Power Supply V- Bonding, Hum, Buzz, and RFI

Should We Bond V- at the Power Supply or Not?

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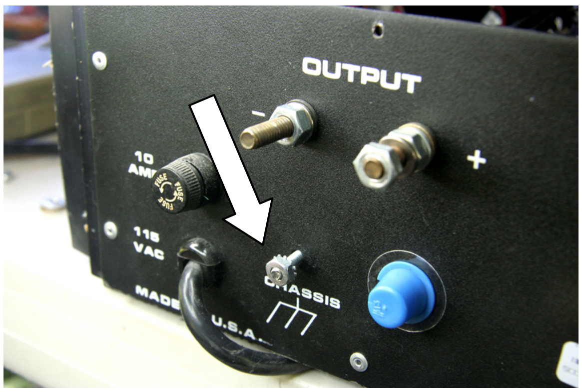
I've seen numerous anecdotal comments suggesting that all might not be right with the grounding of Astron power supplies, and that the result could be RFI. I own four, one of them an RM35 that's out on loan, an RM50M, and two RS70Ms, but have never bothered to check this out. A major reason is that I rarely use them – instead, I run my 14VDC gear from a big Costco deep cycle battery that is float charged by a small 10A switching supply.

Last week, motivated by a rather interesting post by W8JI, I finally got around to studying it, and the results were surprising. More about Tom's post later – that's the most interesting part. Astron schematics show the 120V green wire bonded to the chassis, and the negative terminal (V-) bonded to the chassis. I began by poking the RM50M with the low Ohms scale of my trusty Fluke 8060A, looking for electrical connections to the chassis. I couldn't find any! The round pin on the AC plug showed open to everything, and so did the output negative terminal. Opening it up and continuing to poke around soon told me why.



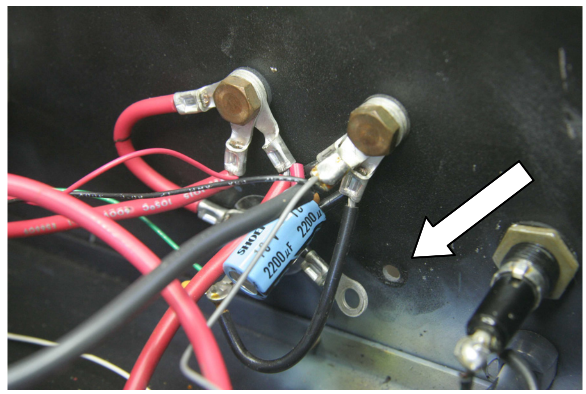


Figure 1a (left) and 1b (right)

<u>Physical construction</u> is pretty straightforward – both V+ and V- terminals are floated from the chassis with robust insulators, and no part of the power supply circuitry is referenced or bonded to the chassis. The only connection is a small black wire, I'd guess #16 or #18, between the V- terminal and the chassis bonding screw directly below it. See Fig 1a and 1b above. Mains power enters close by, and is bonded to the mounting lug of a 2-circuit terminal strip which is screwed down to the bottom cover. Inside the box, both bonding points still read open to the chassis.

<u>It's all about paint</u> Next, I loosened the chassis grounding screws to find a lovely coat of paint on both sides. As if that wasn't enough, the ohmmeter tests also revealed the lack of a bond between parts of the chassis. Again, there's paint in the way, and no easy way to fix it – the rear panel is riveted to the sides of the chassis. The only bond between the rear panel and the rest of the chassis is via the top cover, which does make connection with the rear panel and both side panels. That's acceptable for low frequency electric field shielding, but the paint turns the junctions between sections of the chassis into slot antennas to let in VHF RF.

