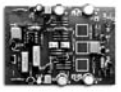

An Audio Isolation Box

This simple transformer-coupled unit allows you to send line-level audio 100′ away, while isolating AC line ground-loop pickup by over 120dB. Audiophile quality is maintained.

By Dennis Colin

My wife wanted to make CD copies on her computer of LPs and tapes, whose players were about 70′ from the computer. A direct cable feed caused audible 60Hz hum. A 2.4GHz wireless A/V link (Radio Shack, about $100) was noisy at that distance. I quickly dismissed the idea of floating the AC line safety ground at one end as dangerous.

The unit I describe here uses a stereo pair of Hammond 850H audio line transformers, rightly described as broadcast quality: electrostatically shielded, hum-bucking windings, rugged metal case, 4Hz –90kHz BW at –1dB, < 2% THD at 20Hz at 2V RMS (0dB full-scale Red Book CD standard), probably less than 0.01% THD at normal line levels.

CONSTRUCTION

Photos 1–5 show the unit, built in an aluminum Hammond 1590S box, 4.35″ × 3.21″ × 1.57″, Digi-Key P/N HM158.

The output RCA jacks must either be of ground-insulating type or floated from the metal box. I did this by punching four ¾″ holes in the box with a Greenlee chassis punch ("knock out punch unit," model 730BB-3/4), then epoxying a strip of 1/8″ hardwood inside, covering the holes. Then I drilled ¼″ holes in the wood, centered in the ¾″ box holes, and mounted the RCA jacks. Before mounting the wood strip I painted it with enamel to prevent moisture absorption electrical leakage. As a testament to the box's overall insulation including the transformers, the input/output leakage resistance is 4000MΩ.

The input/output ground (cable shield) capacitance coupling is 436pF, which at 60Hz is a 6MΩ impedance. Therefore, even in the unlikely (and dangerous!) event that the audio equipment being driven has its "ground" shorted to the hot 120V AC line, the 60Hz leakage current through the box would be only 20μA, not even enough to feel a tingle.

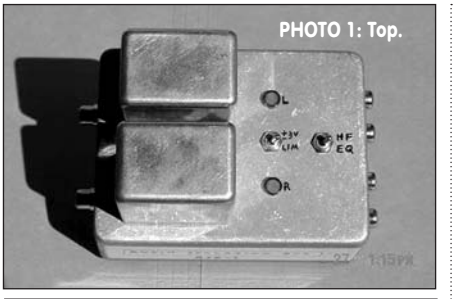

PHOTO 1: Top.

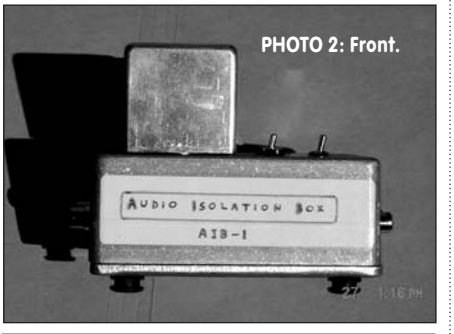

PHOTO 2: Front.

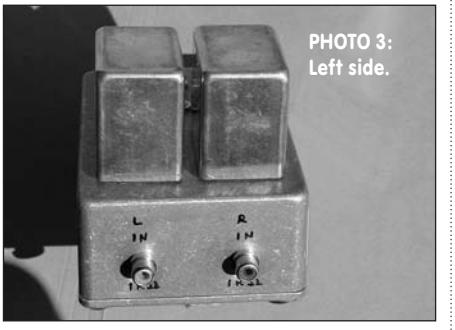

PHOTO 3: Left side.

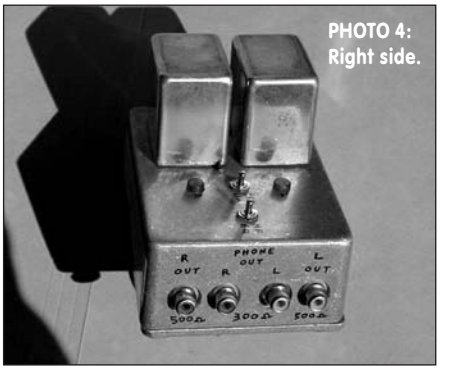

PHOTO 4: Right side.

