Power, Grounding, Bonding, and Audio for Ham Radio

Safety, Hum, Buzz, and RFI

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Don’t Bother Taking Notes

• These slides are on my webpage k9yc.com/publish.htm
Why An Earth Connection?

• Lightning Safety
  – That’s all!
• Does **not** help with RFI
• Does **not** make an antenna work better
Bonding Is Critical

- Lightning Safety
- Life Safety – Electrical shock
- Minimizes hum, buzz, and RFI
What is Bonding?

• A Robust, **Low Impedance** connection between grounds, and between equipment enclosures
  - Low impedance => short, fat
  - Fat => low resistance
  - Short => low inductance
Lightning is **NOT** a DC Event

- Lightning is an impulse, with most of its energy concentrated in a very broad spectrum centered around 1 MHz
  - Mostly from 100 kHz – 10 MHz
- Above 1 kHz, impedance is dominated by inductance, not resistance
What Must We Bond?

EVERYTHING!
What Must We Bond?

- Power Service Entry
- Telephone Entry
- Cable TV Entry
- Antenna Entry
- Operating Desk
- All ground rods
- Towers near the building
- Building structural steel
- Grounded metallic plumbing
Everything Must Be Bonded Together

- Separate grounds are illegal and unsafe!
ALL GROUNDS MUST BE BONDED TOGETHER FOR SAFETY
Bonding All Building Grounds

Grounding is for SAFETY
Lightning protection
Blow a breaker if a power system short
Connections should be big copper and
Bonding All Building Grounds

Power

CATV

Telco

Shack

Ant Panel

Tower

ROD

ROD

ROD

ROD

ROD

ROD

ROD

ROD

ROD

ROD

ROD
Bonding All Building Grounds

Power

CATV

Telco

Shack

Tower

Ant Panel

ROD ROD ROD ROD

ROD ROD ROD ROD

ROD ROD ROD ROD

ROD ROD ROD ROD

ROD ROD ROD ROD

ROD ROD ROD ROD
Bonding All Building Grounds

Power  CATV  Telco  Shack  Tower

Ant Panel

R O D  R O D  R O D  R O D

R O D  R O D  R O D  R O D

R O D  R O D  R O D  R O D

R O D  R O D  R O D  R O D

R O D  R O D  R O D  R O D
Bonding Tower To House

• If close to the house, it **must** be bonded to house ground

• If distant from house, it should **not** be bonded to house ground
  – Coax shield will provide inductive connection, so most lightning current will go to tower grounds
  – “Distant” >200 ft cable run from base to house
If Tower is Widely Separated

Power  CATV  Telco  Shack  Tower

Ant Panel

Long Coax
If Tower is Widely Separated

- Power
- CATV
- Telco
- Shack
- Tower

Ant Panel

ROD ROD ROD ROD
ROD ROD ROD ROD
ROD ROD ROD ROD
ROD ROD ROD ROD
ROD ROD ROD ROD

INDUCTOR
Tower Grounding

• Bury copper strap in concrete
• Bond copper strap to rebar cage
• Bond copper strap to tower legs
• Bond each tower leg to at least two buried rods spaced radially
  – Spacing equal to their length
  – At least 8 ft long rods
• Concrete forms Ufer ground
Tower Grounding

• Bond coax shield to the tower at top and bottom
  – Keeps coax at the same potential as the tower
  – Prevents arc-over between coax and tower from lightning
  – Arc-over fries the coax (or hard line) at points where it occurs

• Run coax and other cables inside the tower
Bonding Conductors

• **Bigger is better**
  – At least #4 around tower, to all rods, between rods, rods to building
  – At least #10 between equipment in the shack
  – Steel conduit is good if properly installed

• **Shorter is better**
  – Minimizes both R and L
Bonding Inside The Shack
Why Bond Equipment?