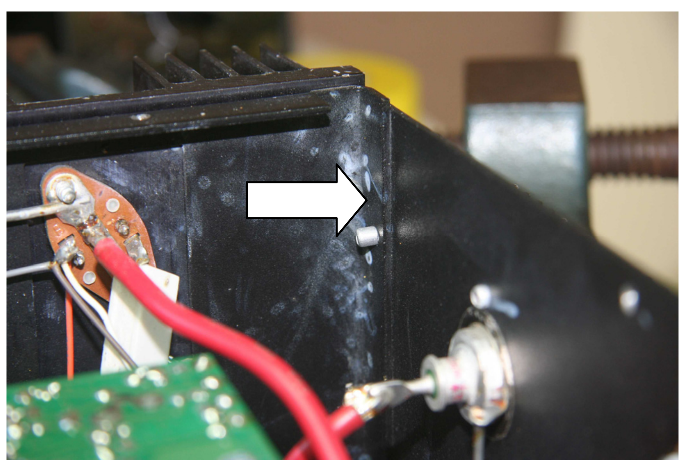


Fig 2 – Connection (or the lack of) between parts of the chassis

There were two faults with the one of the RS70Ms – the screw grounding the terminal strip for the power cord green wire was insulated by paint from the chassis, and the mounting screws for the power transformer failed to make contact with the chassis. Scraping the paint fixed both faults. No faults were found with the other RS70M.

The W8JI Contribution On several occasions, Tom has posted to the Elecraft list noting that there will be significant modulation of the V- line by IR drop during SSB transmission, and that if that voltage appears in the audio return path between a rig and a computer feeding unbalanced audio to the rig, the result will be severe distortion that sounds like SSB being rectified by an AM detector. This coupling only occurs if the V- terminal is bonded at the power supply, and if the audio is direct coupled (that is, not transformer isolated).

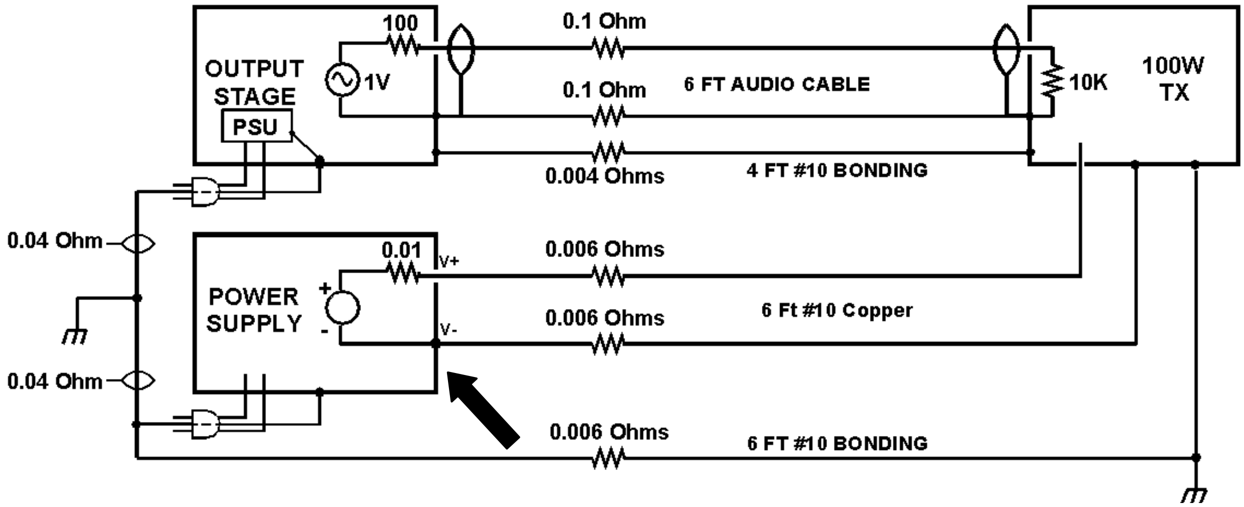


Fig 3 – Ham Transceiver with Typical 14VDC Supply with V– bonded to chassis

Fig 3 shows the problem. Bonding conductors shown are those recommended in my Ham Interfacing tutorial to eliminate power-related hum and buzz. Because V– is bonded and both computer and power supply are bonded to the power system ground by the green wire, some of the IR drop on V– appears between the computer chassis and the radio chassis, and since the audio is unbalanced, is added in series with the audio signal. Resistance of the green wire to ground assumes 6 ft #18 power cords plugged into the same outlet. This resistance will be much greater if they are powered from different outlets.