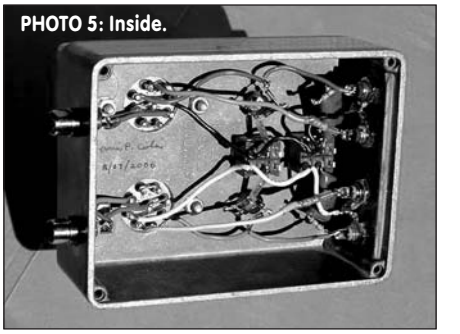
PHOTO 5: Inside.

SAFETY WARNING: VERY IMPORTANT—Before you contact both source and receiving setup cables simultaneously (yes, people have been electrocuted by "only" 120V!), please measure the AC voltage between those two cable shields! If all is well, it shouldn't be more than 5V, the maximum drop expected between line grounds at opposite ends of a house.

My house originally had the safety "ground" of an outside outlet connected to the hot 120V by some "electrician"—I discovered this when some contractors were using the outlet for some equipment, when someone started yelling about shocks! Thankfully, he lived—of course, I should have checked the wiring when moving in. I promptly had it fixed and tested it (and all the other outlets, inside and out). Whew!

I recommend reading Charles Hansen's excellent articles about the AC power grid and safety in this magazine. The reason I'm emphasizing this is that the box described here isolates two audio systems' (supposed) AC line grounds, and that it's all too easy to take "only 120V" for granted. OK, enough preaching.

SCHEMATIC

The transformers (**Fig. 1**) have a nominal stated impedance of 1200 to 600Ω, but will provide this 2:1 impedance transformation (1 to 0.707 voltage step-down) over a wide range of source and

load impedances. Most CD, SACD, and so on, players have a 1kΩ output impedance, which is optimum for the Hammond 850H units (T1, T2). The 3dB voltage reduction (I measured 3.25dB) is easily accommodated by preamps, power amps, and audio/video A/D converters used for computer disc recording.

Two stereo pairs of box ground-isolated RCA jack outputs are provided. J3 and J4 are the cable-driving outputs, while J5 and J6 are 300Ω headphone-monitoring outputs.

HIGH FREQUENCY EQUALIZER

With no load, or up to 100′ of cable driving hi-Z loads, the transformers have a "ringing" resonance at between 200kHz (no load) and about 50kHz (driving 100′ of Alpha 2466C twin-insulated pair cable). Source impedances below 1kΩ (such as headphone outputs) exacerbate this resonance. The resonance is between transformer leakage inductance and load capacitance (the windings' shunt C as a minimum).

While the resonance frequency is ultrasonic, SACDs can have content up to 100kHz, and vinyl records can also have ultrasonic content. R3/C1 and R4/C2, when switched on by S2 ("HF EQ"), form a resonance damping network.

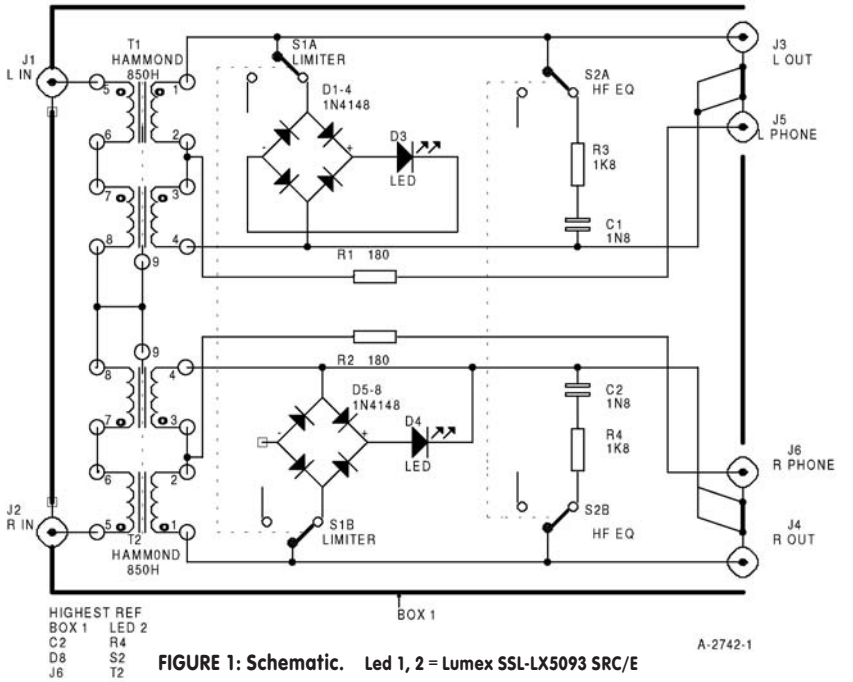

FIGURE 1: Schematic. Led 1, 2 = Lumex SSL-LX5093 SRC/E
Digi-Key 67-1612 Hammond 1590S Digi-Key HM158 4.35″ × 3.21″ × 1.57″.