• Lightning Safety

• Kill hum, buzz, and RFI
  - Shields of unbalanced connections carry power system leakage currents that are added to the signal
  - Shields act as antennas, pick up our transmitted RF
  - Pin One Problems couple RF inside the box, where it is detected
Interconnections in our Shacks

- **Audio from the computer**
  - Playback voice messages to radio
  - Transmit RTTY, PSK31, WSJT

- **Audio to the computer**
  - Decode RTTY, PSK31, WSJT

- **Mic to computer**
  - Record messages for contests
Interconnections In Our Shacks

• Sending CW
  – Computer to radio
  – Paddle and keyer to radio

• PTT from computer to radio
  – Or use VOX
Interconnections In Our Shacks

• Rig control and data for logging software
  – Frequency and mode readout, band changes

• Rig control for MMTTY (RTTY software)
  – Needed only if you’re not using VOX

• RS232, USB to most rigs
Simple RTTY Setup w / VOX

- Computer generates AFSK RTTY signal, sends to rig
- Rig sends received RTTY signal to computer, which decodes it
- This setup works for PSK31, JT65, etc.
Unbalanced Interconnections

• All of our interconnections are unbalanced
  – Shields of unbalanced connections carry power system leakage currents that are added to the signal
  – Shields act as antennas, pick up our transmitted RF
  – Pin One Problems couple RF inside the box, where it is detected
What’s A Pin One Problem?
Pin 1 Problem in Balanced Interfaces
Pin 1 Problem in Balanced Interfaces
Pin 1 in Unbalanced Interfaces

- SHIELDING ENCLOSURE
- SIGNAL CIRCUITRY
- PSU
- RIGHT
- SIG REF
- WRONG
“Green Wire” Pin One Problem

SHIELDING ENCLOSURE

SIGNAL CIRCUITRY

PSU

WRONG

SIG REF

RIGHT

Green Wire Misses Chassis
Most RFI is caused by Pin 1 Problems!
That Includes “RF in the Shack,” AKA “RF Feedback!”
Nearly All Equipment Is Built With Pin 1 Problems

• Audio and Video Gear
  – Home and Professional Audio Systems
  – TV Sets, Video Recorders, Cable Boxes

• Computers and Accessories

• Ham Rigs and Accessories

• Telephone Equipment
How Do Pin 1 Problems Happen?

- Connectors mounted to PC board
- Shell not bonded to chassis
  - Should be, but is not – that costs more!
- Often very difficult to fix
- All inputs and outputs are usually wrong
  - Audio and video
  - Serial and USB interfaces
  - Control wiring
How Do Pin 1 Problems Happen?
Insulating rings around connectors prevents chassis contact!
Nice Radio, Has Pin 1 Problems
Ten Tec Omni V
A Pin 1 Problem in FT-1000MP

RF Feedback on 75 and 15 Meters
Multiple Pin 1 problems cause hum, buzz, and probably RF feedback.
Where are the Chassis Connections for this laptop’s sound card?

• Hint: It isn’t an audio connector shell!
– They should be, but they are not!
Where are the Chassis Connections for this laptop’s sound card?

Yes, it’s the DB9, DB15, and DB25 shells!
Pin One Problems in Elecraft KX3

- Only the mic and BNC connectors are bonded to the chassis
Dayton 2014 Booth Survey

- Rigs With Apparent Pin One Problems
  - Yaesu (all I could look at)
  - Kenwood (all I could look at)
  - ICOM (all I could look at)
  - Ten Tec (all I could look at)
  - Elecraft (KX3)
  - Many (most?) other booths
  - Flex (most models)
Green Wire Pin One Problems

- Astron Power Supplies
  - Green Wire goes to Terminal Strip insulated from chassis by paint
  - More about Astron later
Killing Pin One Hum, Buzz, RFI

- **Rewire/rebuild the connector**
  - Wire shield to the **chassis**, not to PC board
  - Bond connector to **chassis**, not to PC board

- **Kill the current**
  - Make the wiring a lousy antenna
  - Add a common mode choke
  - Short out the current
  - Kill voltage that causes current flow
The Unbalanced Interface
Preventing Hum and Buzz
Typical Noise Spectrum on “Ground”

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

10 - 100 mV typical
The Problem with Unbalanced Interfaces

- 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
Typical Noise Spectrum on “Ground”

Measured between two outlets on opposite walls of my ham shack, into a high impedance
That’s Not 60 Hz!

• Where did all those harmonics come from?
The Harmonic Problem

Recognize this power supply?

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

Recognize this power supply?

Current flows in short pulses to recharge the filter cap 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
  - Distortion => harmonics
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 a factory or business down the street does, so you get your 120V-0-120V service from a “High Leg Delta” service in your alley!

• Much of the factory’s neutral current may flow through your neutral to ground.

