RFI and Ham Radio

Pin 1 Problems, Poor Shielding, Poor Filtering, and Unintentional Antennas

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Don't Bother Taking Notes – This Presentation is on My Website

http://audiosystemsgroup.com/publish.htm

Two Major Kinds of RFI

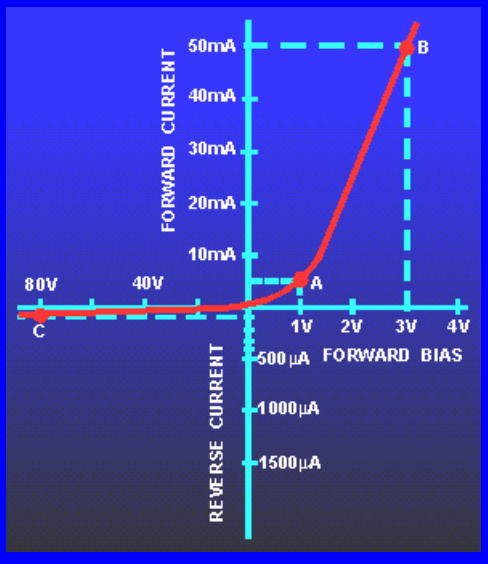
- RFI From Our Ham Statio
  - –TVI, Audio/Video Equipment
  - –Security Systems, Garage Doors
- RFI (Noise) To Our Station
  - –Digital Equipment
  - –Power Supplies, Chargers
  - –Motor Controllers
  - –Power Line Equipment Failures

The Heart of the Problem

RFI From Our Ham Station

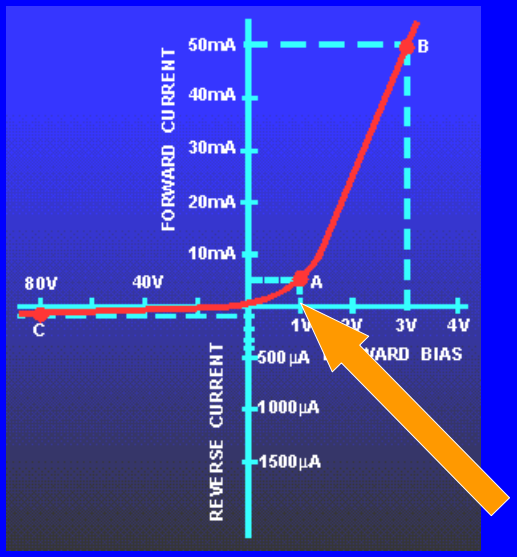
- Most electronic equipment can work as a radio receiver if allowed to do so
- The wires inside that equipment, and cables that interconnect equipment, are antennas, and can bring radio signals into that equipment

Square Law Detection



- Diodes
- Transistors
- IC's

Square Law Detection



- Diodes
- Transistors
- IC's

Differential Mode Coupling

- Current flow is in <u>opposite</u> directions on conductors in a signal circuit
- Voltage difference <u>between</u> conductors
- Desired signal is differential mode

Differential Mode Coupling

- Current flow is in opposite directions on conductors in a signal circuit
- Voltage difference between conductors
- Noise can be differential mode too

Killing Differential Mode RFI

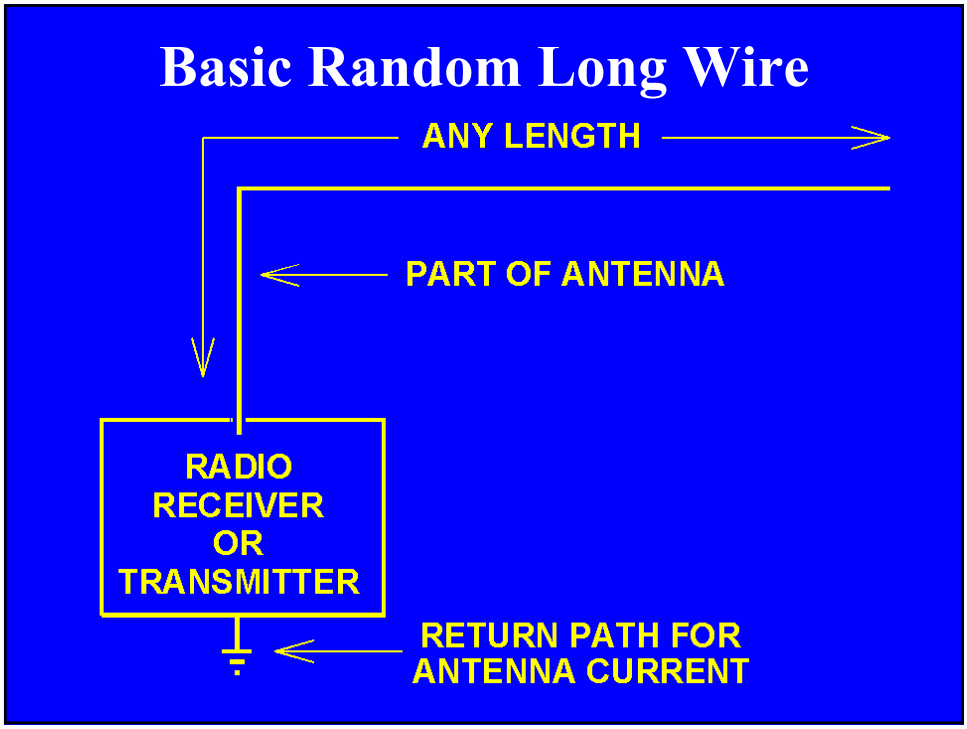
- Low pass filters kill RF, pass the signal
  - Simple bypass capacitor shorts out noise
  - Series L (or R) blocks noise
- Most RFI is not differential mode