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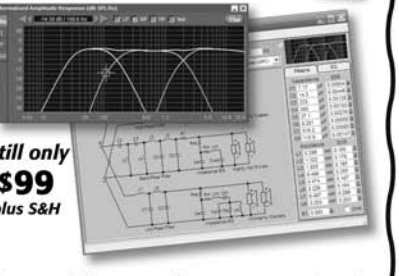

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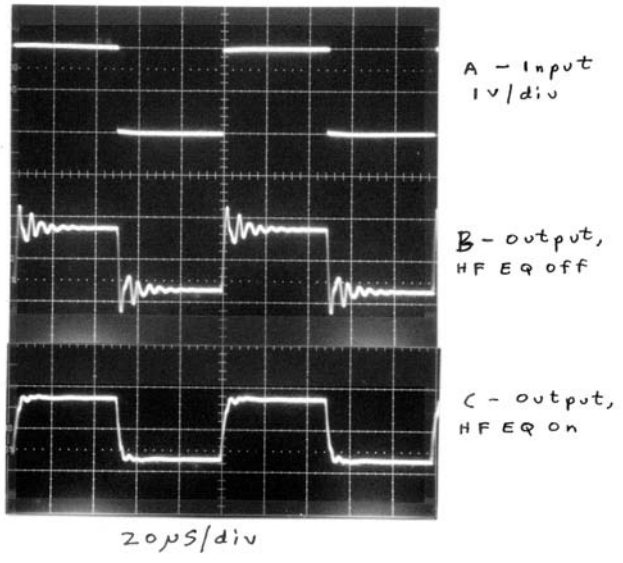

FIGURE 2: 10kHz squarewave, 1k source, no load.

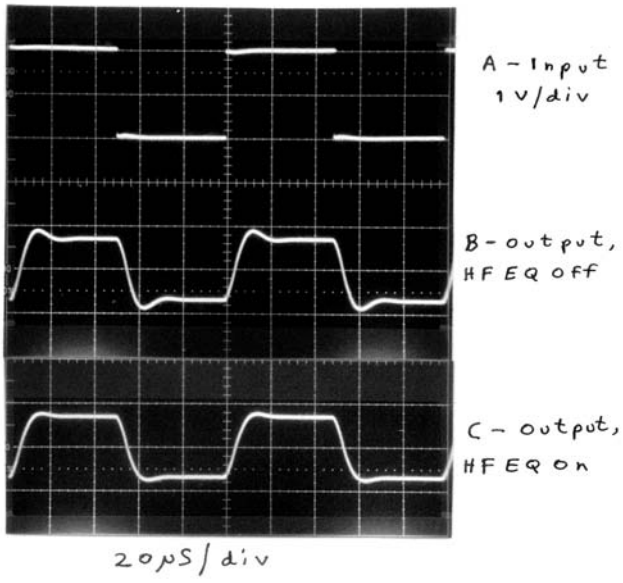

FIGURE 3: 10kHz squarewave, 1k source. Output at end of 100' Alpha 2466C cable with 47k load.

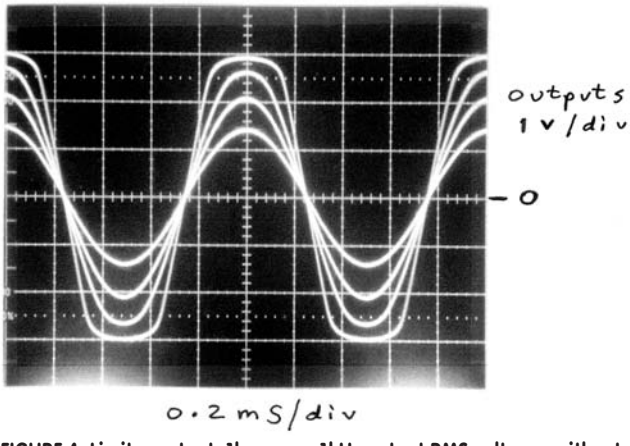

FIGURE 4: Limiter output, 1k source. 1kHz output RMS voltages without limiting are 1.02, 1.51, 2.00, and 3.12V.

Figure 2 shows 10kHz squarewave responses with 1k source and no load, with (2C) and without (2B) the HF EQ.