• High Leg Delta feeds my home in the Santa Cruz Mountains.
“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)
“High Leg” Delta

- Part of Neutral current from 3-phase customers goes to ground through single-phase 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 neighbors
Phase Currents – Fundamentals and Third Harmonics
What Happens in the Neutral?

- Triplen harmonics ADD!
  - Third, sixth, ninth, etc

- Neutral current up to 1.7X the phase currents, even in a perfectly balanced system!

- Potentially dangerous overheating
  - Neutral conductors (and contacts)
  - Transformers

- Use bigger copper in neutrals

- Use harmonic-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 rarely are), they cancel in the neutral
In Three Phase Systems

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

BUT:

- Triplenn 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
Our Power System Ground Wiring
(The “Green Wire”)

- **BREAKER PANEL**
- **OUTLET**
  - 5 Ft #18
  - 75 Ft #14
  - 195 mΩ
- **OUTLET**
  - 5 Ft #18
  - 75 Ft #14
  - 195 mΩ
- **OUTLET**
  - 5 Ft #18
  - 75 Ft #14
  - 195 mΩ
- **COMPUTER**
- **RADIO**

- **32 mΩ**
Leakage Currents On the Green Wire

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”)

WHAT’S MISSING FROM THIS PICTURE?
Home Power Ground Wiring
(The “Green Wire”)

BOND FOR SAFETY

10 ohms to earth

10 mA = 0.32 mV
195 mΩ

10 mA = 1.95 mV
195 mΩ

100 mA = 19.5 mV

100 mA = 3.2 mV

10 ohms to earth

75 Ft #14

5 Ft #18
32 mΩ

5 Ft #18
32 mΩ

25 mV

163 x 100

BOND FOR SAFETY

10 ohms to earth

205 x 302

195 mΩ

10 mA = 1.95 mV

100 mA = 19.5 mV

100 mA = 3.2 mV

BOND FOR SAFETY

10 ohms to earth

10 ohms to earth

75 Ft #14

5 Ft #18
32 mΩ

5 Ft #18
32 mΩ

25 mV

163 x 100
Home Power Ground Wiring
(The “Green Wire”)

BOND FOR SAFETY

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

Take this large component out of the equation

BOND FOR SAFETY

10 ohms to earth

10mA = 0.32 mV
5 Ft #18 32 mΩ

100mA = 19.5 mV
75 Ft #14 195 mΩ

10mA = 0.32 mV
5 Ft #18 32 mΩ

100mA = 3.2 mV

Take this large component out of the equation
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 (or even #10) 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
Home Power Ground Wiring
(The “Green Wire”)

- BREAKER PANEL
- OUTLET
- OUTLET
- 240V
- COMPUTER
- RADIO
- AMP

- 10mA = 0.32 mV
- 10mA = 1.2 mV
- 100mA = 15 mV
- 100mA = 1.2 mV
- 5 Ft #18: 32 mΩ
- 5 Ft #18: 32 mΩ
- 5 Ft #14: 12 mΩ
- 75 Ft #12: 150 mΩ
- 10 ohms to earth
- 10 ohms to earth
Hum/Buzz 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 typically reduces buzz by 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"
  - Add boxes, bolted together as needed
  - When outlets can’t be bolted, bond them together with steel conduit or heavy braid
  - When different green wires, bond together all outlets for all stations
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 **short, fat** conductor between the two chassis

• 50\(\mu\)V would yield 76 dB S/R ratio
Hum/Buzz Step #2

- 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.
Guidelines For Bonding

• Add bonding in parallel with every unbalanced audio and data path

• Use #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

• Always as short as possible
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 buzz

• Make bonding conductor SHORT
  – Half the length = 6dB less buzz
Equipment Bonding – A Basic QRO Station

Rig

Computer

Amp Pwr Supply

Amp

Most Critical
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
Equipment Bonding – SO2R Station

Rig #1

SO2R Box

Computer

Rig #2
Equipment Bonding – Two Rigs, Two Computers
SO2R Box Bonding

• Bond transmitters together
• Bond computer(s) to transmitters
• Bond SO2R box to computer(s) and tranceivers
  – 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
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
  – RF pin 1 problems still possible
How Well Does This Work?
Noise Reduction From Simple Bonding

-34.3 dBu (16 mV)

-83.6 dBu (0.05 mV)

