Does the waterfall display of your digi-mode software have a lot of 50/60 Hz harmonics and other noise in it - that doesn’t come from your receiver itself? Chances are, if you see such noise and harmonics garbage in your waterfall display, it will also be on the audio output of your PC! This means that you may actually be transmitting it with your digi-mode software. You don’t want that!

The screenshot below shows what my 100-2500 Hz waterfall display used to look like - not anymore! For a long time, I blamed it on QRM generated in/by the apartment building that I live in, and big-city QRM levels in general.

Lots of noise and 50 Hz power harmonics in my receiver’s audio spectrum

All the way up to about 8-9 MHz, my receiver’s S-meter showed a noise level of at least S8 - try working DX with that!

Then I installed a multi-strand copper bonding wire (#14 AWG, 1.6 mm Ø) between the chassis of my laptop-PC and the ground/return of the external 12 VDC power supply of my transceiver. My laptop is an older model Dell, so it has several D-sub connectors: a DB9 serial-port, and a DB15 display output. Their shells are connected to the laptop’s chassis. The metal shell of some other connectors (USB, FireWire) is also connected to the chassis. The DB-connectors have two nuts, for the lock-screws of the mating plug. I made a bonding wire with a small ring lug on one end, and a large ring lug on the other. The small lug is screwed onto one of the D-sub connectors. The large lug goes on the “-” binding post of my transceiver’s external 12 VDC power supply.

The bonding wire is connected to the chassis ground of my laptop

This made quite a difference!
To determine where the remaining noise traces came from, I disconnected the laptop's external power adapter (from the wall outlet!!!) and ran the laptop on its internal battery. Ref. 1. The audio spectrum is now basically clean above about 300 Hz:

![Audio spectrum comparison](image1)

*Installing the bonding wire and running on battery completely cleaned up the audio spectrum*

On 80m, the S-meter of my receiver also shows the noise reduction: as much as 5 S-points!

![S-meter comparison](image2)

*S-meter with laptop on battery (power adapter disconnected), with bonding wire (noise = S2+)*

The particular laptop power-adapter that I used with this laptop, is a cheap, simplistic switched power supply (not OEM). It has totally inadequate filtering on both the input side (ref. 2, 3) and the output side (ref. 3). Note that not all laptop power adapters (or desktop internal power supplies) are this bad!

![Circuit card](image3)

*The circuit card of a cheap laptop power adapter*
Note that interference from the power adapter is not just *conducted* to the transceiver. It is also *radiated*. If I unplug the 19 VDC from the laptop and touch the barrel connector (and not touch anything else), most of the power supply noise returns. I have a second laptop, on the same desk as the other one. It is not connected to my transceiver, other than via the filtered 220 VAC power strip. I have now also added a bonding wire between this second laptop and the power-supply of my transceiver. This has reduced the receiver noise a tiny bit more. Every little bit helps! As this laptop is in a docking station, the bonding wire is screwed onto one of the D-sub connectors of the dock.

![S-meter when second laptop is now also bonded to the power-supply of the transceiver](image)

**REFERENCES**

- **Ref. 1**: "Computer to Rig Interfacing - You Don't Need to Buy an Interface", Jim Brown (K9YC), 91 slides presentation  [pdf]
- **Ref. 2**: "Reducing switching supply racket (RF interference)", Clint Turner (KA7OEI), blog, December 8, 2012  [pdf]
- **Ref. 3**: "Completely containing switching power supply RFI", Clint Turner (KA7OEI), blog, August 18, 2014  [pdf]
Computer to Rig Interfacing
– You Don’t Need to Buy an Interface!

Jim Brown
K9YC
Santa Cruz, CA
http://audiosystemsgroup.com

Interconnections Needed

• Audio from the computer
  – Playback voice messages to radio
  – Transmit RTTY, PSK31, WSJT
• Audio to the computer
  – Decode RTTY, PSK31, WSJT
• Mic to computer
Interconnections Needed

- Sending CW
  - Computer to radio
  - Paddle and keyer to radio
- PTT from computer to radio
  - Or use VOX
- Rig control and data for logging software
  - Frequency readout, band changes

Pre-Recorded CQs are Crucial!

- Without them, you can’t munch or drink coffee!
- Rest your voice
- Think about what you’re going to do next
- Listen on another radio to find QSOs on another band
Simple SSB Setup

• The logging program feeds your mic to the rig
  – Allows you to record new messages during the contest
  – This setup uses VOX to key rig

Simple RTTY Setup

• Computer generates RTTY signal, sends to rig
• Rig sends received RTTY signal to computer, which decodes it
• This setup uses VOX to key the rig
Simple RTTY Setup with PTT

- This is the same as the first setup, but it uses PTT rather than VOX
  - PTT for RTTY requires a second serial port
  - No good reason for PTT – VOX works fine!

Simple CW Setup

- Buy WinKey as a kit ($78)
  - Build it in two hours
  - Use your paddle with it for things that aren’t programmed in your Logger
  - It’s a nice stand-alone keyer too
What's a WinKey?

Why WinKey?

- Logging programs aren’t very good at sending CW on serial port or printer port
  - It's a byproduct of Windows multi-tasking
  - Sending CW hogs the processor
  - Putting spots on a bandmap also uses a lot of processing cycles
  - CW can get choppy if the processor is too busy
- Sending CW to WinKey uses much less of the processor
- WinKey has two outputs, so it can key two radios for SO2R (Single Operator 2 Radios)
Another Simple CW Setup

- If you already own an outboard keyer
  - I’ve used this with an AEA MM-1 keyer on Elecraft, TenTec, Icom, and Kenwood rigs

This Works With A Few Rigs

- Most rigs with built-in keyers let you use the “key” input or the built-in keyer, but not both at the same time
- Some rigs can be modified to work
- An outboard keyer is usually easier
Audio Interconnections

The Elements of the Problem

• We must connect the right pins of the right connectors to each other
• We must match audio levels properly
  – Avoid overload of transmitter input stage
  – Optimize operation of sound card
  – Avoid distortion in sound card
• We do not need to match impedances
• All these interconnects are unbalanced
  – Noise voltage between equipment grounds
  – This is where hum and buzz comes from
Which Pins Do I Connect to What?

• Every radio is different
• Study the reference section of the manual for your rig
• Line Inputs and Line Outputs are best
  – Phone Patch connections
  – RTTY/PSK connections
  – Often on accessory DIN connectors
• Mic Inputs can work fine
  – More about that later

Audio Levels and Impedance
600 Ohm Circuits are a Myth!

- 600 ohm circuits have not been used in pro audio for nearly 50 years!
- In the olden days, telephone circuits loaded and equalized for up to 20kHz bandwidth were used as broadcast studio-to-transmitter links, and for other special uses. These were 600 ohm lines, but they have been very rare for more than 35 years!

600 Ohm Circuits are a Myth!

- Those who talks about 600 ohms for audio circuits must have slept through the last 50 years!
  - Video people
  - Marketing people (product literature)
  - Hams
In the World of Audio

- We **never** match impedances
- We **must** match levels!

**Pro Balanced Line Level**

- Almost no audio current flows
- Wire size doesn’t matter
- **Twisting** is important for hum/buzz/RFI rejection
- Shield is **not** necessary!
- Some pro stages are 6 dB hotter (20V peak)
Consumer Unbalanced Line Level

- Almost no audio current flows
- Center conductor wire size doesn’t matter
- Shield resistance increases hum/buzz

Speaker Level (Medium)

- For a power amp:
  - 8 volts = 8 watts @ 8Ω, 16W @ 4Ω
  - 15 volts = 28 watts @ 8Ω, 56W @ 4Ω
- 8-15 volts is pro line level (+20 to +26 dBu)
  - It drives headphones just fine – just don’t turn it up!
Speaker Levels (Low)

• For a typical computer sound card:
  – 1.4 volt = ¼ watt @ 8 ohms, ½ watt @ 4 ohms
  – 1 volt = ¼ watt to 4 ohm speaker
  – 1 – 1.4 volt is consumer line level!
  – It drives headphones just fine too!

Audio Level Matching

• Maximum Level is just before audio clips
• Clipping causes distortion
  – Harmonics, intermodulation
  – Muddy sound
  – Splatter!
• Consumer Line Ins and Outs clip at about 1 volt sine wave
• Mic Inputs may Clip at 100-200 mV
• Good output stages work best near their maximum output
Computer Output Level

• Computer sound cards usually produce less distortion about 6dB below clip
• VERY important for digital modes
  – PSK31
  – AFSK RTTY
  – Distortion produces sidebands (extra copies of your signal)
• Run the computer about 6 dB below clip

Finding Computer Level Controls

• Click the Speaker Symbol in the TaskBar
  – You should see some volume controls
  – Or Accessories, Entertainment, Volume Control
  – Click On Options
• Select Playback to set levels to the radio
  – Use the WAV control for Voice Playback and RTTY tones
  – If you have a mic plugged into the computer, use the Mic control to set its level when fed to the radio by your logging program
• Select Record to set input gain for the RTTY or PSK signal from the radio
Setting Computer Output

• Before connecting to radio, set the computer to transmit PSK31 (or AFSK RTTY) and watch audio on a scope
  – Increase output level until you see clip
  – Turn down output by 6 dB (half the voltage)
• This should optimize the computer
• The same computer settings should work for SSB message playback

Setting Computer Output

• If you don't have a scope, listen to the computer output while it’s sending PSK or RTTY tones, and increase the output level until you hear the sound change (get harsh, raspy). That’s clipping.
• Now back off the level until that harshness goes away and it sounds about half as loud.
• This is the right setting for the computer, both for tones (RTTY, PSK) and SSB.
To Avoid Overloading the Radio

- Use a simple resistive pad (voltage divider) at the input of the radio
  - 2.2K in series, 1K across line input (10 dB)
  - 4.7K in series, 1K across line input (15 dB)
  - 4.7K in series, 470Ω across mic input (20 dB)
- The mic gain should be set about the same as it is for your mic
- Always use the 20dB pad if computer feeds the mic input
- Use the 10dB or 15dB pad on the line input if needed to put the mic gain in the right place

K6DGW Simple RTTY Interface

- Set rig for SSB, VOX operation
- No PTT required
- Follow Hum/Buzz steps 1 & 2
- MMTTY needs serial cable for rig control
K6DGW Simple SSB Interface

- This works for SSB too!
- Plug your mic into the computer
  - Most logging programs will mute it when playing messages

The Unbalanced Interface
Preventing Hum and Buzz
The Problem with Unbalanced Interfaces

Noise current flows on the shield, and the IR drop is added to the signal.