The reason for including switch S2 is that depending on cable and load, there might be enough HF damping to not need the EQ.

Figure 3 shows the outputs at the end of 100´ of Alpha 2466C cable (5.35nF capacitance) terminated in a 47kΩ resistive load. With HF EQ on (**Fig. 3C**) the overall frequency response reaches a "peak" (insignificant) of 0.07dB at 10kHz, and is –0.03dB at 20kHz. Above this the response monotonically falls (no peaks or dips) to –3.2dB at 50kHz, and –31dB at 250kHz. The latter provides good rejection of AM radio interference and the digital noise surrounding computers.

PEAK LIMITER

You do not want to ever overload the input to an A/D converter preceding a digital recording setup. Even momentary peak "digital clipping" produces a broken-glass-sounding "crunchy splash" of musically irritating wideband IM transients.

The Red Book CD standard defines 0dBFS (full scale) as 2V RMS for a sinusoidal peak, meaning a maximum peak voltage excursion of ±2.83V. Several CD/SACD players I've measured can output peaks (with some recordings) reaching about ±3.5V.

The –3dB voltage stepdown of this isolation box provides additional margin. Just in case (e.g., driving the box from a headphone output, or a phono preamp or tape recorder), switch S1 enables a diode bridge/LED peak limiter. The specified LEDs have a low drop (1.70V at 5mA) and high brightness, visible even with 0.1mA.

Figure 4 shows the limiting characteristic, which limits very smoothly, producing low-order odd harmonics similar to a push-pull tube amp without feedback. Much, much better than "digital clipping!"

MEASUREMENT SUMMARY

Table 1 shows data on the isolation box alone, **Table 2** is with the box driving 100´ at Alpha 2466C cable, and **Table 3** shows characteristics of the cable. Parts cost for the isolation box is about $220.

CABLE DATA

I purchased a 100´ spool of Alpha 2466C SL 005 (SL for slate color) cable from Digi-Key, P/N A131-100, for $43.52. It has two individually shielded pairs of 22-gauge conductors, plus an overall shield. I think the three shields are in contact, but I connected them and one conductor of each pair together. At each end I connected a red (right) and green (left) RCA stereo pair of plugs. The green plugs (Digi-Key CP-1452) connect to the cable's green wire (hot) and white wire plus all three shields (plug shell); the red plugs (Digi-Key CP-1448) connect to the cable's red wire (hot) and black wire plus three shields (plug shell).

This provides a nice convenient thin and flexible 100´ stereo RCA cable, easy to use and roll up when not in use (wives don't like leaving long cables all over the floor, but

neither do I after having tripped on it).

Figure 5 shows 200′ of this cable (left plus right looped back) responding to a 100kHz squarewave. At the cable input, you can see the delayed reflection (in phase with open load, **Fig. 5A**; out of phase cancellation with shorted load, **Fig. 5C**). **Figure 6** shows a time-expanded view of the cable's delayed and HF-attenuated response.

You may take such waveforms for granted, but **Fig. 6** shows a signal traveling at 449 million mph, which is 67% of the speed of light. Needless to say, with 100′ of this cable having a delay of 0.3% of a 20kHz cycle period (1° of linear phase shift), there are no "wavelength effects" to influence sound quality! (Of course, you could spend $30,000 for 100′ of "audiophile interconnect.")

LOW FREQUENCY PERFORMANCE

With a 1kΩ source, the 850H transformer has an LF (–3dB) point of 1.7Hz, and is down only 0.32dB at 20Hz. But I wanted to determine its 20Hz signal-handling ability. Hammond states +15dBm as maximum power, which is 4.36V RMS across 600Ω; I'm using the "600Ω nominal" winding as the output secondary. Hammond states 1.5% THD at 20Hz, +15dBm.

But that's with the windings each seeing their nominal impedances for source and load, equivalent to driving the 1200Ω winding (used here as primary) from a 600Ω source with no load, as far as magnetizing current distortion is concerned (more on this follows).

With my 1kΩ source/47kΩ load testing, the nonlinear magnetizing current will produce more distortion of the signal voltage. **Figure 7** shows 20Hz sine response. In **Fig. 8**, a 20Hz squarewave is used. **Figure 8A**, with an input of ±1V peak (1V RMS for a squarewave), shows only a slight tilt due to phase shift from the 1.7Hz 3dB rolloff.