49 dB Better
Proper Bonding For The Shack

Computer

Rig

Amp

Tuner

Pwr Supply

Ant Panel
Proper Bonding For The Shack

- Computer
- Rig
- Amp
- Tuner

- USB Interface
- Pwr Supply
- Ant Panel
And It’s Right for Lightning Safety and RFI

- Step One eliminates voltage between power outlets
- Both steps minimize voltage between our gear
- Both steps minimizes the area of loops for magnetic coupling
- Magnetic coupling is proportional to loop area
Thinking About Loops
Red Lines are Unbalanced Cables

Computer

USB Interface

Rig

Pwr Supply

Amp

Tuner

Ant Panel
Single Point Creates Loops
Red Lines are Unbalanced Cables

- Computer
- Rig
- Amp
- Tuner
- USB Interface
- Pwr Supply
- Ant Panel
- Grounding Bar Behind Rig
Ground Bar At Back of Desk

• We have unbalanced connections (cable shields) between gear, so bonding to the bar creates a loop
• Magnetic coupling to the loop
  – Leakage flux from transformer
  – Lightning
• Bonding path between gear is longer, so more resistance, more hum, buzz, and RFI
Single Point Creates Loops
Red Lines are Unbalanced Cables
Single Point at Ground Rod

• The much longer path creates a much larger loop
• Magnetic coupling is proportional to the loop area
• Bonding path between gear is much longer, so more resistance, more hum, buzz, and RFI
This is NOT Better!
Red Lines are Unbalanced Cables

Computer
USB Interface
Rig
Pwr Supply
Amp
Ant Panel
Tuner

Red Lines are Unbalanced Cables
Single-Point Madness

• Virtually all interconnects are unbalanced, tie chassis to chassis

• We may call them an audio cable or computer cable or “coax between rig and amp,” but Mother Nature sees their shields as part of a big loop with star bonding conductors

• Most equipment has a Pin One Problem
  – Current in the loop will get inside our gear
  – Hum, buzz, RFI, lightning damage
Single-Point Madness

• Ground bar at back of desk is a bad idea

• Individual bonds from each piece of gear to a common ground inside or outside the shack is a bad idea

• Greatly increases resistance between interconnected equipment
  - More power line buzz
  - Creates loops for magnetic coupling
Killing Pin 1 Hum, Buzz, RFI

• Use Step 1 and Step 2 Bonding
  – Ohm’s Law causes most audio current to flow on low impedance bonding conductors rather than much smaller interconnect cables
  – Forces most RF currents to bonding conductors

• Add ferrite choke(s) to interconnect cables if still some RFI
  – k9yc.com/RFI-Ham.pdf
Still Have Hum/Buzz?

• Carefully Investigate Building Grounds
Another Cause of Buzz

Noise on neutral

200 mA

75 Ft #14
195 mΩ
200 mA = 39 mV

5 Ft #18
32 mΩ

10 mA = 0.32 mV

5 Ft #18
32 mΩ

200 mA = 6.4 mV

10 ohms to earth

Missing Ground
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)
• With 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

• We do need a transformer to bring audio in from another building on wires
  – 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 mostly confined to the very small area between conductors – that is, between the wires
Field With Double-Bonded Neutral (Wrong)

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

- 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 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

[Diagram showing electrical components and connections]
Load Connected Hot to Ground In Alpha 77, 500 mA

- Field may engulf large areas of a building!
- Puts hum voltage on green wire (chassis)
Measuring 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 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)
Measuring Ground Currents

• This method won’t work if equipment is bonded, so measure before bonding and connections to other gear

• 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?
Power For A New Shack

• One 20A 240V circuit
• Bring 4 wires to the shack
  – Both sides of 120V
  – Neutral
  – Ground (Green)
• One or two 240V outlets (for SO2R)
  – Both sides of 240 plus ground (green)
• Use #10 for reduced IR drop
Power For A New Shack

• Add 120V quad boxes, at least two per leg (wired 120, neutral, green)
  – Feed from the same 20A-240V circuit
  – More than enough power for all the radio (and computer) equipment in any single-op legal limit station

• Mount all outlets in steel backboxes
  – Backboxes must be bonded together
  – Steel conduit between boxes (EMT is fine) provides excellent bonding
Power For A New Shack

• Lowest cost alternative
  – Only one run from breaker panel to shack
  – Most of the cost is labor
  – Wire, outlets, backboxes are cheap
  – Use good quality 20A outlets
  – Use #10 copper for everything