Any voltage between the two chassis is added to the signal.

- Input stage is high impedance, so very little signal current through $R$ and $R_S$
  - Resistance of center conductor doesn't matter
- Noise current flows on the shield
  - Resistance of the shield is very important
  - Hi-fi cables have lousy shields

10 - 100 mV typical
Typical Noise Spectrum on “Ground”

-34.3 dBu (16 mV)

Measured between two outlets on opposite walls of my ham shack and office, into a high impedance

The Harmonic Problem

Recognize this power supply?

Something like it is in every piece of electronic gear – audio, video, computers, printers, copiers (even switching power supplies)
The Harmonic Problem

Recognize this power supply?

Current flows in short pulses that recharge the filter caps on each half cycle
Current is not even close to a sine wave

The Harmonic Problem

• Nearly all electronic loads have power supplies with capacitor-input filters so:
  • Load current is drawn in short pulses at peaks of the input sine wave thus:
    • **Phase, neutral, and leakage currents are highly distorted**
Problems With Pulse Currents

- Because current flows in short pulses, the IR drop at the peak of the current waveform can be much greater than for a sine wave
  - Greater $I^2R$ losses
  - Voltage waveform is distorted
  - Lower voltage delivered to equipment
  - Increased dissipation in phase and neutral conductors
  - Increased dissipation in transformers

Load Currents in a 3-Phase System
But I Don’t Have 3-Phase at Home!

- No, but that factory or business down the street does, so you may get your 120V-0-120V service from the “high leg” of a 240V Delta in your alley!
- Some of their neutral current may flow through your neutral to ground!

“High Leg” Delta

- Common in mixed industrial/residential areas where both single phase and 3-phase power are needed
  - A-N-C feeds residences (120-0-120)
  - A-B-C feeds industrial users (240-240-240)
  - Part of Neutral current from 3-phase system goes to ground through residential ground connection!
Sources of Noise on “Ground”

• Capacitance from AC “hot” to ground
  – Leakage capacitance in transformers
  – AC line filters

• Magnetic induction
  – Leakage fields from power transformers
  – Wiring errors in buildings and homes
    • Double bonded neutrals
  – Leakage fields from motors and controllers
    • Variable speed drives

• 3-Phase noise current from neighborhood

Power System Ground Wiring
(The “Green Wire”)

These leakage currents are not sine waves, they are pulses recharging power supply filter capacitors!
These leakage currents are not sine waves, they are pulses recharging power supply filter capacitors!

Noise currents are complex and different in each product, so how they add is unpredictable.
Home Power Ground Wiring
(The “Green Wire”)

BOND FOR SAFETY
10 ohms to earth

Noise on neutral

AND BONDING REDUCES THE NOISE CURRENT IN YOUR SHACK
Hum/Buzz Step #1

- Get all the power for your ham station from outlets connected to the same “green wire”
  - A 15A circuit can run three 100W radios (transmitting simultaneously) and two computers
  - If you need more outlets, bolt multiple quad boxes together
  - If installing new wiring, always run #12 for 20A circuits
- Put 240V outlet in a backbox bolted to the 120V box(es)
A Quad Box in My Shack

Use Gangable Boxes for More Outlets

A Generator Filter for Field Day
### Home Power Ground Wiring (The "Green Wire")

#### Breaker Panel

<table>
<thead>
<tr>
<th>Distance (Ft)</th>
<th>Cable Size</th>
<th>Resistance (Ω)</th>
<th>Voltage Drop (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>#18</td>
<td>32</td>
<td>0.32</td>
</tr>
<tr>
<td>75</td>
<td>#12</td>
<td>32 mΩ</td>
<td>1.5</td>
</tr>
<tr>
<td>150 mΩ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100mA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Noise on neutral: 10 ohms to earth

- 1.5 mV
- 240V
- 5 Ft #14
- 12 mΩ
- 100mA = 1.2 mV

#### Step #1

- This reduces the voltage between outlets to a few millivolts or less
- What’s left are the IR drops on line cords within your station
- Step #1 is typically good for 20 dB
Hum/Buzz Step #1 for Multi-Multi

- Get all the power for as many stations as possible from outlets connected to the same “green wire”
- Bolt more boxes together as needed
- When outlets can’t be bolted, bond them together with steel conduit or heavy braid

Hum/buzz step #1 reduces this voltage, but often not enough
So we need step #2
• Short out the remaining noise (reduce the IR drop) by adding a BIG conductor between the two chassis
• 50µV would yield 76 dB S/R ratio

• Bond all interconnected equipment together with short, heavy copper braid
  – Radio to power supply
  – Radio to computer
  – Radio(s) to SO2R box
  – Radio to other band decoder, etc.
Equipment Bonding – A Basic QRO Station

- Rig
- Computer
- Amp
- Amp Pwr Supply

Most Critical

Equipment Bonding – SO2R Station

- Rig #1
- SO2R Box
- Rig #2
- Band Decode
- Band Decode
- Computer
Equipment Bonding – SO2R Station

Guidelines For Bonding

• Add bonding in parallel with every unbalanced audio and data path
• Bonding should be #10 copper or larger
  – Strip braid from transmitting RG8, RG11
  – Or buy braid if you see it cheap enough
  – #10 THHN stranded is fine, but stiffer
• Bond to chassis of rigs and computers
  – Retaining screw of D-connector on laptops
• Keep bonding conductors short
Guidelines For Bonding

- Noise is proportional to resistance of the bonding path
- Make conductor BIG
  - Double the size = 6dB less buzz
  - Two conductors in parallel = 6dB less buzz
  - Four conductors in parallel = 12 dB less
- Make bonding conductor SHORT
  - Half the length = 6dB less buzz

SO2R Box Bonding

- Bond transmitters together
- Bond computer(s) to transmitters
- Bond SO2R box to computer(s) or transmitters
  - This can be difficult – many SO2R boxes are built with pin 1 problems
  - Bonding all equipment connected to the SO2R box will usually kill the buzz
Multi-Transmitter Bonding

• Bond all transmitters together
• Bond all power outlet green wires together
• Use bigger copper for longer runs
  – Multiple RG8/RG11 braids in parallel

When There’s No Metal to Bond To

• Power that unit from a good DC power supply and bond the chassis of the supply
• Bond to a D-connector retaining screw
Or
• Use a double-insulated power supply (legal 2-wire power cord) for the SO2R box and bond only the rig, amp, and computer(s)
**Hum/Buzz Steps #1 & #2**

- Should eliminate most hum and buzz
- No need to replace crummy cables
- AND it puts a band-aid on power-related pin 1 problems!
  - No shield current, no pin 1 problem (at audio)
- RF pin 1 problems still possible
- Still have hum/buzz?
- Suspect Magnetic Fields
- Move on to Step #3

---

**How Well Does This Work?**
Noise Reduction From Simple Bonding

And It’s Right for Lightning Safety and RFI
Still Have Hum/Buzz?

- Suspect Magnetic Fields
- Move on to Step #3

Hum/Buzz Step #3

- Fix magnetic field problems
  - Big transformers in power supplies can couple hum into audio transformers
  - Move power xfmr away from audio xfmr
  - Rotate the power supply to put the field at 90° to the audio transformer’s field
  - Rotate the audio transformer
  - Get rid of the audio transformer (you don’t need it!)
  - Shield the audio transformer
The Problem with **Cheap** Audio Transformers

An unshielded audio transformer can cause a hum problem!

**Audio Transformers**

- An expensive fix for “ground loops”
- **Sitting duck for magnetic fields**
  - Must be well shielded!
  - Shielding is expensive (typically $50-$70)
- If you’ve done Hum/Buzz steps #1 and #2
  - You don’t need a transformer!
  - You don’t need an optoisolator!
- An **unshielded** audio transformer can cause more problems than it solves!
Audio Transformers

• You do need a transformer to bring audio in from another building
  – Remote operation, etc.
  – Need **mu-metal shield** to reject magnetic fields
  – Need **dual Faraday shields** to reject RFI

• Lundahl
  – http://lundahl.se

• Jensen
  – http://jensen-transformers.com

A Double-Bonded Neutral Creates An Interfering Magnetic Field
Field with Single-Bonded Neutral (Right)

- Field mostly confined to the very small area between conductors – that is, between the wires

Field With Double-Bonded Neutral (Wrong)

- Field may engulf large areas of a building!
Hum/Buzz Step #3

• Fix magnetic field problems
  – Double-bonded neutral
    • Neutral must be bonded to ground ONLY at the breaker panel, NEVER anywhere else
    • Use AC voltmeter to look for zero volts between neutral and ground (that’s bad – it indicates an extra bond)
    • “Normal” is 20mV – 2 volts
    • This will be buzz, not hum

Load Connected Hot to Ground (Also Wrong)

• Field is much stronger and spreads out over much more area!
• Field may engulf large areas of a building!
• Puts hum voltage on green wire (chassis)
• Fans in some older power amps
120V Fan in Power Amp - **Wrong**

**120V Fan in Power Amp - Right**
Load Connected Hot to Ground
In Alpha 77, 500 mA

Field is much stronger and spreads out over much more area!

• Field may engulf large areas of a building!
• Puts hum voltage on green wire (chassis)

Hum/Buzz Step #3

• Finding big ground currents
  – Use AC voltmeter to measure voltage drop on green wire between outlet and the chassis
  – Use Ohm’s law and the wire resistance to find the current (measure the length – 5-6 ft is typical)
    • 5 ft of #18 = 0.032 Ω (most IEC line cords)
    • 5 ft of #16 = 0.020 Ω (a few heavier IEC line cords)
    • 5 ft of #14 = 0.0126 Ω (maybe on your power amp)
  – 6 mA is maximum leakage permitted by NEC; more is illegal, and should trip a GFCI
Hum/Buzz Step #3

- Fix magnetic field problems
  - Hot to ground loads
    - NEVER do this – causes current to flow on ground
  - Current on green wire to station ground
    - Station ground better than power system ground?
    - Power system ground not bonded to station ground?
    - Power system not properly grounded?