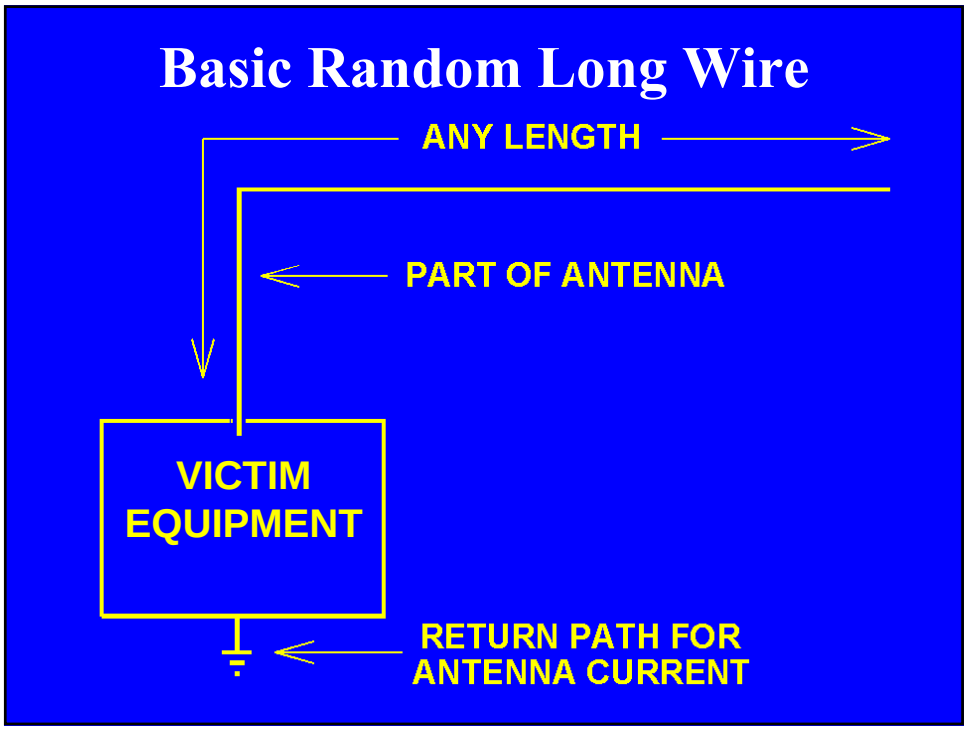
Common Mode Coupling

- Current flows in same direction on all conductors (or on outside of coax shield)
- Voltage difference along conductors
- I/O wiring acts as long wire antenna

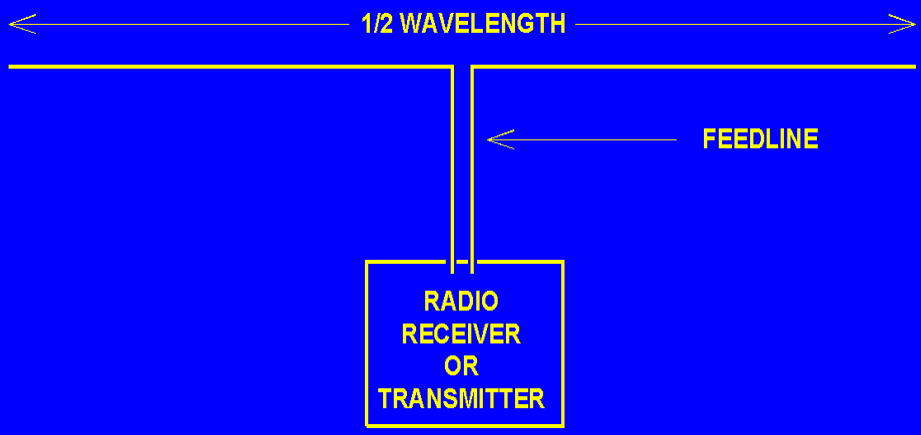
Common Mode Coupling

- Current flow in same direction on all conductors (or outside of coax shield)
- Voltage difference along conductors
- Also couples power line hum and buzz

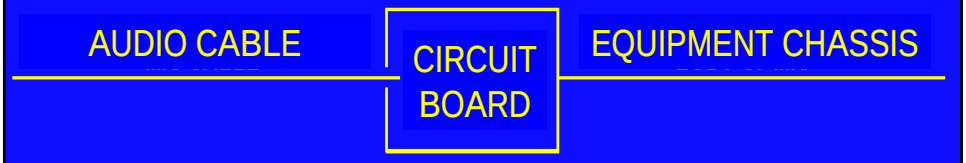

Basic Random Long Wire
ANY LENGTH
PART OF ANTENNA
RADIO
RECEIVER
OR
TRANSMITTER
RETURN PATH FOR
ANTENNA CURRENT


Basic Random Long Wire
ANY LENGTH
PART OF ANTENNA
VICTIM
EQUIPMENT
RETURN PATH FOR
ANTENNA CURRENT

A "Textbook" λ /2 Dipole



Equipment Can Form The Other Half of a Dipole



That's how a rubber duck works on a talkie – the chassis, plus our arm holding it, are part of the antenna!

Common Mode Coupling

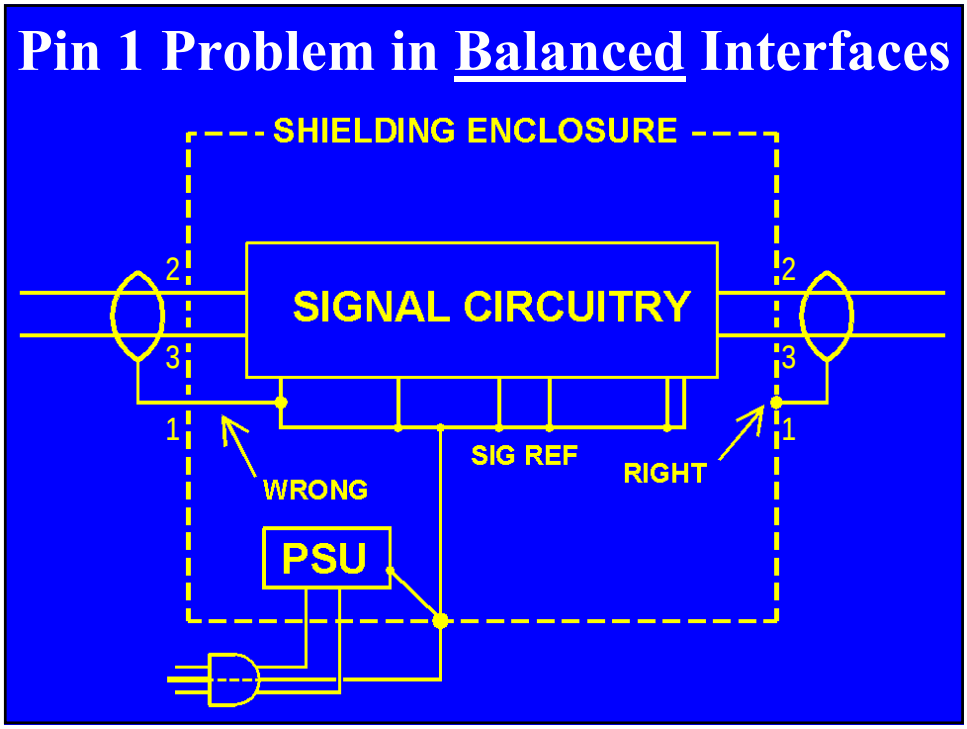
- So How does RF get inside the box?