But in **Fig. 8B** I increased the driving amplitude until core saturation became evident. The output, at each squarewave jump, starts with a large, fast overshoot, as the core "snaps" out of saturation from the previous half-cycle.

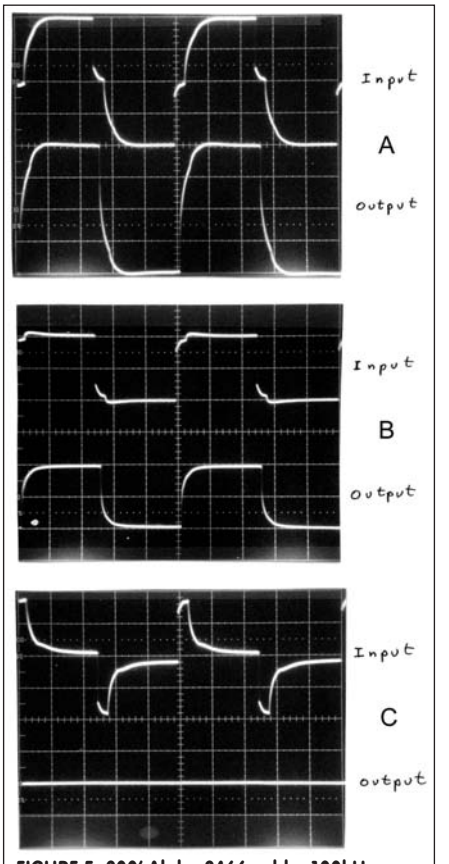

FIGURE 5: 200′ Alpha 2466 cable, 100kHz squarewave from 50Ω source. 1V/div, 2μS/div.

TABLE 1: AIB-1 MEASUREMENTS.

In/out ground isolation: 126dB at 60Hz, 76dB at 20kHz
in/out ground coupling: 436pF, 4000MΩ
AC line pickup, 12″ from an 80W power supply:
1.8μV RMS = -113dBu = -121dBFS (0dBFS = 2V RMS)
impedance stepdown ratio = 2:1
voltage transformation ratio = 0.688 = -3.25dB
insertion loss re stepdown ratio = 0.24dB
frequency response, 1kΩ source, 47kΩ load, HF EQ on:
–0.32dB at 20Hz, + 0.08dB at 20kHz
–1dB at 4Hz, 90kHz
–3dB at 1.7Hz, 150kHz
maximum input (2% THD): 2.0V RMS at 20Hz, 10V RMS at 100Hz
THD at 0dBu (0.775V RMS) input:
0.3% at 20Hz; approximately 0.01%, 100Hz – 20kHz

TABLE 2: AIB-1 DRIVING 100′ OF ALPHA 2466C SL005 CABLE.

HF response w/47k//100pF load, 1k source to AIB-1:
+0.6dB at 20kHz (HF EQ off)
–0.03dB at 20kHz, -3dB at 48kHz (HF EQ on)

TABLE 3: CHARACTERISTICS OF 100′ ALPHA 2466C SL005 CABLE.

(2 pair, shielded individually and overall; between one #22 conductor and other one connected to shield)
DCR: 1.61Ω (conductor), 1.57Ω (shield)
C = 5.35nF
L = 12.6μH round trip, measured at 50kHz
Zo (characteristic impedance) = 48.5Ω at 50kHz
fo (quarter-wave resonance) = 1.348MHz
propagation velocity = 67% speed of light

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Then it maintains the desired 10V level for about 10mS, followed by saturation, gradual at first, then complete just before the next jump. At this point, the magnetic flux can't continue increasing (as needed to maintain an induced voltage) so the voltage collapses to zero.

The product of voltage and time duration is a constant for a given number of turns on an iron core; in this case that saturation constant is about 100 millivolt-seconds.

HYSTERESIS LOOP (B-H CURVE)

I saved the most interesting waveshapes for dessert (**Fig. 9**). "H" symbolizes magnetic driving force (magnetization), analogous to voltage or water pressure. It's proportional to current times the number of winding turns (ampere turns).

Iron atoms have an organized electron-spin effect, making the atoms microscopic magnets. In unmagnetized iron, the atoms are randomly oriented, so the individual magnetic fields cancel, averaging out to zero. But an applied external magnetic field makes these tiny magnets tend to align. In "hard" steel, they stay aligned after the external force is removed. This is called "remanence" (for "remaining") and is used in permanent magnets.

But in "soft" iron used for transformer cores, remanence is undesirable, causing energy to be wasted overcoming this magnetic "stickiness."