Now Let's Talk About Mics
Mic Levels and Impedances

• Audio circuits operate on voltage
• Unbalanced line level is 1 volt sine wave on peaks
• Audio is quite dynamic. A low impedance mic may produce less than 1 mV with soft sounds, but 2 volts with very loud music
• Low impedance mic outputs are 150-250Ω
• Low impedance mic input stages are typically 1,000 – 4,000Ω
• Most ham mics are low impedance mics

Dynamic and Electret Mics

• Mics convert sound vibrations to voltage
• Electret mics have a pre-polarized capacitive diaphragm connected to a FET “follower” impedance converter. The FET needs a small DC voltage (bias) to operate.
• Dynamic mics have a diaphragm attached to a coil that vibrates in a magnetic field.
  – These mics do not need bias, but they can tolerate bias from a high resistance source (5K)
• Many modern ham mics are electrets, but dynamic mics work fine with ham gear too
Laptop Mic Input (Type 1)

- DC voltage not critical (5-12VDC)
- Resistor value not critical (4.7K-6.8K)
  - Use lower resistor value for low voltage, higher for high voltage
  - Can fit inside ham mic connector
  - Built into K3, turn it on and off from setup menu

Biasing an Electret Mic

- DC voltage not critical (5-12VDC)
- Resistor value not critical (4.7K-6.8K)
  - Use lower resistor value for low voltage, higher for high voltage
  - Can fit inside ham mic connector
  - Built into K3, turn it on and off from setup menu
Laptop Mic Input (Type 2)

- Less common configuration
- Tip is audio input
- Ring provides DC to FET in electret mic

Ham Mic to Laptop

- Many ham mics are electrets
  - Need power for the FET
- If a 1/8-inch connector
  - Wire mic audio to Tip (audio input)
  - Wire mic “power” to tip thru 5.6KΩ
  - Wire mic audio ground to Shell
  - Wire mic shield to Shell
- In laptop, turn on mic pre-amp
  - Called “mic boost” in my Thinkpad
  - Not all sound cards have a mic pre-amp!
  - If no preamp, it may not be loud enough
Yamaha CM500

- About $45
- Great response for contesting
- Electret mic
- Plugs into rear panel of K3 (turn on bias)
- 1/8-in plug, so needs cable adapter for other rigs, get bias from mic connector
- Plugs straight in to most laptops
- Headphones are very comfortable, good isolation, and sound very good

CM500 Mic to Icom, Kenwood, Yaesu

- Much nicer than Heil headsets
  - Mic sounds much better
  - Headphones more comfortable
  - Much less expensive!
- Build cable adapter
  - Tip of 1/8-in connector to mic in
  - Tip of 1/8-in connector thru 5K to +8VDC
  - Shell to mic connector ground
  - No connection to ring
Make Your Own Cables

• Much better than you can buy
• Raw Audio Cable
  – Small coax with braid shield
    • RG58, RG174, etc.
  – Miniature shielded twisted pair
    • Gepco XB401 (braid shield)
    • Belden 1901A (braid shield)
• Connectors
  – Switchcraft and Neutrik are the good brands
• Avoid Radio Shack, Fry’s, and hi-fi shops
  – Cheesy construction, dissimilar metals

Cable-Mount Audio Connectors

<table>
<thead>
<tr>
<th>Description</th>
<th>Switchcraft</th>
<th>Neutrik</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-ckt male 1/8” plug</td>
<td>35HDNN</td>
<td>NYS231BG</td>
</tr>
<tr>
<td>2-ckt male 1/8” plug</td>
<td></td>
<td>NYS226BG</td>
</tr>
<tr>
<td>3-ckt female 1/8” jack</td>
<td></td>
<td>NYS240BG</td>
</tr>
<tr>
<td>Phono (RCA) male plug</td>
<td>3502</td>
<td>NYS352</td>
</tr>
<tr>
<td>Phono female jack</td>
<td>3503</td>
<td></td>
</tr>
</tbody>
</table>
Buying **Good** Audio Connectors

- Stick to Switchcraft, Neutrik
- Full Compass Systems
  - Madison, WI
- Sweetwater
  - Ft Wayne, IN
- Buy in quantity – much of the cost is shipping

**Now Let’s Talk About Rig Control Interfaces**

- Nearly all rigs use RS232
  - All rigs except Icom
  - Each radio needs its own RS232 port
- Icom has their own interface (CI-V)
  - Converts one RS232 port to two wire 1/8” plug
  - One RS232 port can control four radios
  - Icom’s RS232 to CI-V is expensive
  - You can build one for about $15
RS232 Control Functions

- **Radio control**
  - Read frequency, mode for logging
  - Remote control – change frequency, radio settings, filters, etc.
  - Elecraft, Kenwood, Yaesu have a serial port
  - Icom is proprietary, needs special adapter

- **CW, PTT**
  - Can be on same serial port used for control
  - Can be on a parallel port
  - Require a simple NPN inverter/level shifter
  - RTTY requires 2nd serial port for PTT

Control Wiring

- **Interconnect is unbalanced**
  - We must eliminate the noise voltage on equipment grounds (bonding helps a lot)
  - Only two circuits for radio control
  - TXD and RXD (pin 2, pin 3, return)
  - Twisted pair (CAT5) has best RFI rejection

- **Send CW on COM DTR (pin 4)**
  - Need simple NPN inverter/level shifter

- **Send PTT on COM RTS (pin 7)**
  - Same simple NPN inverter/level shifter

- Can also use parallel port for CW and PTT
Low Cost Kenwood Interface

![Diagram of Low Cost Kenwood Interface](image)

- Can fit inside a DB9 or DIN

Low Cost Icom Interface

- By KG7SG, in July 1992 QST
  - Get circuit board from Far Circuits $5
- 4-transistors, 2 diodes, easy to build
- W1GEE builds them and N3FJP sells them
- Self-powered from RTS line
  - Must modify circuit if you want to use RTS for PTT
  - Get power from a 12V source instead
The K9YC Serial Cable

- Eliminates RFI, minimizes hum and buzz
- Use ordinary CAT5, CAT6 (4 twisted pairs)
- Use one pair for each circuit
  - Pin 2 Brown
  - Pin 3 Orange
  - Pin 4 Green (DTR, used to send CW)
  - Pin 7 Blue (RTS, used for PTT)
  - Connector shell – Brown/White, Orange/White, Green/White, Blue/White
- Don’t use pin 5 – it’s a pin 1 problem!
  - RFI, hum, buzz, noise interferes with RS232

The CW Inverter

- Almost any small signal NPN works
- Can fit inside a DB9 M/F adapter
- Build a “thru” adapter to work with any radio
  - Carry control signals through it (pins 2, 3, common)
  - Break out CW and PTT (4, 7, common)
Diodes Add a Keyer to DTR Keying

- Works with almost any keyer
- Si diode works with most radios, but for a few, lower voltage of Ge diode may be needed

PTT Inverter is the Same
Serial Port Connections

To prevent RFI:
Use CAT5 for computer to radio interface
Use chassis (DB9 shell) as return, not pin 5

Universal Adapter

To prevent RFI:
Use CAT5 for computer to radio interface
Use chassis (DB9 shell) as return, not pin 5
Building a Universal Adapter

Jumper pins 2, 3, and 5
Add transistors, resistors for Key, PTT
Drill hole(s) for Key and PTT cables to exit

Building a Universal Adapter

This costs about $1 at HSC (Halted)
Remove jumper block between connectors
Add transistors, resistors, and jumps for 2, 3, 5
Adapter – Cost of Parts

- Connector to hold adapter $1 - $2
- Transistors $0.20 at HSC
- Diodes $0.05 at HSC
- Resistors $0.01 at HSC
- DB9 Connector for Computer $1 at HSC
- DIN connector for radio $7 for a good one
- Plug for key input
  - RCA phono male $1
  - 1/4-inch stereo plug $2

Computers Without Serial Ports – What are the Options?

- Real RS232 Ports on a PCI Card
- Real RS232 Ports on a PCMCIA or PC Card
- Real RS232 Port on Port Replicator
- USB to RS232 Emulators
- A Used Computer with real RS232 ports
Computer Serial Ports

• Real Serial Ports are best
  – Look for 16550 or 16750 UART
  – PCMCIA (PC Card) Adapter for laptop
    • Quatech
    • Buy at B&B Electronics $150 2-ports
  – Buy a port replicator for your laptop
    • Ebay –$15-$50
    • Look for seller with at least 99.5% positive rating
  – PCI card for desktop or tower computer
    • B&B, Quatech $90 for one port, $115 for two, $165 for four

USB Serial Ports

• Emulate a serial port
  – Compatibility can be a problem
  – Mostly a driver and/or chip problem
  – May work with some programs and not others
  – Takes more processor overhead than a real serial port
  – Cheap

• Cheap USB to single serial port $15 - $30
• Edgeport 4-port USB to serial $270
USB Serial Ports
From a ham email list:
“Issues with USB are mostly in the drivers, but not always.”
“ The Elecraft USB adapter uses a Prolific chip set. It is not always trouble-free.”
“There is no universal answer to USB com port issues. Two people with identical setups, one will have problems, the other not, probably only differing in the order that applications were installed on the hard drive.”