Common Mode Coupling

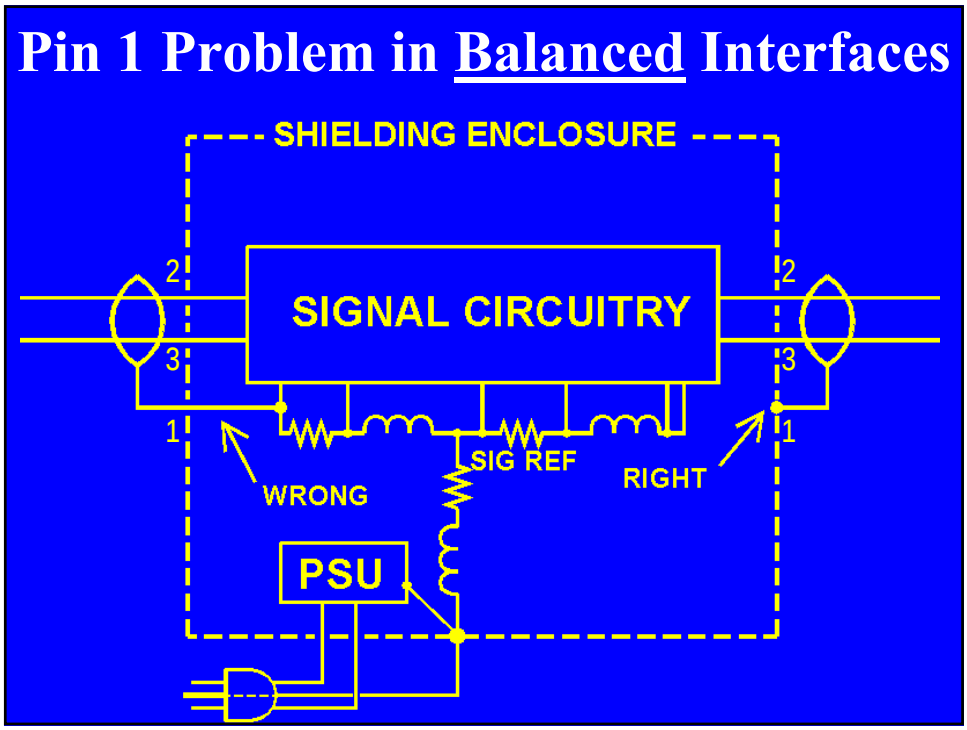
- So How does RF get inside the box?

Pin One Problems!

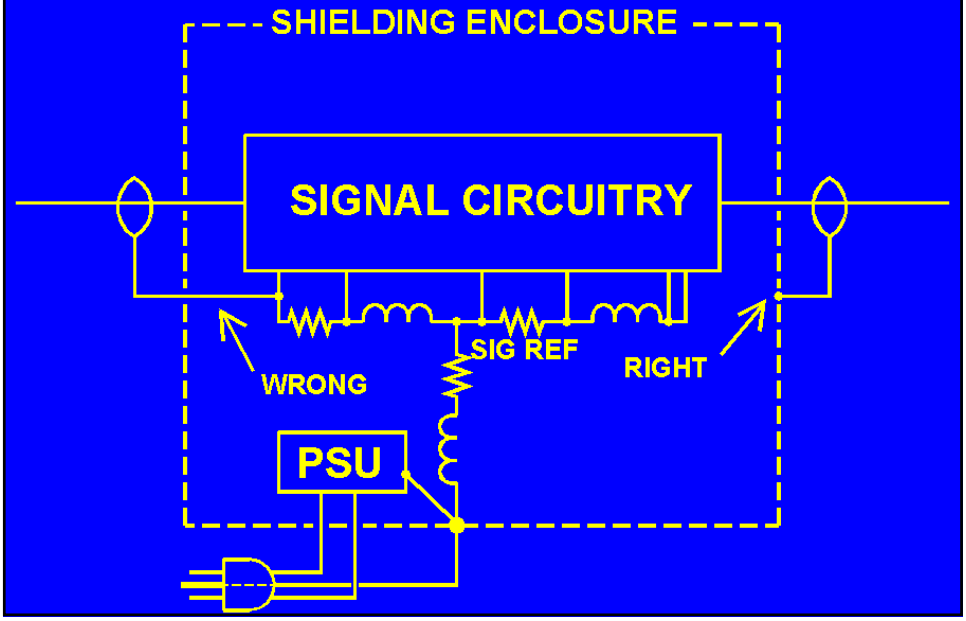
Pin 1 Problem in Balanced Interfaces



Pin 1 Problem in Balanced Interfaces



Pin 1 in Unbalanced Interfaces



Most RFI is caused by Pin 1 Problems!

That Includes "RF in the Shack," or "RF Feedback!"

How Does It Happen?

- Connectors mounted to PC board
- Shell not bonded to chassis
  - It should be, but it isn't – that costs more!
- Often very difficult to fix
- All inputs and outputs are usually bad
  - Audio and video
  - Serial and USB interfaces
  - Control wiring

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

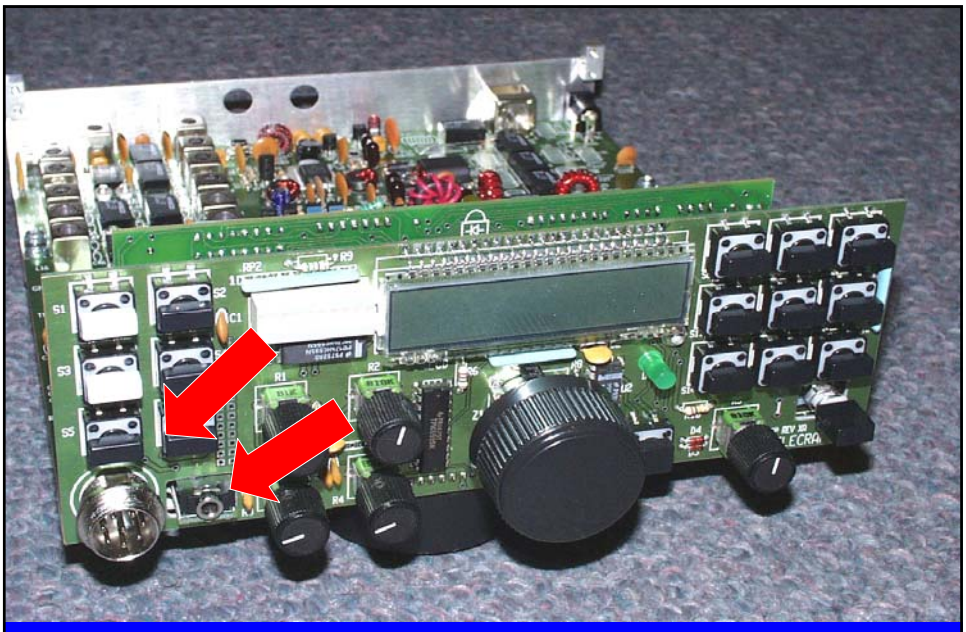
How Do Pin Problems Happen?