• 30A circuit will run two legal limit amps at the same time (Multi-2)
Power For A New Shack

• A 30A 240V circuit split to 120V 20A outlets will require a small sub-panel in (or near) the shack
  • Will run two legal limit amps, rigs, and computers at the same time (Multi-2)
  • #10 AWG is legal for 30A, but #8 would be better
USB Audio Interfaces
Outboard USB Interfaces

• Decoders for digital modes work best with better quality A/D converters
  – Good linearity around the noise floor helps weak signal decoding
    • PSK31, JT65, JT9, FSK441, ISCAT, WSPR
  – Lower distortion, flat response improves RTTY decoding

• Inexpensive USB interfaces for DJs and small home studios work very well
Semi-Pro USB Audio Interfaces

• Features in common
  – Two channels of A/D and D/A
  – 16-bit, 48 kHz
  – RCA connectors for line level ins and outs
  – Output level control
  – Powered from USB port
  – Use standard Windows drivers
Semi-Pro USB Audio Interfaces

• Numark Stereo I/O USB (~ $50)
  – Lowest cost “good” product
  – Bare bones unit, decodes as well as more expensive (and fancier) Tascam
  – Lacks input gain control
  – Lacks signal level indicators
Semi-Pro USB Audio Interfaces

- Tascam US100, 122, 125, 144 (~ $100)
  - More inputs (mic, guitar) provide more flexibility of signal level, ¼-in and XLR
  - Input and output level controls
  - Input signal presence indicator (green LED) and Input clip light (red LED) allow positive setting of good input gain
Semi-Pro USB Audio Interfaces

• Models change every few years
  – Some are discontinued but may be found used
  – Quality and features remain good

• Tascam is old line audio manufacturer
Some Good Vendors

• B&H Photo (NYC)
• Full Compass (Madison, WI)
• Sweetwater (Fort Wayne, IN)
How I Tested

- First test – compare each unit to the internal sound card of a T43 Thinkpad
  - JT65A
  - Two computers, each running JT65-HF
  - K3 fed both to mic input of computer #1 and to computer #2 via the USB interface
  - Hundreds of decode cycles

- Results – both decoders “twice as good” as T43 sound card
  - Twice as many decodes on a cycle
  - Decoded signals 10-12 dB lower into the noise
How I Tested

• Second test – Numark vs. Tascam
  – Two computers, each running JT65-HF
  – K3 fed to both USB interfaces, each to its own T43 computer
  – Many hundreds of decode cycles

• Results – equally good decoding
  – With 6-8 decodes per pass, one might miss one signal the other copied, but which decoded better was statistically random
Recommendations

• If money is tight, buy the Numark
• The Tascam units provide more flexibility at about twice the cost
• The Tascam US100 is on my primary radio and primary computer
• I use the Numark with WSJT and WSJT-X on 2M, and with my second radio and a second computer for RTTY SO2R contesting
SignalLink USB – A Poor Choice

- Only one channel
- Support info indicates a Pin One Problem
- Voltage regulation problem
- QST noted problem below 600 Hz, provided fix
- Each radio needs a custom interface cable
- I have not tested this unit – I bought other products for my own use, and my research made it clear that I didn’t want to own one
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 adds hum and buzz
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 nearly 40 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**!
• Almost no audio current flows
• Wire size doesn’t matter
• Twisting critical for hum/buzz/RFI rejection
• Shield is not necessary!
• Some pro stages are 6 dB hotter (20V peak)
• 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!
• For a typical computer sound card:
  – 1.4 volt = $\frac{1}{4}$ watt @ 8 ohms, $\frac{1}{2}$ watt @ 4 ohms
  – 1 volt = $\frac{1}{4}$ 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 6 dB below clip
  - Poor quality analog output stage
- VERY important for digital modes
  - PSK31
  - AFSK RTTY
  - Distortion produces sidebands (extra copies of your signal)
- Run the computer about 6 dB below clip
Audio in the Digital Domain

- Analog audio is converted to a digital signal by an Analog to Digital (A/D) converter.
- Massive distortion occurs at "digital clip," when the signal is so strong that the A/D has filled all the bits and tries to go higher.
- Mild distortion occurs near the noise floor.
Setting Digital Levels

• Always set levels so that
  – there is never clipping on peaks and
  – The weakest signals are well above the noise floor