A New (Used) Computer
• Use a modern computer for Windows
  – Windows 2000 Pro, XP Pro
  – Avoid Windows 7, Vista
• Use enough RAM (512MB min, 1 GB better)
• Thinkpads work well for ham radio
  – Decent sound card, with mic preamp
  – T20-series, T30-series have a real serial port
  – T40-series and later have no serial port
• Off-lease IBM desktop $125 - $250
  – Real serial ports, XP Pro
  – Tiger Direct and other sources
LPT1: Keying and PTT

- Same inverters as for serial port keying
- Almost any small signal NPN works
- Can fit inside a DB25 shell or M/F adapter

Junk DIN Connectors

- Virtually all DIN connectors sold to hams are JUNK (but they’re CHEAP – about $1)
  - Contact metal doesn’t take solder
  - Body of connector melts with heat
- Some guilty parties (Hams are cheap)
  - RF Connection
  - HSC
  - Digikey
- The good ones cost $5-$7 each
  - Switchcraft, Tuchel
  - Buy from Allied, Newark, etc.
**Good DIN Connectors**

buy from Newark, Allied, $5 - $7 each

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Configuration</th>
<th>Switchcraft Part Nr</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 pins at 210°</td>
<td>Yaesu FSK</td>
<td>09BL4M, 09GM4M</td>
</tr>
<tr>
<td>5 pins at 180°</td>
<td>Icom, Yaesu</td>
<td>05BL5M, 05GM5M</td>
</tr>
<tr>
<td>5 pins at 240°</td>
<td></td>
<td>12BL5M, 12GM5MX</td>
</tr>
<tr>
<td>6 pins at 240°</td>
<td>Icom, Kenwood, Yaesu</td>
<td>12BL8M, 15GM6MX</td>
</tr>
<tr>
<td>7 pins at 270°</td>
<td>Icom, Yaesu</td>
<td>15GM7MX</td>
</tr>
<tr>
<td>8 pins at 262°</td>
<td>Kenwood</td>
<td>20BL8M, 20GM8M</td>
</tr>
<tr>
<td>8 pins at 270°</td>
<td>Icom, Yaesu</td>
<td>15BL8MX, 15GM8MX</td>
</tr>
</tbody>
</table>

**Stuttering CW??**

- Use a modern computer for Windows
- Use enough RAM (at least 512MB)
- My 8 year old IBM T22 with 512MB runs
  - N1MM or WriteLog
  - DXKeeper
  - DXView (map)
  - Browser with Propagation
  - VE7CC Cluster software
  - Zone Alarm
  - Quattro Pro Spreadsheet
Simple SSB SO2R with N1MM

- Use VOX to key radio

Simple CW SO2R with N1MM

- Buy WinKey as a kit (about $70, two hours)
  - Use your paddle with it, a good stand-alone keyer too
Simple RTTY SO2R with N1MM

See the Appendix for Slides that wouldn’t fit in 45 minutes

- More about mics for ham radio
- How all that buzz ends up on the green wire and our equipment chassis
- How 3-phase buzz from a business down the street ends up on your ground wiring
- More about audio levels and wiring standards
References

- *A Ham’s Guide to RFI, Ferrites, Baluns, and Audio Interfacing* by Jim Brown
  - Chapter 8 – Solving Problems in the Shack
  - Appendix 6 – Audio For Ham Radio

- *Ham Interfacing (this presentation)*
  http://audiosystemsgroup.com/HamInterfacing.pdf

- *Power and Grounding for Audio and Video Systems – A White Paper for the Real World* by Jim Brown

Computer to Rig Interfacing

You Don’t Need to Buy an Interface!

Jim Brown
K9YC
Santa Cruz, CA
http://audiosystemsgroup.com
Appendix

–

Slides and Topics That Don’t Fit in 45 Minutes

Jim Brown
K9YC
Santa Cruz, CA
http://audiosystemsgroup.com

Where Does All That Buzz Come From?
Noise on “Ground” from Power

- Leakage currents to green wire
  - Power transformer stray capacitances
- Intentional currents to green wire
  - Line filter capacitors
- Power wiring faults
- Shunt mode surge suppressors
- Magnetic coupling from mains power
  - Harmonic current in neutral
  - Motors, transformers

Sources of Noise on “Ground”

- Capacitance from AC “hot” to ground
  - Leakage capacitance in transformers
  - AC line filters
- Magnetic induction
  - Leakage fields from power transformers
  - Wiring errors in buildings and homes
    - Double bonded neutrals
  - Leakage fields from motors and controllers
    - Variable speed drives
- 3-Phase noise current from neighborhood
Leakage Current to Green Wire

- Capacitance from phase (“hot”) to equipment ground (green wire)
- \( I = \frac{E}{X_C} = \frac{120}{X_C} \)
- \( X_C = \frac{1}{(2\pi f C)} \)
- Maximum permitted leakage current is 5 mA with 110% of rated line voltage
- \( X_C = \frac{E}{I} = 1.1 \times 120 / .005 = 26.4 \, \text{k}\Omega \)
- \( C = \frac{1}{(2\pi f X_C)} = 0.1 \, \mu\text{F} \) is the largest capacitance that can exist from line to ground within equipment

Leakage Current to Green Wire

- 0.1 \, \mu\text{F} \) is the largest capacitance that is permitted from line to ground within equipment
  - This includes stray capacitance within the power transformer
- We often have many pieces of equipment connected to the same branch circuit
  - All capacitances (and leakage currents) are in parallel, so they add
  - More noise
The Harmonic Problem

• Nearly all electronic loads have power supplies with capacitor-input filters so:

• Load current is drawn in short pulses at peaks of the input sine wave thus:

• **Phase, neutral, and leakage currents are highly distorted**

Recognize this power supply?

Something like it is in **every** piece of electronic gear – audio, video, computers, printers, copiers (even switching power supplies)
The Harmonic Problem

Recognize this power supply?

Current flows in short pulses that recharge the filter caps on each half cycle

Current is not even close to a sine wave

Problems With Pulse Currents

• Because current flows in short pulses, the IR drop at the peak of the current waveform can be much greater than for a sine wave
  – Greater $I^2R$ losses
  – Voltage waveform is distorted
  – Lower voltage delivered to equipment
  – Increased dissipation in phase and neutral conductors
  – Increased dissipation in transformers
Load Currents in a 3-Phase System

Fundamentals and Third Harmonics
What Happens in the Neutral?

- Triplen harmonics ADD!
  - Third, sixth, ninth, etc
- Neutral current can be 1.7X the phase currents, even in a perfectly balanced system!
- Potentially dangerous overheating
  - Phase conductors (and contacts)
  - Transformers
- Use bigger copper in neutrals
- Use *K-rated* transformers

25% 3\textsuperscript{rd} Harmonic on the Phases becomes 75% 3\textsuperscript{rd} Harmonic on Neutral
In Single Phase Systems

• 120V – 0V – 120V
• If leg currents are equal, they cancel in the neutral

In Three Phase Systems

• If leg currents are equal, fundamental and most harmonics cancel in the neutral and in the ground

BUT:
• Triplen harmonics (3rd, 6th, 9th, etc.) ADD in the neutral and in the ground
• This tends to make 180 Hz, 360 Hz, 540 Hz, etc. dominant buzz frequencies
But I Don’t Have 3-Phase at Home!

3-Phase Noise in Santa Cruz Mountains!

Measured between two outlets on opposite walls of my ham shack and office
**Triplen Harmonics and Leakage**

- 3-phase equipment has stray capacitance to ground too
- Triplen harmonics contribute to leakage current, and ADD, just like in the neutral!
  - Third, sixth, ninth, etc
- Adds to noise current on cable shields
- Fundamental (50/60 Hz) and low harmonics (150/180 Hz, 450/540 Hz) are perceived as “hum”
- Higher harmonics are heard as “buzz”

**The Hum/Buzz Problem**

- Ham Interfaces are Unbalanced
  - One Conductor goes to chassis at each end
- There is noise voltage between chassis #1 and chassis #2
- “Ground” isn’t a single point!
  - “Grounds” are connected by resistors (wires)
  - Capacitance from 120V to chassis causes current in those resistors (wires)
  - There are other sources of ground current
  - There’s a voltage drop from that current
For Unbalanced interconnections, shield resistance can be important!

- **Shield current (noise)** creates IR drop that is added to the signal

- \( E_{\text{NOISE}} = 20 \log (I_{\text{SHIELD}} \times R_{\text{SHIELD}}) \)

- Coaxial cables differ widely
  - Heavy copper braid (8241F) \( 2.6 \, \Omega /1000 \, \text{ft} \)
  - Double copper braid (8281) \( 1.1 \, \Omega /1000 \, \text{ft} \)
  - Foil/drain shield #22 gauge \( 16 \, \Omega /1000 \, \text{ft} \)

- Audio dynamic range 100 dB
  - For 1 volt signal, 10 µV noise floor

---

**A Calculated Example**

- 25-foot cable, foil shield and #26 AWG drain with resistance of 1 S
- Leakage current between two pieces of equipment is measured at 100 µA
- From Ohm’s law, noise voltage =100 µV
- Consumer reference level = 316 mV
- Signal to noise ratio = 316 mV ÷ 100 µV = 3160:1 = 70 dB = not very good!
- Belden #8241F cable, shield resistance of 0.065 S, would reduce noise \( \approx 24 \, \text{dB}! \)
Audio Noise Coupling Mechanisms

- IR drop on shields of unbalanced signal wiring
- Pin 1 problems – current on shields
  - Improper shield termination within equipment
- Magnetic field coupling to wiring
  - POWER TRANSFORMERS
  - Audio Transformers

The Problem with Unbalanced Interfaces

Noise current flows on the shield, and the IR drop is added to the signal.

- Mutual coupling rejects RF noise, but doesn’t help at audio frequencies
  \[ R_s \gg X_L \]
Line Filters Contribute Noise to the Green Wire

The Problem with Unbalanced Interfaces

- Noise voltage between the two chassis is added to the signal.
  - So we have 1v signal (on peaks) and 10mV – 100 mV of noise
  - Average value of speech is 10 dB below peak
    So only 10dB - 30 dB S/N ratio!
The Problem with Unbalanced Interfaces

- Reduce the noise voltage between the ends of the cable
- Use a “beefy” cable shield
  - Minimizes the drop

Noise current flows on the shield, and the IR drop is added to the signal.

Why we hear more buzz than hum
- Noise is leakage through capacitance, so it’s a voltage divider between $C_L$ and $R_S$
- The noise is dominated by harmonics
Audio Levels and Impedances

• Audio line outputs have low impedance
  – 100 ohms for pro circuits
  – 300 ohms for consumer gear
  – 0.1 ohms for loudspeaker power amps

• Audio line inputs have high impedance
  – 10K for pro circuits
  – 50K for consumer gear

Audio Level Matching

• Line level circuits are not designed to provide current
  – That is, they want to see a 10K or 50K load
  – If you load them with 600 ohms, distortion increases!

• Mic level circuits are not designed to provide current
  – Loading them with 600 ohms reduces their output and can increase distortion

• Loudspeaker and headphone outputs are designed to supply power (current)
Interface Logic – QSK CW

Note: PTT is not used for QSK CW

QSK logic in power amp prevents hot switching of T/R relay. Amp has fast-switching vacuum T/R relay, follows fast CW Keying pulls in T/R relay, senses relay position, then keys transceiver.