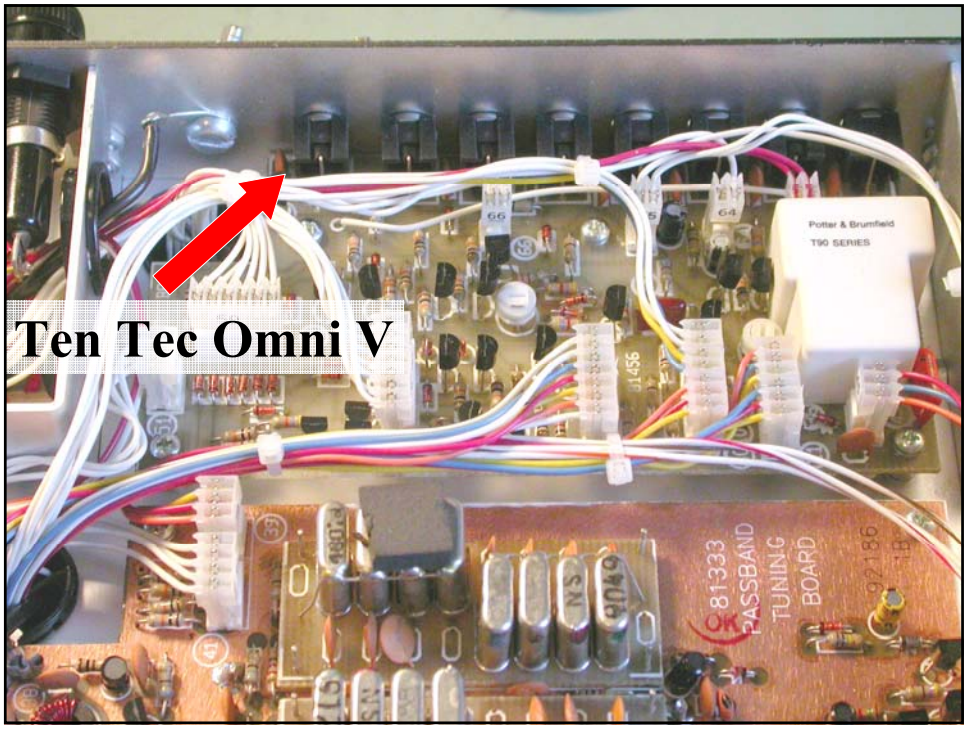
Insulating rings around all connectors prevents chassis contact!

How Do Pin Problems Happen?

- Pin 1 of XL's go to chassis via circuit board and ¼" connectors (it's cheaper)
- XLR shell not connected to anything!
- RCA connectors not connected to chassis

Nice Radio, Has Pin 1 Problems

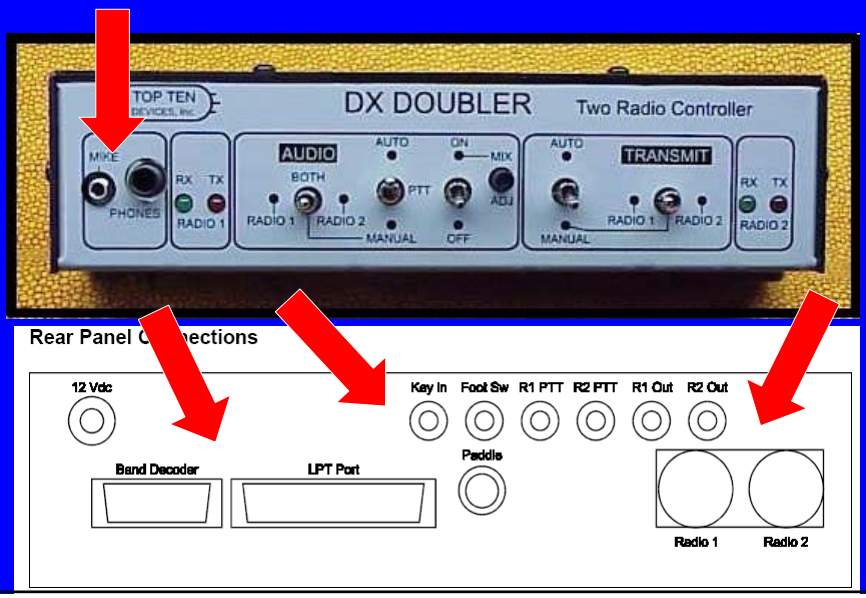




A Pin 1 Problem in FT-1000MP

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 <u>should</u> be, but they are <u>not</u>!

Where are the Chassis Connections for this laptop's sound card?

Yes, it's the DB9, DB15, and DB25 shells!

Two Ways to Kill Pin 1 RFI

- Rewire/rebuild the connector
  - Wire Pin 1 to the chassis, not PC board
  - Bond connector to chassis, not PC board
- Kill the current
  - Make the wiring a lousy antenna
  - Add a common mode choke
  - Short out the current
  - Kill the voltage that causes current flow

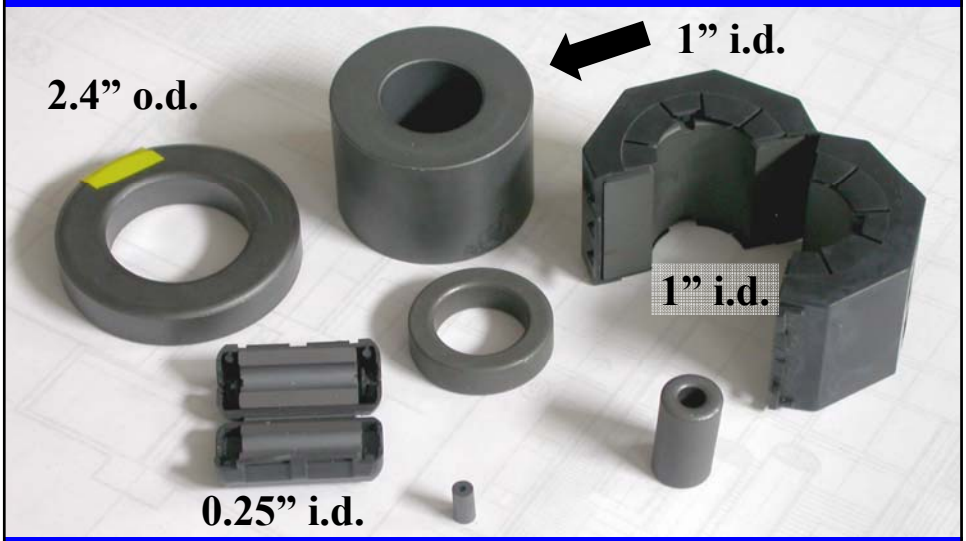
Using Ferrites to Tame the Antennas

Ferrites can block the current!

What's a Ferrite?

- A ceramic consisting of an iron oxide
  - manganese-zinc – 1-30 MHz
  - nickel-zinc – 30 MHz-1 GHz
- Permeability (μ) much greater than air
  - Better path for magnetic flux than air
  - Multiplies inductance of a wire passed through it
- Is very lossy at radio frequencies
- Does not affect audio

Different sizes and shapes



They can look alike, but be very different

They're brittle!