• With the Tascam USB interfaces
  – The green signal presence is always on
  – The red clip light never flashes, even on static crashes
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
Mic Settings to Record Messages

• Feed Mic into the Computer Mic Input
• Click the Speaker Symbol in the TaskBar
  – You should see some volume controls
  – Or Accessories, Entertainment, Volume Control
  – Click On Options
• Select Record to set input gain for the mic
  – Most computers will have a mic preamp
  – Called “mic boost”
Recording Voice Messages

• A webinar I did a few years ago
  • http://nccc.cc/misc/RecordingVoiceMessages-K9YC.wmv
• The editing software I showed may no longer be free
  – Other editing software works fine, some commands are different, all the principles are the same
  – Audacity
Setting Computer Output Level

• Three ways to do it
  – Scope (Best)
  – AC Voltmeter with good low volts scale (very good)
  – Your ears (better than you think!)
Setting Computer Output

- Before connecting to radio, set the computer to transmit PSK31 or AFSK RTTY and watch audio on a scope
  - Set sweep to see sine waves of audio
  - 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 no scope, use AC voltmeter at computer output while it’s sending PSK or RTTY tones, and increase the output level control until voltage stops increasing. That’s clipping.
• Now reduce the level to one half of the measured voltage at clip.
• This is the right setting for the computer, both for tones (RTTY, PSK) and SSB.
Setting Computer Output

• If no voltmeter or 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 reduce the level until harshness is gone and it sounds about half as loud.
• This is the right setting for the computer, both for tones (RTTY, PSK) and SSB.
Feeding Audio to the Radio

• 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
Setting Levels in the Radio

• The mic gain should be set about the same as it is for your mic

• Use a 10dB or 15dB pad on the line input if needed to put mic gain in “normal” range

• Always use the 20dB pad if computer feeds the mic input

• Resistive pads
  – 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 line input (20 dB)
- Set rig for SSB, VOX operation
- No PTT required
- Follow Hum/Buzz steps 1 & 2
- MMTTY needs serial cable for rig control
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 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.
  - 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 (Typical)

Bias Resistor

1/8" TRS Jack
• DC voltage not critical (5-12VDC)
• Resistor value not critical (4.7K-6.8K)
  – Use less resistance for low voltage, more for high voltage
  – Can often fit inside ham mic connector
• Built into K3, turn it on and off from setup menu
Ham Mic to Laptop

• Many ham mics are electret
  – Need power for the FET

• If a 1/8-inch connector
  – Wire mic audio to Tip (audio input)
  – 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 $60
- Great response for ham radio
- 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
Wearing a Headset Mic

- Not too close
- Prevent breath pops
- Prevent bass buildup
- Space to munch, drink coffee
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 Audio Cables

• Much better than you can buy
• Cables that work well
  – Small coax with braid shield
    • RG58, RG174, etc.
  – Miniature shielded twisted pair
    • Gepco XB401, Belden 1901A
# 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, share with friends – much of the cost is shipping
- Avoid Radio Shack, Fry’s, Best Buy, etc. – Cheesy construction, dissimilar metals
Junk DIN Connectors

• Virtually all DIN connectors sold to hams are JUNK (but they’re CHEAP – about $1)
  – Contact metal doesn’t take solder
  – Dielectric melts with heat

• Some guilty parties (Hams are cheap)
  – RF Connection, Digikey, HSC

• The good ones cost $5-$7 each
  – Switchcraft, Tuchel
  – Buy from Allied, Newark, etc.
DIN Connectors

• An acceptable low cost alternative
  – Kobiconn
  – 8-pin male plug is Mouser 171-0278
  – About $0.75

• Takes solder well, doesn’t melt

• “Clamshell” pieces don’t mate very well
  – OK for very light duty use
  – OK if connector goes in once and stays there
  – Bad if connector will be plugged in and out
**Good DIN Connectors**

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

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

- Most modern rigs use RS232
  - Kenwood, Yaesu, Elecraft, Ten Tec
  - New ICOM, some Flex use USB
  - Each radio needs its own port

- Older Icom had unique CI-V interface
  - Icom adapter was needed $$$
  - Converts one RS232 port to two wire 1/8” plug
  - One RS232 port can control four radios
USB / RS232 Control Functions

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

- CW, PTT (from contest logger)
  - Can be on same serial port used for control
  - Can be on a parallel port
  - Require a simple NPN inverter/level shifter
RS232 Control Wiring

• Interconnects are unbalanced
  – We must eliminate the noise voltage on equipment grounds (solved by bonding)
  – 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
The K9YC Serial Cable

• Eliminates RFI, minimizes hum and buzz
• Use ordinary CAT5, CAT6 (4 twisted pairs), one pair per 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
Computers Without Serial Ports – What are the Options?