Interface Logic – Non-QSK CW

Hot-switch protection in some power amplifiers may chop the first character.
Interface Logic – SSB

This setup allows direct recording of new voice messages “on the fly” (for example, “CQ contest, listening this frequency and 7065”)

Note: Assumes VOX operation

Interface Logic – RTTY, PSK

No RTTY software I know of works with “control” and PTT sharing a COM port

PTT can be on parallel port or second COM port
Pro Dynamic Mic to Laptop

• No power required
• Pro mics use XLR connector
  – Wire mic audio to Tip (audio input) (XLR pin 2)
  – Wire mic audio return to sleeve (XLR pin 3)
  – Wire shield to sleeve (XLR pin 1)
• In laptop, turn on mic pre-amp
  – Called “mic boost” in my Thinkpad
  – Not all sound cards have a mic pre-amp!
  – If no preamp, it may not be loud enough

Pro Balanced Electret Mic to Laptop

• Balanced *Phantom power* is required
  – Cannot plug directly into computer
  – External phantom power supply and transformer are needed
  – Wire transformer output like a dynamic mic
Pro Pigtail Electret Mic to Laptop

- Unbalanced electret mics with pigtail leads are built for use with wireless mics
  - Can work fine with a laptop
- On 1/8-inch TRS plug
  - Wire audio to Tip
  - Wire power to Ring (resistor may be needed)
  - Wire shield (audio return) to Shell

Pro Dynamic Mic to Ham Gear

- Plenty of good clean audio
- But also a lot of low end we don’t need!
This rolloff is built into ham rigs, thanks to the TX and RX crystal filters.

2 – 6 kHz is critical for speech intelligibility, but the filters reduce it.
The response of the mic is tailored to correct for the TX and RX filter response.

High Quality Professional Mic

Broad, flat response to sound great on music and voices.
The K9YC Mic Equalizer

- Add capacitor in series with audio
  - \( C = \frac{1}{2\pi f R} \)
    - \( f \) is 3,000 Hz
    - \( R = \) (input Z of input stage) + (Z of mic)
    - In this example, \( C = 0.047\mu F \)

Cost: about $0.25
Directional Mics

- Most ham mics are omni-directional – they pick up sound from all directions
- Most performance mics are unidirectional
  - Pick up best from the front, reject room noise
- Most directional mics have proximity effect – bass is boosted for sounds very close to the mic
  - Breath pops
  - Very “bassy” sounding
  - Not good for communications!

Proximity Effect

- Bass boost when you talk very close to it
- Present in almost all directional mics
- K9YC equalizer will reduce it!
- Most pro mics have some low cut built-in
Directional Mics without Proximity Effect

- EV RE20, RE27
- EV RE11, RE16
- AKG D202
- AKG D224

Good Low-Cost Headset Mics
ALL GROUNDS MUST BE BONDED TOGETHER FOR SAFETY

Grounding is for SAFETY
Lightning protection
Blow a breaker if a power system short
Connections should be big copper and short
Home Power Ground Wiring
(The “Green Wire”)

- **10mA = 0.32 mV**
- **10mA = 3.2 mV**
- **10mA = 19.5 mV**
- **10mA = 3.9 mV**
- **20mA = 0.64 mV**

*Noise on neutral 10 ohms to earth*

*Bond grounds together*
Hot Switching in Amplifiers

• It takes a few msec for a T/R relay to pull in
• Keying transmitter before T/R pulls in is called “hot switching”
  – Amplifier transmits briefly without loading, can damage output stage
  – Contacts arc, causing relay failure
• Methods to prevent hot switching
  – Amp locks out input until relay has pulled in or:
  – Key amplifier, amp senses relay operation and keys exciter when relay has pulled in
KA7OEI's blog

Random musings - usually on a technical (nerdy) subject - perhaps related to things found at http://ka7oei.com

Saturday, December 8, 2012

Reducing switching supply racket (RF Interference)

Note:

There is a follow-up to this posting in the August 18, 2014 blog entry - link - where there are details given to contain the switching supply noise even more!

Switching power supplies are ubiquitous these days - and for several good reasons:
- They are more efficient than plain old iron transformer power supply with a linear regulator.
- They can be much smaller and lighter than their transformer/linear counterparts.
- They are cheap by comparison since they use less material overall - particularly iron and copper - in the transformer.

They do have several real drawbacks:
- Most tend to be less reliable than their old heavy iron counterparts. I've observed that the typical switching-type "wall wart" (plug-in power supply) seems to last just 2-4 years whereas the old-fashioned iron types would usually outlast the device to which they were connected.
- They can generate some terrible radio interference!

On the first point, I often wonder if the amount of power they save due to their efficiency is outweighed by the fact that they often fail after just a few years, often causing it and the device it powered to end up in the trash because of the failure of less than $1 worth of components - but that's another topic of discussion!

Shown in figure 1, above, is a typical power supply of the sort used on a laptop computer. As far as switching supplies go, this is one of the better built units, now used to power a small form-factor PC that I have attached to my TV to watch digital/online media - and because of this, it's plugged in pretty much all of the time.

Note: I have since plugged this supply into a "smart" power strip. This strip has a sensing circuit that detects when the TV is turned on and only then are the "switched" outlets powered up, saving energy by powering down those devices that are never used when the power is off.

As it turns out I could hear some (admittedly weak) harmonics of a switching supply on my HF receivers, but I generally ignored them until I happened to tune across the AM band on my newly repaired Sarns receiver (see the previous blog entry) and heard some very strong hum/RF carriers every 30-50 kHz across the broadcast band that blanked out most of the local stations. Unplugging nearby mains powered devices soon revealed that the source was (mostly) the power supply pictured above, located only a few feet away from the receiver.

Taking this as a challenge - and an excuse to take some pictures and do a write-up for this blog - I set about to make this power supply much less obvious, RF-wise, so I put the power supply on the bench and popped it apart.

Figure 1:
Typical laptop-type switching power supply. This very unit that was modified. Click on the image for a larger version

Figure 2:
Typical "Common Mode" AC line filter. The capacitors form RF to be "common mode" so that the bifilar inductor (in the middle) can best do its work.
The usual warnings about high voltages:

- This power supply - and others like it - operate from potentially lethal line voltages.
- DO NOT attempt to open or modify a power supply unless you are thoroughly familiar with the proper techniques and safety precautions when working with these voltages.
- If done improperly, modifications to the power supply may make it unsafe to use and become a fire and/or shock hazard, so do not do this sort of work unless you know exactly what you are doing!

The main RFI suppressing components of the power supply may be seen in figure 4 with the AC input on the left - namely the black device with the green and yellow wire wound on it (a bifilar-wound inductor) and a capacitor - the black rectangular box (marked with "104") below it.

A switching power supply is really a powerful oscillator with the voltage being transferred to the load with a small transformer - the size reduction compared to the old-style "wall-warts" being permitted because the power supply operates at a frequency much higher than that of the line voltage's 60 (or 50) Hz, and at several 10s of kHz, usually in the 60-60 kHz range for most of these types of power supplies. This higher frequency of operation is also the reason why switching power supplies often cause interference issues to radio receivers. It is the harmonics from this high-power oscillator that are more likely to be conducted to the outside world via the AC power connector and/or the DC output.

In figure 3 is a diagram of a typical "common mode" AC line filter. Looking similar to a transformer is the bifilar choke that is doing most of the work of filtering the high frequency components of the switching supply plus it also can do a pretty good job of actually isolating the power line at these higher frequencies so that not only are those spectral components generated inside the power line contained therein, but also that the supply itself won't supply a path to conduct RF energy from whatever it is that is being powered by the supply (a computer, set-top box, modem, etc.) into the power line itself.

The way that this works is that any RF energy on one side of the choke will get coupled to the other side of the choke equally. Since this bifilar choke is a choke, its inductance will form a series impedance to block higher frequencies from passing through, the effectiveness being related to the inductance of the winding itself.

Key to this working property is that any RF energy on one side of the bifilar choke must be exactly equal to the other side or else the imbalance can actually cause more interference as unequal RF energy from one side would be induced on the other side. To form the RF energy to be equal is the job of the two capacitors shown - one on the input, and the other on the output.

This particular power supply had only a capacitor on the load side of the power supply - where the noise was being generated. While this will do most of the work, it does help to have a capacitor on both sides, but this is often not done as a cost-saving measure.

Since the yellow-green wired inductor didn't seem to be adequate, I removed it from the power supply and measured it (see figure 5). Noting that the inductance is a mere 268 uH, I thought that I could do better with some other line-filtering inductors that I happened to have in my junk box - this one measuring about 4.594 millihenries (4594 uH) which is about 17 times as much inductance which also means that it will, ideally, offer 17 times as much impedance to RF energy that might escape from the power supply via the AC power line.

Since the original choke was 268 uH, let's find out how much equivalent series resistance that amount of inductance offers at, say, 1 MHz - in the middle of the AM broadcast band. The formula for inductive reactance is:

\[ Z = 2 \pi f L \]

Where:
- \( f \) = Frequency in Hz
- \( L \) = Inductance in Henries
- \( Z \) = Inductive reactance in Ohms

So, plugging 268 uH at 1 MHz into the above we get 1683 ohms - not too bad, actually. By replacing this choke
KA7OEI’s blog: Reducing switching supply racket (RF Interference) http://ka7oei.blogspot.fr/2012/12/reducing-switching-supply-racket-rf.html

with the 4.594 mH toroid version our impedance scales up proportionally to 28.85k ohms at 1 MHz! In addition to the bilateral action of the choke, this significant amount of inductive reactance will go a long way toward both keeping the RF energy from the switching supply off the power line, but it will also keep the power supply itself from acting as a pathway to couple potential interference from the devices connected to it to/from the power line.

Comment:

It is common to attempt the use of ferrite beads to suppress RF interference of this sort, but it’s very unlikely that it will help much - particularly at lower frequencies (e.g. lower HF bands such as 160 and 80 meters, not to mention the AM broadcast band) because these devices simply cannot add enough inductance to add a significant amount of impedance. At these frequencies (say, below 10 MHz) it takes multiple turns on a chunk of ferrite to add enough reactance to make even a small dent in the amount of conducted interference!