What Common Mode Chokes Do

- Add high resistive impedance in series with the common mode circuit, reducing antenna current
- Have no effect on differential signals carried between the conductors, inside the cable

This single-turn choke is effective from 80-300 MHz

This 4-turn choke is about right for 15-30 MHz

This 5-turn choke is about right for 10-30 MHz

An Effective Choke for 2-10 MHz

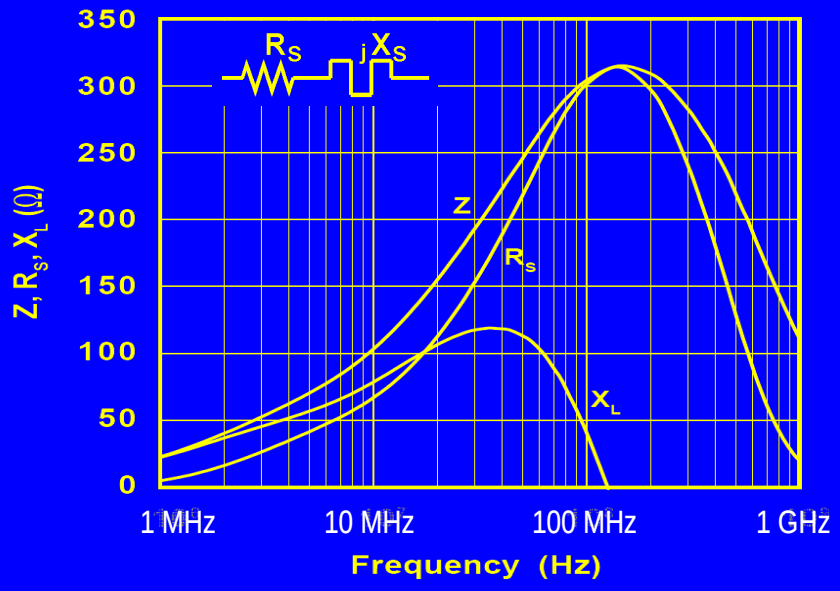
14 turns around a #31 core

Ferrites and High Power

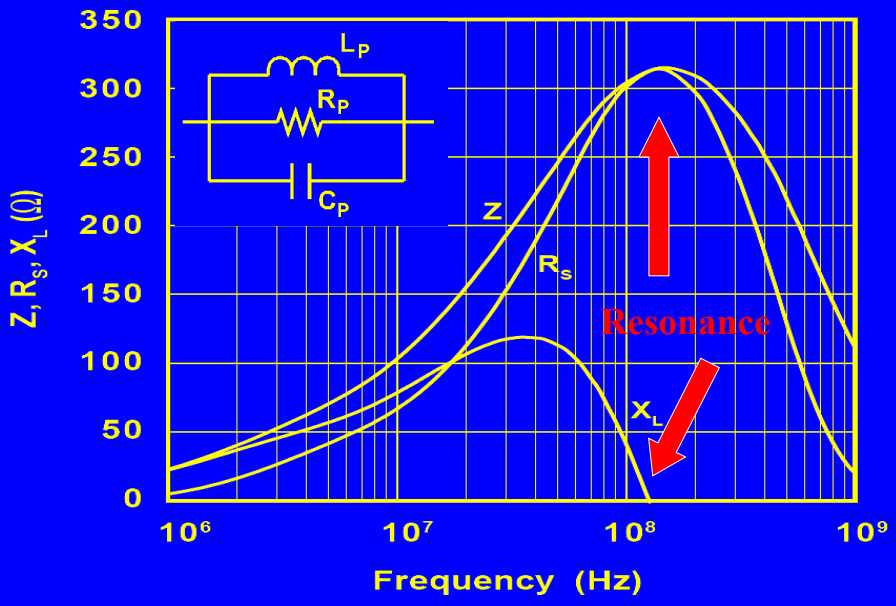
- If both conductors of high power circuits are wound through core, the fields cancel, so only the common mode current contributes to saturation
- Thus, ferrite common mode are effective on loudspeaker and power wiring
- Common mode chokes have no effect on audio, video, or control system signals – they are all differential signals