- Older Desktop Computers
  - Real RS232 Ports on a PCI Card
  - USB to RS232 Emulators

- Older Laptop Computers
  - 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
Serial Ports For Older Laptops

• 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
PC-Card to Two RS232 Serial Ports

About $150
USB Serial Ports

• Buy **only** adapters using FTDI chipset
• Emulate (pretend to be) a serial port
• Compatibility with hardware and software can be a problem
• May work with some programs and not others
• More processor overhead than a real serial port
• Cheap
USB to Four RS232 Serial Ports
A New (Used) Computer

• Use a modern computer for Windows
  – Windows XP Pro, Windows 7
  – Avoid Vista

• Use enough RAM (1 GB min, 2 GB better)

• Thinkpads work well for ham radio
  – OK (not great) sound card, with mic preamp
  – T40-series and later have serial port in port replicator

• Off-lease IBM desktop $125 - $250
  – Real serial ports, XP Pro
  – Tiger Direct and other sources
Power Supply Bonding
V– Bonded to Power Supply Chassis (BAD)

120 mV P-P

120 mV

BAD

0.04 Ohm

0.04 Ohm

Power Supply

Output Stage

PSU

1V

100

0.1 Ohm

6 FT AUDIO CABLE

10K

100W TX

6 Ft #10 Copper

6 FT #10 Bonding
The Power Supply V– Bonding Problem

• If V– is bonded to the power supply chassis, the IR drop in the V– lead between the radio and the power supply appears on the shield of audio wiring to an accessory fed by that power supply

• On SSB or RTTY, that current, and the IR drop, vary with the envelope of the transmitted audio
The Power Supply V– Bonding Problem

• With SSB, the modulated IR drop sounds like SSB in an AM radio

• It will appear in the unbalanced audio feed from the accessory to the rig, and will sound like RF feedback
Power Supply V – Not Bonded (Good)

No Chassis Bond GOOD!
Solving The Power Supply V-Bonding Problem

• Always do Step 1 & 2 bonding recommended to kill hum and buzz
  – This will often be enough

• Open the power supply and remove the bond (most good power supplies are not bonded, and most with bonds are designed so that the bond can be removed with no problems created)
  – This is a complete solution
V– Bonded to Power Supply Chassis (BAD)

120 mV p-p

100W TX

0.1 Ohm

6 FT AUDIO CABLE

0.1 Ohm

10K

120 mV p-p

0.04 Ohm

0.01 Ohm

0.006 Ohms

0.006 Ohms

0.006 Ohms

6 Ft #10 Copper

6 FT #10 BONDING

BAD

OUTPUT STAGE

PSU

POWER SUPPLY
Bonding Rig to Audio Box Shorts

Out Noise Voltage (−20 dB)

120 mV

BAD

12 mV p-p
Removing The Power Supply

V– Bond

• In Astrons, the bond is at the V– terminal to the chassis ground screw below it.

• In many Astrons (like this one), paint gets in the way of the bond, so many Astrons that appear to be bonded are not!
Other Solutions

• Get power for the accessory from
  – A split of the power connector where it plugs into the radio (zero length lead between the split and the radio)
  – The accessory jack of the radio (if it can provide enough current)
  – A separate power supply dedicated to the accessory
References

• A Ham’s Guide to RFI, Ferrites, Baluns, and Audio Interfacing
  http://k9yc.com/RFI-Ham.pdf
  – Chapter 8 – Solving Problems in the Shack
  – Appendix 6 – Audio For Ham Radio

• Power, Grounding, Bonding, and Audio for Ham Radio (this presentation)

• Power and Grounding for Audio and Video Systems – A White Paper for the Real World
See the Appendix for Slides that wouldn’t fit in an hour

- More about mics for ham radio
- More about serial port adapters for CW and PTT
Power, Grounding, Bonding, and Audio for Ham Radio

Safety, Hum, Buzz, and RFI

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