"B" symbolizes magnetic flux, analogous to electric current or water flow rate. In iron, and other magnetic materials, the permeability (ratio of flux to magnetic force, or B/H) is greater than that of a vacuum or air (defined as permeability = 1). This is because an external magnetic field starts aligning the tiny iron atom magnets; this alignment increases the overall flux much more (by thousands) than in air. But as the externally applied field is increased, eventually the iron atoms are as aligned as the molecular structure allows; this is saturation. Beyond this point, only the vacuum permeability of 1 can add flux; beyond hard saturation you have an air-core transformer, useless except perhaps at radio frequencies.

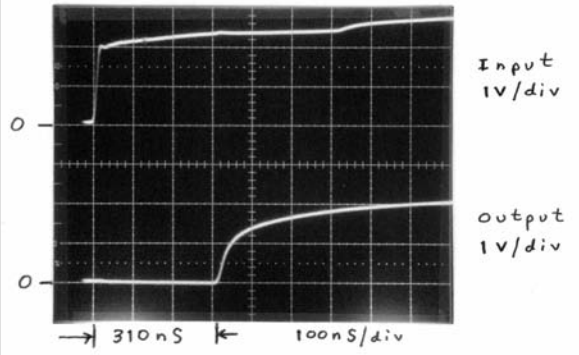

FIGURE 6: 200' Alpha 2466 cable + 5' RG58 C/V cable, 500kHz squarewave from 50Ω source. Cable load = 50Ω. 2466C cable Zo = 48.5Ω. BW (-3dB) = 1.2MHz.

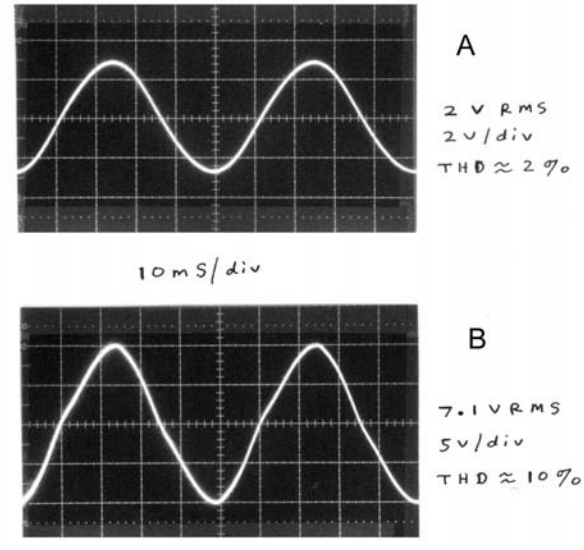

FIGURE 7: 20Hz output, 1kΩ sine wave source, 47kΩ load.

Figure 9A shows the test setup for displaying B-H curves. Primary current, which is sensed by R1, is proportional to H, the magnetic driving force. The primary voltage, proportional to the rate of change of flux, could have been sensed, but I used the secondary voltage for two reasons: 1) the primary voltage has an additonal component, the drop across its DC resistance, whereas the secondary current

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load is only about 1mA, and 2) the secondary can be conveniently ground-referenced.

Note that (excluding DC resistance drop) the magnetically induced winding voltages are nearly equal, even in saturation, for tightly-coupled windings such as these. This latter fact, by the way, explains why magnetic flux nonlinearity (short of hard saturation) distorts mostly the winding's current, whereas the secondary voltage closely follows the primary. With a low source impedance and tightly coupled windings (desirable in a tube amp), the signal voltage distortion is much lower than that of the primary magnetizing current.

Because the induced voltage is proportional to the rate of change (time derivative) of flux B, the latter can be obtained by integrating (the inverse of the derivative) the winding voltage. R2 and C1 serve as an integrator. An op amp with feedback cap would form a virtually ideal integrator, but because the lowpass filtering of R2/C1 has a –3dB frequency of 0.318Hz, much lower than the 18.9Hz test frequency, its phase shift is only 1° short of the ideal –90° shift of a true integrator.