Fig 3 can also be used to estimate the magnitude of the noise, and from there, the signal to noise ratio. For the conductors shown, 20A peak current produces a peak IR drop during transmit of 122 mV on both positive and negative power leads. The audio noise is 122mV peak to peak on the V– conductor. Program audio from a well adjusted computer sound card should be about 1V peak. If there were no bonding conductors to reduce the noise level, the signal to distortion ratio would be on the order of 18dB, which would sound pretty nasty. The magnitude of the IR drop will be reduced by the voltage divider ratio between the resistance of the green wires and the resistance of the added bonding conductors. The relatively good bonding shown could be expected to improve that by roughly 20dB, which would likely be perceived as fairly clean.

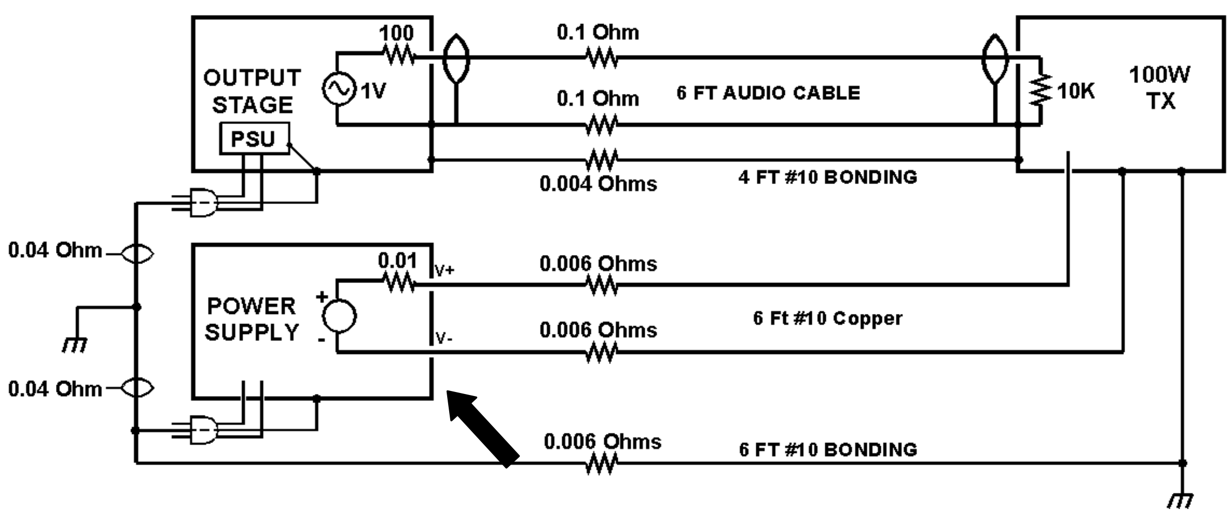


Fig 4 – Ham Transceiver with Typical 14VDC Supply with V– not bonded to chassis

Ham Station with V– Not Bonded at Power Supply Fig 4 shows the same installation with V– not bonded to the power supply chassis. Because V– is not tied to the chassis, no noise current is coupled to ground wiring or to unbalanced audio.

Some Measurements To confirm all of this, I pulled out an Audio Toolbox, an audio analyzer that can simultaneously function as an audio voltmeter, real time analyzer, and headphone amplifier, and can read down to a μv or so. My 14VDC wiring is a collection of large Power Pole splitters and short small power pole cables running from the battery to the K3, with splits to other DC-powered accessories. DCR between the battery and the K3 is probably close to the equivalent of 3 ft of #12. The V– terminal is not bonded at the supply.