A (too) simple equivalent circuit of a wire passing through a ferrite

Impedance of Wire Through Ferrite

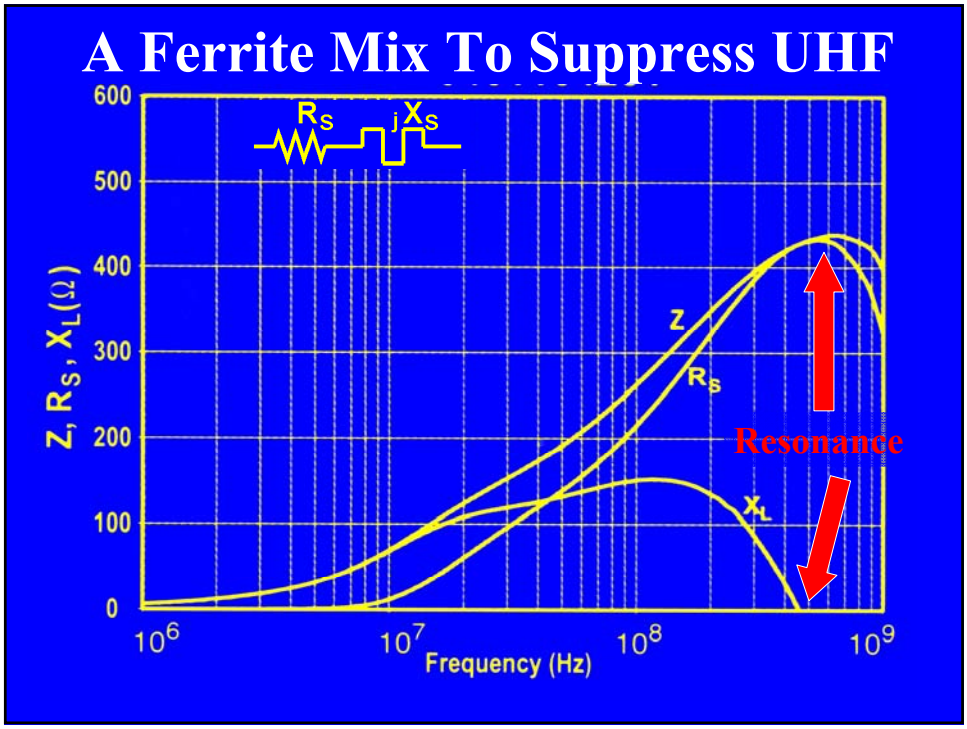


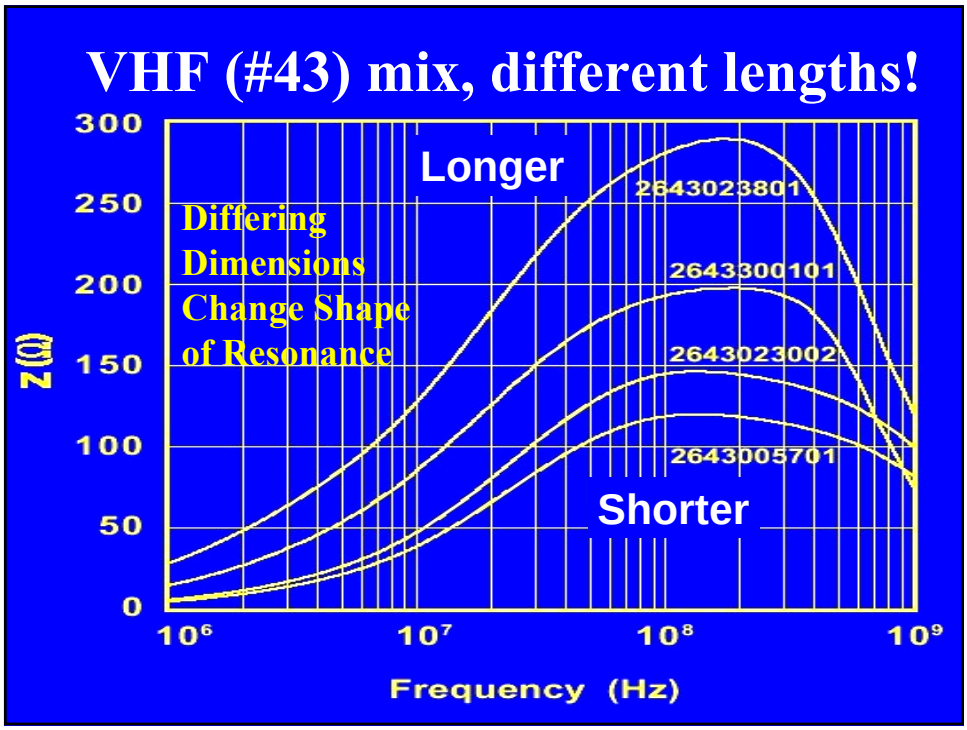
It's Really a Parallel Resonance

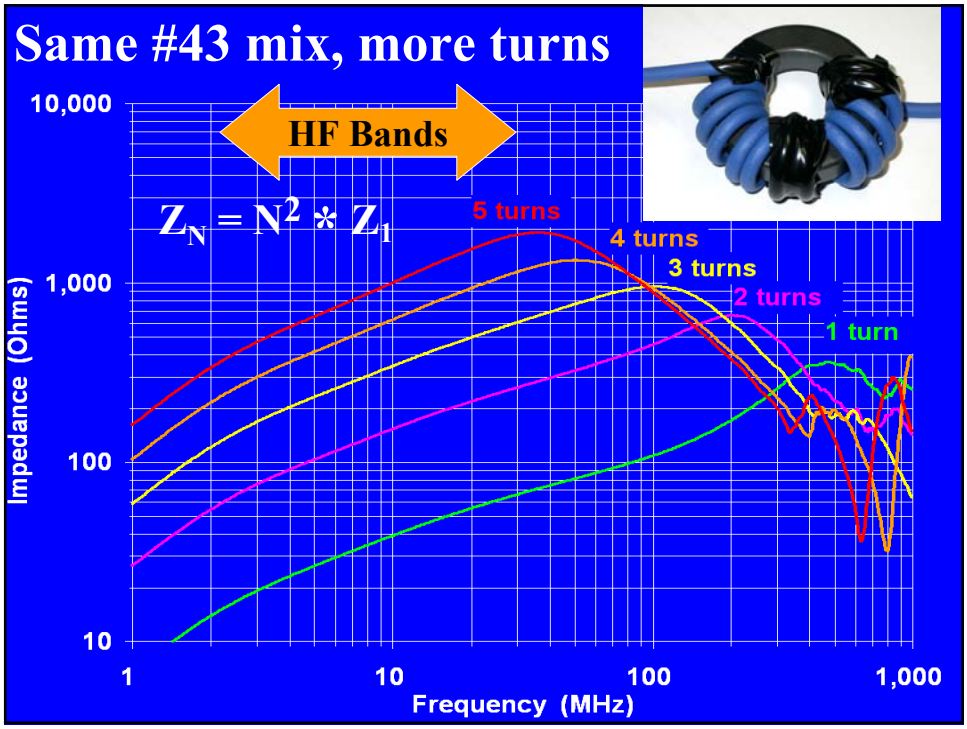


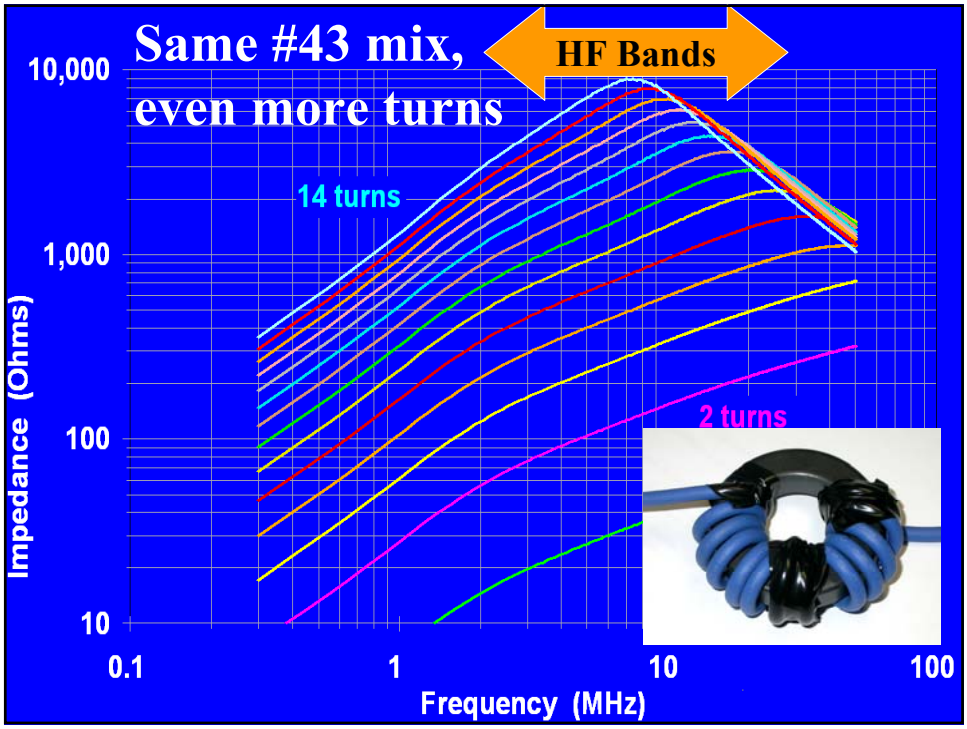
Where's the Capacitance here?