Cramming this much larger component into the same space as the original bilateral choke was a bit of a challenge, but laying it on its side and using "flying leads" to connect the inductor to the circuit board made it possible to fit it inside the case.

For good measure I also added another capacitor (a 0.047 uF device) to the "other" side of the inductor (the side opposite the black capacitor mentioned above) to better-equalize any RF currents that might occur across it (the small green capacitor in figure 7). Just to be safe, I also put some polyimide (a.k.a. Kapton™) tape on the aluminum heat sink (visible in figure 9) to make sure that the windings of the coil could not touch (and electrify) the heat sink itself or other nearby components.

Having installed this new bilateral inductor I still had the original bilateral device (the one with the green and yellow wire) on hand so I decided to put it on the DC output to further contain any RF energy emitted by the power supply - and why not, since it was "free"! Using its color coded windings, I connected it as shown in figures 7 and 8 with heat shrink tubing to insulate the soldered connections on the power supply's DC output cord.

Putting everything back in the case I carefully re-checked the clearances and insulation to make certain that not only would everything fit, but also that nothing could short out - especially when everything was smashed together when the cover was put back on. While I could have glued the two halves of the cover back together, I decided to use some of the same polyimide tape mentioned above as it has a very strong adhesive and I would be able to easily take the power supply apart should there have been a problem. After reassembly, I then re-checked the DC polarity of the output connector to make sure that I didn’t accidentally reverse it when connecting the output choke.

The result?

While I can still "hear" the harmonics radiated from this power supply on the AM radio that’s just a few feet away, they were now weaker that most AM stations instead of being "extremely loud" and obscuring much of the AM dial - this fact indicating a reasonable amount of success. While the intent was not to attempt to completely "clean up" the power supply's spurious radiation, the radical difference indicated that all spurious radiation from this particular power supply was likely to be very much reduced. Elsewhere in the spectrum, I can no longer hear even a hint of this power supply on any HF band!

Since these types of power supplies are seemingly everywhere, it should come as no surprise that there are several of these in my ham shack and I’ve applied the above techniques to those other power supplies that were found to cause interference on the HF frequencies. Depending on the power supply and the amount of extra room inside the case, one may (or may not) be able to add as many additional inductors and capacitors as was needed to quash the RFI emitted by the power supply, so in several instances I’ve added filtering outside the case, typically inserting capacitors and a bilateral inductor on the DC lead (but close to the power supply) where it would be safe to do so.

I would put such filtering (e.g. inductors) on both the AC and DC leads, but it’s worth remembering that these power supplies pollute the RF environment largely by conducting the harmonics of the switching frequencies through the input and output leads. If one blocks the RF energy from being conducted on just one lead or the other (e.g. the AC input or the DC output) the circulating currents carrying this energy through the power supply (e.g. in on the AC side and out on the DC side) are significantly reduced and adding such blocking can considerably reduce emitted RFI. Also worth mentioning is the fact that many switching-type DC supplies -
particularly "wall wart" types - have **minimal or no** common-mode filtering (e.g. using a bifilar choke or two separate series chokes) on their DC output, probably because it's a bit more expensive to do it this way.

I've noticed upon opening the case that some switching power supplies - perhaps of dubious origin and quality - are completely missing the RFI filtering components. In these same power supplies it is often apparent that there is a position on the circuit board for these components, but they are either empty (in the case of missing capacitors) or jammed over (in the case of missing inductors) - clearly a cost-saving measure and probably illegal in some countries. For these power supplies the addition of any RFI suppressing components will likely have a significant effect on reducing interferences that they may generate! I've also observed that many of these same supplies of unknown pedigree often use the cheapest possible components and it may well be that they will not prove to have a long lifespan!

Where does one get these bifilar inductors? Most computer-type power supplies have these on their inputs and they may be found in most reasonably-quality switching supplies. Remember how I mentioned that these switching supplies often die after just a couple of years? These dead supplies may be a ready source of components to better RFI-proof the supply that may be causing interference to you!

**Figure 7:**
The original bifilar inductor, now connected on the DC output to provide additional filtering. Heat-shrink tubing was used to insulate the output DC connections. Click on the image for a larger version.

**Figure 8:**
The modified power supply with the reconfigured filtering and placed in the bottom half of the original case. Click on the image for a larger version.

**Figure 9:**
Examples of RFI filtering components found in junked switching power supplies. On the left is a PC (computer) power supply while on the right is a power supply from a VCR. Click on the image for a larger version.

These two inductors - while somewhat different in style - are split in two with one side of the AC power line on one side, and the other side of the AC power line on the other. Being wound on a common core, their windings are very tightly AC-coupled (at radio frequencies, at least) which is how they function to prevent conduction of this energy onto the AC power line. Before removing them from the board, verify with an ohmmeter from the original AC power connection that the inductors you spot are, in fact, in series with the power line - with one half on one side, and the other half on the other side!

You'll also notice that these two power supplies have something in common: They are capacitors very near the bifilar inductor. In the case of the PC power supply (on the left) there is a large, yellow rectangular capacitor on the AC input of the power supply and on the opposite side, there are two blue disk-ceramic capacitors (one of them covered with heat-shrink tubing). In the case of the VCR power supply (on the right) you'll see even more filtering: There are several blue capacitors sprinkled throughout, but also the orange-red capacitors next to the bifilar inductor itself.

It is quite typical for there to be blue capacitors on the inputs of power supplies for filtering - these being "safety components" that are specifically designed for both filtering, and for reliability so that their failure won't inadvertently cause the case of the device to be connected to the dangerous AC line voltage! The other capacitors - the big yellow one on the PC supply and the two orange-red ones on the VCR supply - actually do much of the filtering. The one thing that all of these capacitors (blue, yellow and orange-red) have in common is that they are specifically rated to withstand the AC line voltage! Careful inspection of these components will reveal not only their capacitance value, but also their voltage rating.

If one is reasonably careful, discarded switching power supplies can offer a ready source of components - both inductors and capacitors - to help reduce their conduction of switching energy and the interference that it may cause.
In severe cases I have found it necessary to enclose the entire switching supply in a larger box such as that of a discarded PC supply, using RFI filtering on the AC line as well as the DC output. This was finally covered in the August 18, 2014 blog entry - link.

On a related topic, see also the September 4, 2013 entry, "Quieting High-Current switching supplies used in the ham shack - link"

Posted by KA7OEI at 12:31 AM

5 comments:

Fi Pohl  
August 13, 2013 at 6:22 PM
Excellent article!
Thank you.
73
VE3ZFP
Reply

Fi Pohl  
August 13, 2013 at 6:26 PM
By the way
I'm building a 6 amp power supply for my QRP rig. I want to put it in a metal box for further improvement. Should I ground the box to the primary, the secondary or leave it floating?

Thanks
Reply

Replies

KA7OEI  
August 14, 2013 at 3:17 PM
If you have a case "ground" available, the filter design changes slightly - take a look at this article:


At the end there is a "Brute Force Line Filter" that looks much like the filter in the blog post, above with the addition of the case ground between a pair of capacitors. These capacitors do double-duty:

- The two in series act as one capacitor to force the RFI to common mode so that it can be quashed by the bifilar line choke.

- Any RFI on the lines is shunted to "ground" - in this case, the case!

The hazard with this approach is in the two capacitors with the ground in the middle. These "MUST" be rated for the AC line voltage, so if you don't see printed on them a voltage rating that indicates that it would be OK to connect them to AC mains voltage (e.g., at least 1000 volts DC, or an AC voltage rating safely above the mains voltage) then "DON'T" use it. If one of these capacitors were to fail, it's possible that the full line voltage could appear on the case ground - a very bad thing, indeed!

(Note: Most RFI filtering "safety" capacitors are a light blue color and are typically found in the AC input filtering sections of scrapped PC power supplies and the like. These will usually have printed on them their AC voltage ratings.)

New and surplus, ready-built power line RFI filter modules are also available and many of these have built-in IEC (computer-type) power cord receptacles on the outside and solder lug terminals on the inside. These work very well and provide everything you need for the AC input filter in one handy package.

---

Another escape route for the RFI is on the DC side and it is best if both the positive and negative lead have series inductors to block RFI and a minimum recommended value for these choke's at RF frequencies is 10uH - although the higher, the better generally speaking. Finding a choke rated for the maximum current and with a low enough DC resistance to offer an acceptable voltage drop under full load is a bit trickier, but these chokes can often be found in scrapped PC power supplies, too.

In addition to a capacitor across the + and - of both the power supply and output side of these series chokes (say, a 0.1uF) on the output side a 0.01uF capacitor should be connected between each DC output lead and ground.

Inside the box it is recommended that the bypass capacitors be connected to the case ground with as short as leads as practical rather than have a long "case ground" lead inside the box to connect it. Also, it is best if the ground of these capacitors on the input (AC) side and the output (DC) side be connected near-ish where their respective wires exit the box.

Best of luck!
GregTheHam: July 16, 2014 at 4:10 AM

Finally, a nice display of the RFI problem and repair, TNX!

Can you do more info/blog on keeping RFI from getting into the AC lines and making an "outboard" brute force filter for the SMPS input? I find that is where most re-radiated hash comes from. Also, how to best handle wall-warts with no ground pin on the AC plug and the use of plastic boxes and radiation from them would be helpful.

Thanks.

PS: My and other friends' story:
SMPS hash as been the last straw and taken me off the air (I can't work them if you can't hear them) and made AM BC listening impossible in our rural home. Same at my girlfriend's place.

When cable TV providers supply their equipment with noisy "wall warts" to power their digital boxes, (and new ones as well) there is no way I can fix a whole neighborhood full of them. The next door neighbor is LOUD and cumulative effect from the whole neighborhood kills the full RF spectrum.

Plus there are so many noisy SMPS in my home, I have to kill the breaker box "mains" and run off battery to use a usable receiver noise floor. To fix all the SMPS's seems a daunting task. But your info has inspired me to tackle the worst offenders. (Replacing them all w/ old style or one large regulated supply is an option but does not solve the neighborhood RFI smog problem)

Sad thing is: the AM BCers don't seem to be doing much with complaints to regulating agencies. A very old established Toronto AM station's solution was to apply for an FM assignment, getting higher AM new "device-noise" levels as the reason. I feel especially sorry for Shortwave listeners who have no protection in the regulations, like a licensed Ham.