For my tests, I connected the probes of the test instrument between the V– terminal of the battery and the chassis ground of the K3. The analyzer is battery powered and has a high input Z, so it has no influence on the circuit it is measuring. I then transmitted with full power on 10M and contest-level audio compression into a 3-el SteppIR 300 ft from the shack and pointed away from the shack, measuring the voltage, studying the spectrum, and listening to it.

The measurements confirmed of all Tom's observations, and the voltages are in line with rough estimates noted above (although they do suggest that peak currents may be greater than 20A). The modulated IR drop does, indeed, sound a lot like rectified SSB RF. This does not get into my transmitted audio, because V– is not bonded in my power system, but it's quite audible and quite nasty on the DC conductor. Tom calls this "audio ripple," which implies a power supply problem. I think envelope modulation of the V– line is a better description. The voltmeter sees sustained readings of -32dBVrms. Audio from a computer sound card to a radio is typically about -13dBVrms (0.7V sine wave on peaks). That puts this trash only about 20dB below audio, which would likely be perceived as distortion if it ended up in series with TX audio.

As a further diagnostic test, I added 70,000 μF in parallel with the Power Pole at the back of the K3. Audibility of the noise fell by about 10dB; the rms voltage dropped by about 6dB. Spectrum analysis showed why – the greatest drop was in the higher octaves (1kHz and above). No surprise, of course – it's brute force energy storage, which has more effect at higher frequencies.

How are power supplies built, and why? All the commercial power supplies I own are built either with their V- terminal isolated from the chassis, or, in the case of the Astrons, so that they can be isolated by cutting the bonding conductor. K6XX says that most commercial supplies are built with V– floating. I'd bet that a lot of Astrons are too (thanks to paint), although the schematic shows otherwise. Does the negative rail ***need*** to be bonded to the chassis? I don't see a good reason why it needs to be, as long as good RF filtering and bypassing is in place. With a simple DC supply like these, all it takes is RF bypassing to the chassis at the point of entry, a common mode choke on the pair of conductors, and a second pair of bypasses on the other side of the choke. For VHF/UHF immunity, I would also like to see all that paint go away at the junctions between chassis sections.

The system implications With any design decision like this, one must always study the big picture. Does bonding V– at the supply cause a problem? Does it solve a problem? Are there stability issues in the power supply under either condition?

Noise on ground The primary problem caused by bonding V– at the power supply is that it puts a lot of noise on ground in a station that is properly bonded. W4TV and N8LP have both noted issues with powering accessories from the 12V bus. Joe, Tom, and I have discussed this quite a bit in private email.

Power System Bonding It should be noted that the NEC strongly prohibits use of the grounding conductor (the green wire) to carry load current, and prohibits bonding neutral to the ground conductor at more than one point (the service entrance, or the secondary of a distribution transformer). Violating this rule not only compromises the safety of the installation, it can also cause significant hum and buzz problems.

Bonding or Transformers? As the computed examples above show, the robust chassis bonding I've long advocated will minimize that problem, but it may not make it inaudible. Tom's solution is audio transformers. While that certainly keeps buzz and this modulated DC out of unbalanced audio, an unshielded transformer is a sitting duck for magnetic fields, and a shielded transformer is not cheap.

RF Filtering the negative lead? Tom is currently designing a couple of big solid state power amps with outboard supplies (48V for the output stage and a lower voltage for other circuitry), and insists on bonding V– to the chassis. He contends that if he didn't, he would need to add RF filtering to the negative line, increasing the cost. I believe he is mistaken from an RFI perspective – because he's filtering differential mode current, the series components must be far more robust than components required to do differential mode filtering (that is, the core of differential mode choke sees the full DC, while the core of a common mode choke sees almost none).

RFI complaints and Astron Supplies Now that I've investigated this, I'm starting to suspect that anecdotal reports of RFI with Astron power supplies may actually be the result of bonding V-. Indeed, this may be the root cause of some hard to identify (and hard to reproduce) RFI complaints with all radios, including Elecraft products.