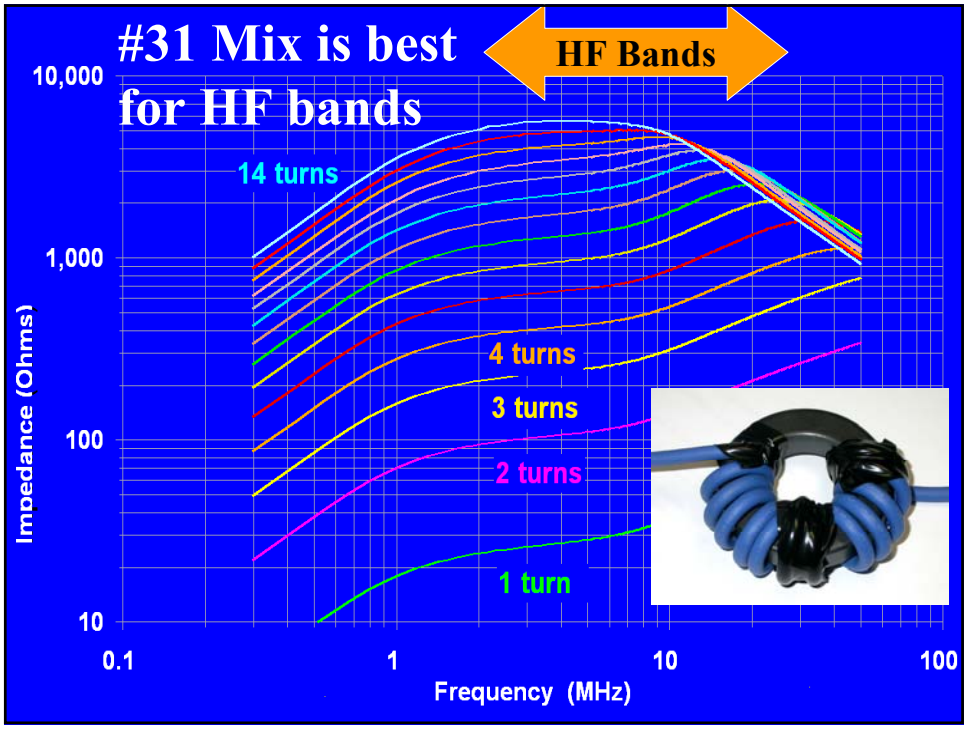
From one end of the choke to the other, through the permittivity of the ferrite (it is a dielectric!)


A Ferrite Mix To Suppress UHF
Rs
jXs
600
500
400
300
200
100
0
Z, Rs, XL (Ω)
Z
Rs
XL
Resonance
10^6
10^7
10^8
10^9
Frequency (Hz)


VHF (#43) mix, different lengths!
300
250
200
150
100
50
0
Z(Ω)
Longer
Differing
Dimensions
Change Shape
of Resonance
2643023801
2643300101
2643023002
2643005701
Shorter
10^6
10^7
10^8
10^9
Frequency (Hz)


Same #43 mix, more turns
HF Bands
$Z_N = N^2 * Z_1$
5 turns
4 turns
3 turns
2 turns
1 turn
10,000
1,000
100
10
Impedance (Ohms)
1
10
100
1,000
Frequency (MHz)


Same #43 mix,
even more turns
HF Bands
14 turns
2 turns
10,000
1,000
100
10
Impedance (Ohms)
0.1
1
10
100
Frequency (MHz)

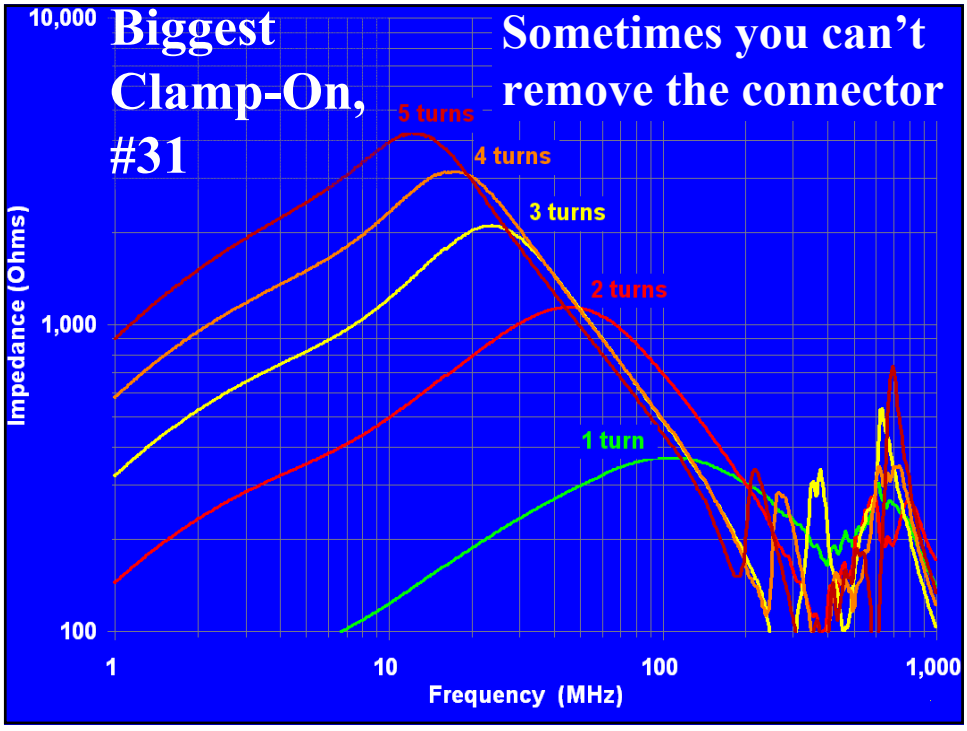

#31 Mix is best for HF bands
HF Bands
10,000
1,000
100
10
Impedance (Ohms)
14 turns
4 turns
3 turns
2 turns
1 turn
0.1
1
10
100
Frequency (MHz)


If You Can't Remove the Connector
1" i.d.
2.4" o.d.
1" i.d.
0.25" i.d.

If you can't easily remove the connector

Biggest Clamp-On, #31

Sometimes you can't remove the connector



Solving RFI Problems

Strategy to Kill RFI

- How bad is the problem?
- Where is it getting in (or out)?
- Work on most common problems first
  - Pin 1 Problems
  - Speaker cable
  - CATV leakage
  - Cables with poor shielding
- These problems have easy solutions

RFI From Your Station

- How bad is the problem?
  - Reduce your TX power until RFI stops
  - Convert the reduction to dB – 10 log (P_2/P_1)
  - That's how much suppression you need
  - Repeat for each ham band and victim gear
- If problem is TVI
  - Interference to picture, or only sound?
  - Interference if TV is off?