Your finding of missing parts when they were used for certification or importing approval is maddening and, again, lack of fines or changes just make the whole priceless RFI spectrum resource destined to be lost and wasted.

Thanks for your info.
G

Reply

KATOEI: July 16, 2014 at 5:33 PM

Hello G,

The noise radiated by switching power supplies does not really get radiated by the power supply itself, but from three main places:

- Differentially on the AC input
- Differentially on the DC output
- Differentially between the DC output and the AC input

The first two can be significantly reduced by the addition of decent filtering (capacitors, inductors) as described in the article above, but the last one is more difficult to address.

To be sure, it can be significantly reduced with the use of a good-quality common-mode choke/capacitor filter that will increase the resistance at high frequencies and reduce the amount of energy that can be conducted onto the AC and/or DC lines and thus onto the "air" and cause QRM. The higher the inductance and the better the filtering, less energy is likely to be conducted and cause a problem, but practically speaking, if the power supply is not contained in a metal case to provide a common reference for both the AC input and DC output to which circulating RF currents can be shunted, one can go only so far in reducing the problem.

To fully address that last point, eliminate the differential RF currents between the AC input and the DC output of the power supply must be put in a metal enclosure, and for smaller supplies, discarded PC power supply cases work nicely for this as they are well-ventilated and they already have an AC attachment for a power cord. What is needed to go inside these are:

- Appropriate AC line filtering to keep the RF energy from getting back out onto the mains.
- Filtering on the DC output, referenced to the metal case at RF, to contain the RF of the power supply within the case.
- All of this would have to be done with safety in mind, considering wiring and/or electrical safety regulations!

It is often possible to put several small switching "wall warts" within one of these cases and completely eliminate (as is made undetectable) the "crud" that they produce - although it is sometimes the case that the devices that they power (e.g., a DSC modems) produce a bit of crud on their own!

As noted on the article above, it is hoped that this will be the topic for a future blog entry - if when I get time, of course!

73
PLEASE NOTE:

While I DO appreciate comments, those comments that are just vehicles to other web sites without substantial content in their own right WILL NOT be posted.

If you include a link in your comment that simply points to advertisements or a commercial web page, it WILL be rejected as SPAM!
KA7OEI's blog: Completely containing switching power supply RFI

Random musings - usually on a technical (nerdy) subject - perhaps related to things found at http://ka7oei.com

Monday, August 18, 2014

**Completely containing switching power supply RFI**

In the old days, radio amateurs were concerned with (or should have been) energy from their transmissions getting into devices unintentionally, the classic being televisions, phonographs, telephones, hi-fi sets, and the like.

A few years ago hams' hackles were raised with the prospect of BPL - Broadband over Power Line - a system by which the already-extant infrastructure used to convey electrical power would be used to transport data all about the land. While it *did* work (sort of) it had the potential to cause a great deal of interference to amateur radio operators.

A lot was written and to their credit, some designers/operators even designed their systems to avoid putting energy within the HF amateur bands - to varying degrees of success. While this wouldn't have really helped the causal shortwave listener, it did still not address the fundamental problem that the power lines were simply not suitable, low-loss, low radiation transmission media for radio frequency energy.

What we *really* should have worried about was not BPL...

As it turned out, when it comes to worrying about devices that had the potential to clobber our HF bands, we really should not have worried too much about BPL - which, as hindsight has proven, wouldn't have gotten anywhere, anyway, but rather devices that are right under our noses. Switching power supplies - particularly the cheap, lightweight ones that are now supplied with everything that we buy and even put in our own shack!

These inexpensive "wall warts" used to consist of a small, iron and copper transformer - often with a rectifier and capacitor. These devices would plug into the wall and operate, typically for 5-10 years until whatever it is that they were powering wore out.

Unfortunately for them, they would consume 1-5 watts all of the time just sitting there doing nothing, even when the device was "off" - the so-called "phantom loads" or "power vampires" and many localities/countries have legislated them out of existence in favor of the newer, much more efficient switching-type devices.

All would be good except for two things:

The first of these is that many of these cheap switching-type wall warts last only 12-24 months before dying - usually a victim of an inferior quality capacitor and/or poor design. What this means is that more often than not, the device to which they were attached is often thrown out as well. While this new-style switching-style wall-wart may take less power to operate, it is my guess that considering that its premature failure caused a premature product replacement, it never actually saved any energy - since it probably took a lot of energy to make the device in the first place - or saved the consumer any money!

Stepping back off the soapbox, these switching supplies - even if well-built and long-lasting (if you are lucky enough to encounter one) bring us to the second of the two problems concerning us about these devices: The generation of RFI, or Radio Frequency Interference.

Such was the case with one of these devices that I use on my TV to run a small multimedia computer. This
computer, obtained surplus, did not come with its original supply so I found an OEM Dell laptop supply of reasonable quality and suitable ratings - about 19 volts and 3 amps. There was one problem: It seemed to radiate a low-level RFI signal that got everywhere on HF.

Now part of this was how it was connected - See Figure 2, above:

- The power supply was connected to the AC power line.
- The power supply was also connected to the TV through the video/audio cables.
- The TV was connected to the high-power stereo system which, in turn, was connected to speakers in different parts of the room.
- The TV was also connected to a coaxial cable that went to the rooftop antenna.

What this meant was that this power supply was, itself, indirectly connected to both ground - via the power line - and several forms of antennas, via the TV, TV antenna, and speakers.

Whatever low-level RFI was being produced by this power supply had exactly what it needed to be conducted out into the world and cause problems: A complete path in and out of the power supply!

What is sounded like:

Typically, switching power supplies sound like a "buzz" every 30-60 kHz - the power supply's switching frequency - up and down the bands, usually worse on lower bands, but not always. This buzz is usually modulated at twice the power line frequency (120 Hz in the U.S., 100 Hz in most locations in Europe, Asia and Africa) but this modulation is usually very "dirty" and full of harmonics: If the radio is switched to "AM" mode the "buzzzy" nature of the modulation becomes much more apparent!

It is often the case that the 30-60 kHz intervals at which the interference is "bunched" together are more apparent at lower frequencies such as the AM broadcast band and 160 through 80 meters (1.8-4 MHz) - that is, one can more clearly hear the distinct switching supply "carriers". As one moves up in frequency the interference may sound like it is decreasing, but this may not actually be the case as these "bursts" of energy often get spread out, changing from a fairly sharp "buzz" as you tune across the switching harmonic to more of a "hiss" and in severe cases - and on higher bands - these "bands of hiss" may actually run together. In the latter case, it may not, at first glance, sound like a switching supply at all, but rather just an elevated noise floor! In this case it may not be until one switches to AM and notices that this "hiss" has a powerline frequency AM component to it and/or that it disappears when the power is removed from the supply that it is, in fact, from a switching supply.

The latter was the case of the power supply depicted in Figure 1: On 160 meters it could be heard every 60 kHz or so as a "dirty" buzz, but on 40 meters it was an indistinct rise in the noise floor of about 2 S-Units that was about 10 kHz wide while on 20 meters it just seemed to raise the noise floor by 1-2 S-Units everywhere that, to the uninhibited, didn't even resemble noise from a switching power supply!

It should be pointed out that I'd already modified this power supply to reduce its conduction onto the AC and DC power leads and that had solved one problem - bothering a receiver that was located next to it - but the lower-level, HF frequency energy that was induced across the power supply between its AC input and DC output was much more difficult to manage as that was not a matter of either shielding or direct power line conduction.

Since I'd already gone out of my way to add bifilar chokes to both the AC and DC leads of this power supply, I'd likely reduced its potential to emit energy by a significant amount, but here, we are talking about residual amounts that are being coupled into what amounts to antennas that are connected to my TV system and being picked up by a sensitive HF receiver.
What will NOT work to solve this problem:

Ferrite beads and snap-on chokes!

Ferrite beads and snap-on chokes will not likely solve this sort of problem because what is needed is to prevent the egress of the RF energy from the switching supply one or more of the following:
- Very high series reactance to block RF energy
- Shunting of RF energy to a common path on the input and output of the power supply to prevent it from circulating elsewhere.

Simply put, a simple, ferrite bead or snap-on ferrite cannot practically introduce enough inductive reactance to effectively knock down the RF energy to the degree that we might like. While it may reduce the energy by a few dB, it is often the case that we need to reduce the RFI by a few 10's of dB and more aggressive filtering is usually required to do that.

Ferrite beads and snap-on chokes are better at minimizing the ingress of energy to reduce its potential of being bothered by external RFI than they are at eliminating the emission of RFI in the first place. In other words, the reactance that they add to the interconnect leads gives whatever built-in RFI immunity the device already has more of a chance of working. They are much less effective in quashing the emission of RFI by that device in the first place.

To get enough inductance to present a high inductive reactance at the lowest desired frequency it is often required that many turns be wound on a piece of ferrite, but the size of the core, the diameter of the wire - and even the length of the wire - usually precludes putting more than a turn or two on all but the largest core.

In our case, I'd already have installed additional filtering in the power supply - and it wasn't enough - so we are going to attack this problem using the second of the above techniques: Shunting the RF energy to a common path.

I knew now that I had to do the complete "filter job" on this power supply.

Having had to do this before on other power supplies, I gathered the necessary parts - this time, documenting my efforts for this blog:
- Dead PC power supply, complete with case and power cord.
- Two brand new low-ESR electrolytic capacitors of suitable voltage for the DC power supply, capacitances between 100uF and 1000 uF.
- Two monolithic 0.1uF ceramic capacitors of suitable voltage for the DC power supply.
- Terminal strip.
- A piece of perforated prototype board.
- Misc. screws/hardware for standoffs.
- A piece of plastic for a shield - see text.
- Four self-adhesive rubber feet.
- Some soldering skills.
- A bit of common sense!

