Coax Leakage The LA-22, like most lab instruments, has BNC connectors for signal input and output. The most common way to wire them up is to use patch cords made from RG-58A/U coaxial cable. While this is convenient and usually works fine, life can be different when we're making low-level measurements. The shield of RG58A/U is a single layer of bare tinned copper braid. It has only about 75% shield coverage, and the continuity of the shield depends on good connections between wires merely laid on top of each other, which we wouldn't rely on anywhere else: single-shielded braided coax leaks like crazy. Double-shielded or braid + foil coax helps a lot, and keeping the cables short helps even more.

Ground Loops Besides porous shields, there's another way that external interference can couple in: *ground loops*. Ambient AC magnetic fields are everywhere, from mains wiring and nearby motorized equipment. These fields couple to both the shields and center conductors of our cables, producing a voltage proportional to the product of the B field, the frequency, and the loop area.

The LA-22's 500-Hz AC coupling attenuates mains-frequency interference by 18–20 dB, which often allows us to ignore it, but there are more difficult sources such as arc welders and HVAC systems.

HVAC blowers usually use induction motors controlled by *variable-frequency drives* (VFDs). Induction motors run nearly synchronously with the AC frequency, so a VFD lets you run them at different speeds, which is handy and economical. It also produces a lot of large magnetic fields in the hundreds of hertz, that get into everything via ground loops.

A single-turn loop, e.g. coax cables on a lab bench, has an inductance of (very roughly) $4\,\mu$H per square meter. At mains frequencies, a 1-m circular loop of RG-58 shield has an impedance of about $(20 + j1)\,\mathrm{m}\Omega$, which is in the range of a large car battery, so even small signals lead to large circulating currents. Most of the time, we connect all the grounds together. This shorts out the shield, but leaves the center conductor alone, so that the (normally common-mode) induced voltage becomes a differential voltage, *i.e.*, an interfering signal.

As before, the best solution is short cable runs, but there are other tricks too. (See *Building Electro-Optical Systems: Making It All Work, 3e*, Section 16.6.)

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