Figure 9B shows the B-H curve of the 850H transformer with an applied primary voltage of 11V RMS, much higher than the 2V RMS full-power usage in this isolation box application. Some features of this plot worth noting are:

1. The vertical (flux B) scale is 36.1mV-sec per division, referred (normalized) to the primary by the turns ratio. Because flux is proportional to the time integral of the induced (or applied) voltage, the units of flux can be expressed as a voltage X time product, just as in the 100mV-sec saturation limit described in **Fig. 8B**. **Figure 9B** shows this same 100mV-sec saturation at about ±3 divisions vertically from center.
2. The opening, or separation, of the two traces (as the scope spot travels upward and downward in a loop) is due to the iron core's remanence (magnetic memory). This is an example of hysteresis, analogous to the "backlash" in worn-out gears having excessive "play." Thus the B-H curve is often called a "hysteresis loop." The area enclosed by the loop represents energy dissipated each cycle in the core, resulting in power loss.
3. The primary current required for saturation is about ±4mA peak, or 2.8mA RMS. However, the primary inductance I measured is 80H, which at 20Hz is an impedance (reactive) of 10kΩ. Thus 28V RMS at 20Hz would be needed to hard-saturate the core, but less voltage is actually needed because even mild saturation lowers the effective inductance.

Fig. 9C shows the B-H curve with only 1V RMS applied, again at 18.9Hz. Here, the curve appears smooth and el-

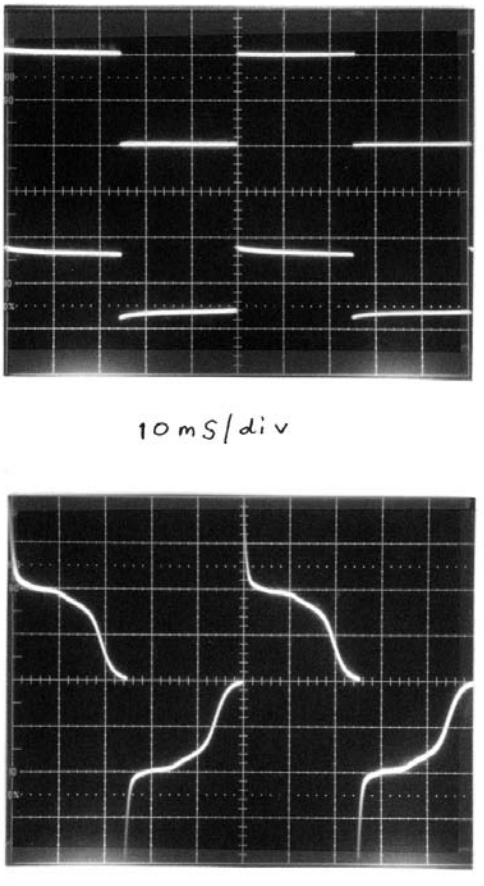

FIGURE 8: 20Hz output, 1kΩ squarewave source, 47kΩ load.

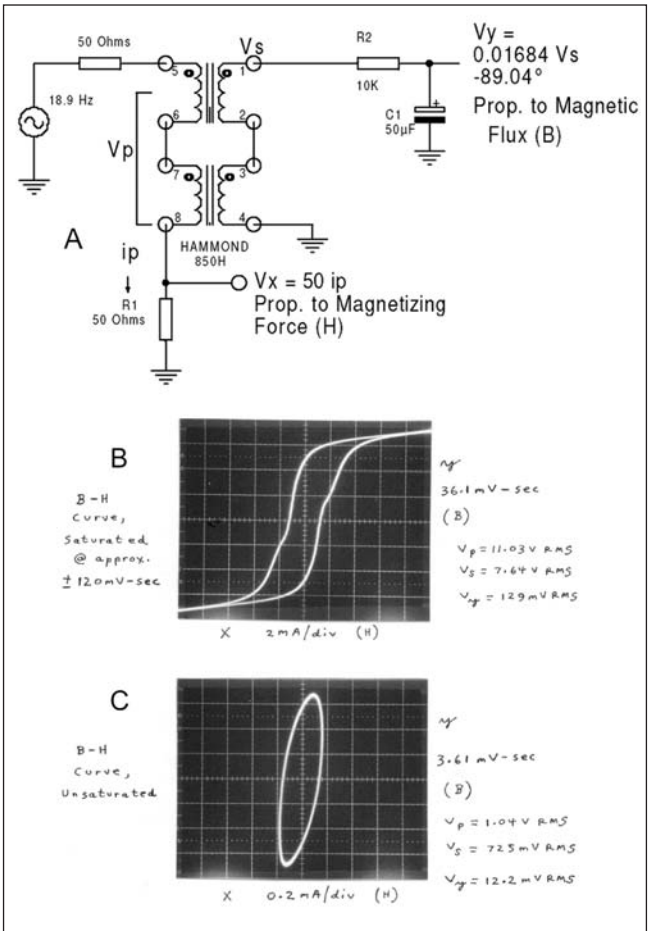

FIGURE 9: Hammond 850H Primary B-H curves (hysteresis loops).

liptical. At this level, much below saturation, the elliptical shape is probably not from hysteresis, but rather from resistive losses, especially the 10k secondary load. A volt-amp X-Y plot of an ideal inductor would be an ellipse or circle (with equal X-Y excursions).