Modifying a commercial product is something I strongly like to avoid unless 1) I am sure that doing so is something the designer considered acceptable; or 2) I am sure that there are no issues (like stability) that could result. In the case of the Astrons, the circuit design and construction, as well as the fact that many of their units lack bonding thanks to a manufacturing defect that must have passed final test, suggests that cutting the V– bond should not cause a problem.

Understanding cable shields A cable shield is effective against capacitive coupling (the E-field) at all frequencies. If the cable is very short as a fraction of a wavelength ($\lambda/20$), a connection at one end is sufficient. The same is true for electromagnetic fields (radio waves).

Transmission lines and magnetic field rejection Ott shows us that a cable shield provides virtually no shielding for magnetic fields. Rather, a transmission line rejects magnetic fields by virtue of mutual inductance between the conductors. In coax, the coupling coefficient is approximately one – that is, virtually all the flux from one conductor is coupled to the other. Thus, any voltage present along the shield results in an equal and opposite voltage along the center conductor. The problem is that this coupling is limited by the DCR of the shield. The shield cutoff frequency is the corner frequency for this mechanism – where the inductive reactance of the shield has increased to the point that it is equal to the DCR of the shield. For coax with very beefy copper shields, that's typically around 1kHz. For the cheap cables likely to be used to carry audio, 20kHz or 40kHz is more like it. So basically the shield is out of the picture for baseband audio noise, and it's just Ohms Law, like we've been talking about.

Differential Inputs are a better solution to this problem, and no transformer is required with a simple wiring configuration called forward referencing. In the circuit below, a typical output stage drives a differential input. Almost no current flows in the twisted pair, because the input impedance is high, so the differential input sees only the output voltage of the driving stage. The shield should be bonded to the enclosure at the sending end; it may or may not be bonded at the receiving end, to avoid exciting a pin 1 problem. The twisted pair effectively rejects magnetic coupling, even at low frequencies. The limit on that rejection is the imbalance in the resistance of the two sides of the circuit, in this case, 10,100 ohms to 10,000 ohms. 30dB is a practical number. While the differential input is drawn with an XL connector, a 3-ckt (TRS) 1/8-in plug and jack work equally well. The only downside to this arrangement is that the user can't buy a cable at Rat Shack.

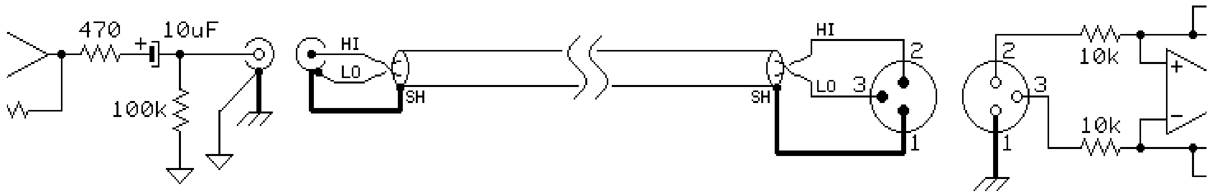


Fig 5 – Forward Referencing Provides 30dB of Noise Immunity with no transformer

In summary If DC envelope modulation is coupled to transmitted audio it will be perceived as RF in the shack. This happens if audio wiring is unbalanced, no transformers are used, and V– is bonded at the power supply. The simple chassis bonding I've recommended to eliminate mains power related noise will also reduce this noise, probably to an acceptable level. It's also long past time for ham gear to be built with differential inputs.

I am just about convinced that <u>all</u> V- lines should be isolated at the power supply end. On the other hand, I've learned that when you're suggesting significant changes to existing practice, there can be considerations you haven't thought of. My expertise is audio systems, interfacing, and RFI, not circuit design, so I'm ready to be convinced otherwise by a circuit designer that there's a real downside with that approach. So I'm not ready to go public with this yet, but I am in information gathering mode. I would greatly appreciate the exchange of information from those of you who can take time to check out as many power supplies as possible. What are they doing with V-?

Thanks and 73, Jim Brown K9YC