Before I go on I must spout out a few weasel words of warning:

- This project involves hazardous/fatal AC power/mains voltages! DO NOT undertake this project unless you have experience with such voltages and the necessary safety procedures in dealing with them!
- Please observe the safety regulations and requirements for your locale noting that the methods described here may not be suitable for your area!
- You MUST make certain that the components that you use are rated for the voltage/current at which they will be operated!
- YOU are responsible for your own safety. I cannot be held responsible for damage, injury, accidents or even death that might occur by following - or failing to follow - any instructions or recommendations on this page!
- If you do not feel comfortable working with high voltages and currents or do not have familiarity with wiring procedures and safety related to such, PLEASE do not even think of doing so!
- **YOU HAVE BEEN WARNED!!!**

Gathering parts:

The first thing to do is to gut the PC power supply, leaving in the case the connector for the power cord and the on/off switch if it has one.

Please be aware that the input capacitor of the power supply may retain voltage even if it has been powered down for a long...
time - check and discharge it if necessary.

The picture shows several of the parts that you will need from the power supply:

- Bilifier input choke. This could either be toroidal, or look like a transformer. Make certain that you identify the two “halves” of the inductor. AC power will flow through each half, separately. These inductors will have values of 100µH to 50 mH per half, depending on the source. Those depicted in Figure 4, below, measured about 4.5 mH per half.
- Common-mode capacitor. This will typically have a value between 0.047µF and 0.22µF and will be connected directly across the AC line - usually located right next to the bilifier input choke. In the U.S., these capacitors are typically 0.1-0.22 µF.
- Two identical high-voltage bypass capacitors. These connect from each side of the AC supply and go to the case ground. These are typically blue or yellow and have values from 1000pF to 4700 pF (e.g., 1nF to 4.7nF).
- The safety fuse(s) from the power supply - if they are not blown. In the U.S., there is typically only one fuse found on the “Line” (black wire) side of the AC input.
- Another Common-mode capacitor. If you have another PC power supply to scavenge - or if the power supply that you have has one, get from it another common-mode capacitor of the same description as above. This is optional.

Comment:
- It has been noted that some REALLY CHEAP and/or “suspected origin” power supplies have been spotted that have none of these RFI suppressing components - or even a fuse - even though their cases had a “UL” and “FCC” certification sticker on them! In this case, it was probably just as well that the power supply was pulled out of service as their were neither safe or compliant with regulations!

Warning:
- All of the capacitors should have on them explicit AC voltage ratings consistent with those of the mains voltage in your area.
- DO NOT use any capacitor unless it has printed upon it the proper voltage rating! The capacitors typically used for these applications are usually blue or a light yellow color and have printed on them an AC voltage rating.

Note:
- You may be able to find a pre-built filter unit that has a standard IEC (e.g. “Computer Plug”) connector on it that you can mount to the power supply case, saving you the trouble of building a filter. These units may be found both new and surplus. You can also find such filter units pre-built as depicted Figure 5, below

Constructing the filter:

The schematic diagram of the filter is shown below.

The filter is of the so-called “Brute Force” type and it is a common-mode low-pass filter that removes high frequency content from the AC power line. Because our main goal is to contain the RFI within the box, any RF energy from the switching power supply first hits the common-mode capacitor which forces it to be equal on both sides of the AC power line. The RF energy then hits the bilifier RF choke which then cancels out any energy that is equal on both sides of the AC power line - a condition that was just enforced by the common-mode capacitor.

Any RF that managed to make it through the bilifier choke will now be greatly diminished and it is now shunted by the two capacitors to the metal case to ground while the (optional) common-mode capacitor on the AC input side
reinforces the equilibrium of any RF energy that might be on that common-mode choke.

The filter shown was built on a piece of phenolic prototyping board, maintaining at least 1/2" spacing (12mm) between any two points that carry mains voltages or between a mains voltage and/or a ground point. On the bottom, short pieces of solid bus wire were used to interconnect components and to make the loops used to solder the interconnecting wires.

As can be seen, the power supply's original fuse was retained and used on the "live" (hot) side of the AC input of the filter as a matter of safety.

![Image of filter](http://ka7oei.blogspot.fr/2014/08/completely-containing-switching-power...)

Figure 6:  
The completed AC input filter, constructed on a piece of phenolic prototype board.  
This one has a common-mode filter on both the input and output.  
Click on the image for a larger version.

The phenolic board was mounted on the side of the PC power supply case, but to protect it from items protruding into a vent hole and causing a short or electric shock, a piece of heavy plastic larger than the perfboard was cut out and mounted against the case. This piece of plastic was cut from a discarded "blister pack" that had contained items bought at the store and was fished out of the trash can. It just so-happened that there was a large enough portion of flat plastic to accommodate my needs and it made a nice, durable and free shield!

The board was mounted using 6-32 screws and spacers as standoffs to hold it about 1/4" (5mm) or so from the side of the case. For a ground connection, a ring lug was put under one of the screws and soldered to the ground connection on the filter - and also soldered to the ground connection on the AC power plug which, itself, was also connected to the case.

Using the original on/off switch and wire from the scrapped power supply, the filter was wired to the AC mains and then over to the power supply. Several push-on pins were found that mated snugly with the power supply's AC input connections and connected to its AC input, but it would have been possible to cut off the original AC power cord.
and wire it in. Some RTV ("silicone") adhesive was then used to secure the push-pins on the power supply's AC input as well as to hold it to the bottom of the case - either of which could be removed later, if necessary.

**DC output filter:**

![Schematic diagram of the DC output filter](image)

- C1, C2 - LOW ESR Electrolytic, 100-1000 uF
- C2, C3 - 0.1uF, monolithic ceramic
- L1 - 10-100uH
- Used ONLY low ESR capacitors for C1, C2!
- Observe voltage ratings for all capacitors!
- Observe current rating for L1!

Figure 8:
Schematic diagram of the DC output filter. The "ground" of this filter was firmly attached to the metal power supply case using the ground lug of the terminal strip seen in Figure 9, below.

With the AC line input now being completely filtered, we still have to isolate the other end of the path through which the low-level RF currents can flow - the DC output.

Inspecting the DC power supply again, I noticed that there were two toroidal inductors and I removed them both. One of them had several different wire gauges and was set aside, but the other consisted of a pair of wires wound in parallel, connected in parallel on the circuit board - and a quick check on the inductance meter showed its value to be around 43 microhenries - plenty good for our purposes.

Had neither toroidal inductor been suitable as is, I would have picked the one with the heaviest gauge wire and removed all but the winding with that wire. Most of these power supplies use toroids with yellow or green cores and a dozen or two turns on these typically yield inductances well above 10 uH - more than enough to block HF energy when bypassed with good-quality capacitors!

On a terminal strip I mounted the inductor and two low-ESR electrolytic capacitors, as shown, bypassing each one a 0.1uF monolithic ceramic capacitor. The use of these low-ESR capacitors rather than "normal" capacitors is important as these types are specially-designed to remove the high-frequency components. Once you get above a few hundred kHz, however, many electrolytic capacitors start to lose their efficacy so monolithic capacitors such as the ones shown take over, shunting the RF to the case ground.

**Important construction notes and comments:**

- Again, use ONLY LOW ESR capacitors for the output filter. These capacitors are almost always rated for 105 degrees C, so if the capacitors that you have say "85C" on them, they are probably not low ESR - but their having "105C" on them that doesn't guarantee that they are low ESR, either!
- While the output capacitors of PC power supplies are (ostensibly) of the low ESR type, it is often the failure of these capacitors (along with the other - that causes these power supplies to fail - so don't count on a failed power supply to be a usable source! Unless you have an ESR meter, don't count on a capacitance meter to tell you if a capacitor is any good, either. It can still read the proper value, but have terrible ESR!
- If a terminal strip cannot be found, a small piece of copper-clad circuit board could be used, instead, with the components mounted "dead bug" on it, using the copper itself as a ground plane. The circuit board material would then be mounted using screws, to the metal case, assuring a solid ground connection.
- **Be sure to ground the output filter directly to the case near the point where the DC cable exits the case rather than run a wire to the AC input filter's ground point!** One of the ways to maximize the effectiveness of the filter is to minimize the length and impedance of its ground/common connection, and the best way to do this is to utilize the case itself.
Note that if you use ordinary 0.1 uF disk ceramic capacitors instead of modern monolithic ceramic units be aware that many of these can have rather low voltage ratings (e.g. 16 volts) unless otherwise marked. Also note that they can lose effectiveness at high frequencies so they should be bypassed with 0.001uF capacitors.

This terminal strip was mounted to the case using a 6-32 screw and a "star" washer. The DC output cable of the power supply was then cut and wired to the terminal strip, using the ground lug as a "common" and passing the DC through this filter which effectively shunts any RF to the case ground.

**Finishing it up:**

Once all wiring is completed, ohmmeter tests should be made to verify continuity (or lack thereof) as appropriate and stick-on feet should be applied to the bottom to prevent it from sliding around and scratching whatever surface it rests on.

**How well does it work?**

At HF frequencies this filter's effectiveness is seemingly **absolute** in that the power supply within cannot be detected from outside the box, even with a portable shortwave radio held within a few inches.

It should be noted that it is not the "shielding" of this box to which one would attribute its effectiveness, but simply the fact that the AC input and the DC output share a solid, common RF ground. Any RF currents on the AC input and DC output simply circulate on this common ground (e.g. the metal case) rather than radiate on the AC power leads and/or the wires connected to the DC output - or the things connected to it.

Were this same circuit arrangement constructed on a flat piece of metal without a shield cover, it would have worked nearly as well. The 100% cover of the case is there mostly to prevent accidental electric shock and shorting of the otherwise exposed AC mains connections. With the cover removed, the RFI can radiate from the power supply, but unless a wire/ground loop is placed within the box such emissions would go only a very short distance.
This blog entry may be considered to be a follow-up to the December 8, 2012 entry about "Reducing Switch Supply Racket racket (RF Interference) - Link"

On a related topic, see also the September 4, 2013 entry, "Quieting High-Current switching supplies used in the ham shack - link"

Posted by KA7OEI at 10:40 PM

Labels: RF enclosure, RFI filtering, RFI prevention, RFI suppression, shielding, Switching power supply

No comments:

Post a Comment

PLEASE NOTE:

While I DO appreciate comments, those comments that are just vehicles to other web sites without substantial content in their own right WILL NOT be posted!

If you include a link in your comment that simply points to advertisements or a commercial web page, it WILL be rejected as SPAM!