But here the R2/C1 integrator's 90° shift would cancel that of a pure inductor. However, any resistive losses (core loss, winding resistance, or most likely the secondary R2 load) will cause a net overall (including integrator) phase shift. That the shape of **Fig. 9C** is not due to nonlinearity is supported by the observed low distortion of this transformer with 1V RMS applied at 20Hz and 18.9Hz.

Figure 10 shows the locations of parts that I used on the box.

CONCLUSION

Table 4 is the parts list. While describing a simple isolation box, I've taken the liberty of graphically displaying some fundamental physical principles of cables and audio transformers, and also electrical safety regarding AC line grounding imperfections. One or more of these boxes will allow you to use your house as a low-noise recording studio. *aX*

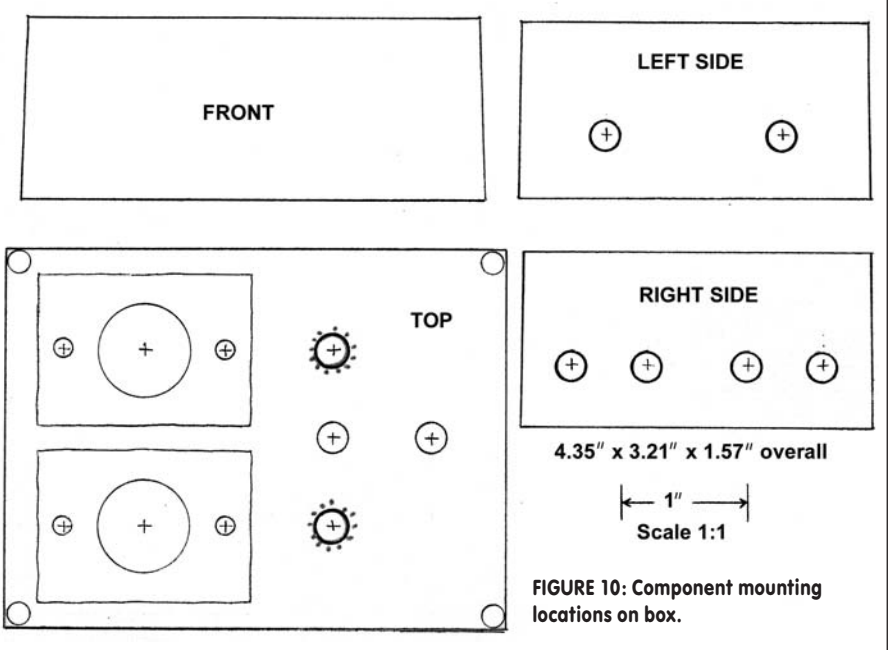

FIGURE 10: Component mounting locations on box.

TABLE 4: PARTS LIST.

Ref	Description	Manufacturer	Part#	Distributor	Part#	Price
Box 1	box, 4.35″ × 3.21″ × 1.57″	Hammond	1590S	Digi-Key	HM158	$10.88
C1, 2	cap, 1.8nF, 100V			Digi-Key	PS1182J	
D1-8	diode		1N4148			
J1, 3, 5	jack, RCA, green			Digi-Key	CP-1417	
J2, 4, 6	jack, RCA, red			Digi-Key	CP-1413	
LED1, 2	LED, red	Lumex		Digi-Key	67-1612	
R1, 2	Res, 180Ω ¼W					
R3, 4	Res, 1.8k, ¼W					
S1, 2	switch, toggle, DPDT			Digi-Key	360-1156	
T1, 2	transformer, 1.2k-600Ω	Hammond	850H	Spartan*		$98.77ea
	cable, twin, 100´	Alpha	2466C SL005	Digi-Key	A131-100	$43.52
	plug, RCA, green (2)			Digi-Key	CP-1452	
	plug, RCA, red (2)			Digi-Key	CP-1448	

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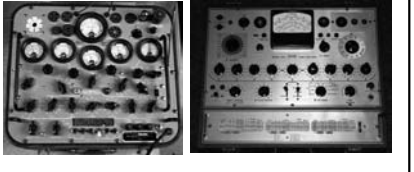

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