Kill Antenna Current

- Identify the most likely antennas
- Add a choke tuned to the RFI

RFI From Your Station

- Identify the most likely RX antennas
- Start with longer "antennas"
  - Rooftop and CATV lead-ins, speaker cables
- Add a ferrite choke tuned to the frequency of the RFI (see graphs)
- Attack shorter antennas if still a problem
  - Interconnect cables in an A/V setup

This 4-turn choke is about right for 15-30 MHz

This 5-turn choke is about right for 10-30 MHz

An Effective Choke for 2-10 MHz

14 turns around a #31 core

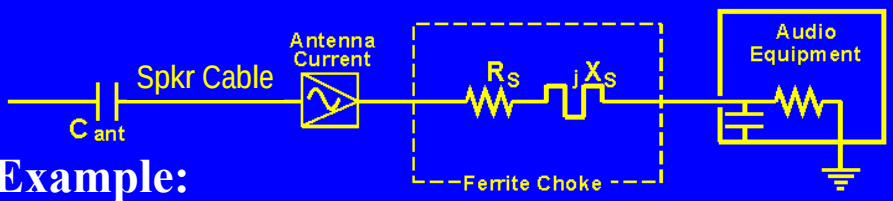
RFI From Your Station

- If RFI is only to sound, and happens with TV turned off (TV feeds A/V system)
  - Problem is in the audio equipment
  - Replace speaker wiring with twisted pair
  - Choke the speaker wiring first
  - Choke cable(s) between TV and audio rig
  - Choke coax from antenna or cable box

You May Not Need an Elephant Gun

- Most detection is square law, so:
  - A 10 dB reduction in RF level reduces audible interference by 20 dB
- But we must add enough impedance to overcome the threshold effect

Threshold Effect



Example:

Our antenna is short, so looks capacitive

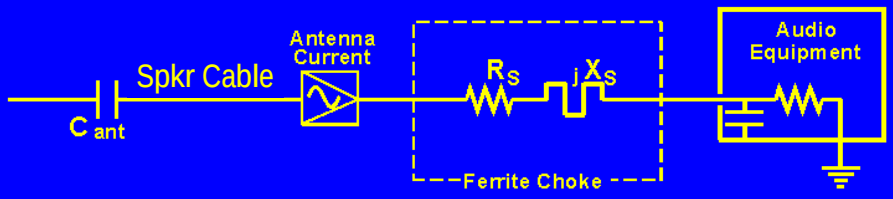
Without the choke, the total antenna circuit is 300∠-60°Ω,

and we add a choke that is 300∠60°Ω,

Z_T = (150 –j260) + (150 +j260) = 300 Ω

Our choke has not helped!

Threshold Effect



But if we make the choke larger (more turns or more cores in series), additional R_S will begin to reduce the current.

Increasing R_T to 425Ω (3 dB) reduces detected RF by 6 dB, and increasing R_T to 600Ω (6 dB) reduces detected RF by 12 dB (assuming no change in X_S).

Threshold Effect

- The ferrite choke should add enough series R that the resulting Z is 2x the series Z of the "antenna" circuit without the choke. This reduces RF current by 6 dB, and detected RF by 12 dB.
- Very little suppression occurs until the added R is at least half of the starting Z.
- More choking impedance is better!

Criteria for Good Suppression

- Choke must be predominantly resistive
  - Low Q, near resonance, #31, #43 only
  - Use measured curves to set resonance
- 1,000 ohms is a minimum design goal
- 5k ohms or more needed for RX noise
  - Use more turns to lower resonance
  - Use chokes in series to get more resistance

Criteria for Good Suppression

- Use only #31 material below 5 MHz
- Use #31 or #43 material above 5 MHz
  - #43 slightly better above 10 MHz

Covering Wide Frequency Ranges

- Use multiple chokes in series, each tuned to a different frequency range
- Put highest frequency choke closer to the equipment
- Example:
  - 14 turns on #31 toroid for 2-10 MHz
  - 8 turns on #31 or #43 toroid for 10-30 MHz

This expensive loudspeaker cable makes equipment vulnerable to RFI

Parallel wire (zip cord) has very poor RFI rejection

Twisted pair cables help equipment reject RFI

#12 POC * is great loudspeaker cable!

POC – Plain Ordinary Copper

RFI From Your Station

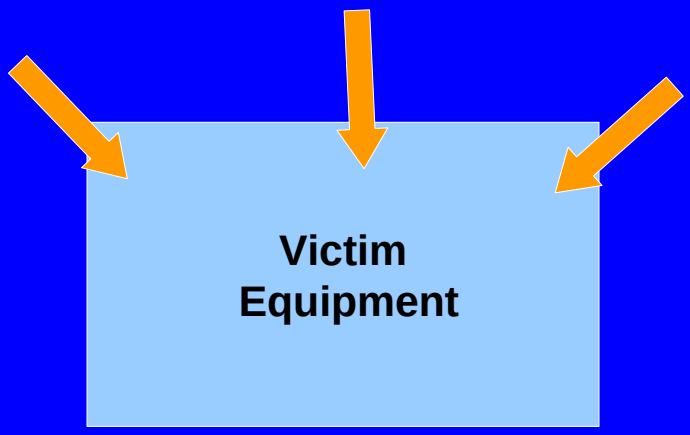
- If RFI causes picture and sound breakup, the TV or cable box is most likely problem
  - Choke coax from roof antenna, cable box, or satellite downlink
  - Choke cables to video recorder, A/V rig
- If chokes don't help and TV is on a CATV system, check for leakage in that system

Leaky CATV Systems

- Tune an FM talkie to 145.25 and probe around CATV wiring look for a buzzy carrier (cable channel 18)
- When you find a buzzy carrier, you've found a leak
- There may be more than one
- The CATV company should fix their leaks
- Leaks also spew RF trash on ham bands

Poor Equipment Shielding

- Internal wiring is receiving antenna



Antennas Inside Equipment

- Wires and circuit traces are antennas too
- Shield the equipment

or:

- Add a ground plane on a second layer
  - Each circuit trace is now a transmission line
  - Current returns on ground plane under trace
  - Minimizes the loop area
  - Minimizes antenna action
  - Microstrip (one ground plane)
  - Stripline (two ground planes sandwich the trace)

Shielding Failures

- Plastic cases
- Openings in shielded cases
  - Gaps between pieces of metal case
  - Paint at joint of metal surfaces creates a slot opening, RF escapes
- Cables enter case without bond to case
- Breaking a ground plane under a trace
  - Defeats the ground plane – current flows in a big loop, becomes antenna and magnetic loop

No Easy Fixes for Most Equipment Shielding Failures

- Scrape the paint to close slot openings
- Bond cable shields to the case
- Most other shielding problems usually require a complete rebuild
- Return to manufacturer as defective
- Give it the bucket treatment

The Bucket Treatment

- Find a bucket large enough to hold the defective equipment
- Fill it with water
- Put the equipment in twice
- Take it out once

Poor Cable Shielding

- Shield current is converted to a differential voltage
- Poor filtering lets it inside the box

Cable Shielding Problems

- Many common A/V cables have poor shields
- Add a ferrite choke to the cable

or:

- Build your own cables using coax with a robust copper braid shield (RG174, RG58)

Making Your Own Audio Cables

- Much better than you can buy
- Use coax with robust copper braid shield
- Use Switchcraft and Neutrik Connectors
  - Full Compass Systems, Madison, WI
  - Sweetwater, Ft. Wayne, IN
- Buy connectors in quantity – shipping is much of the cost
- Expensive high futility stuff not a solution

Cable-Mount Audio Connectors

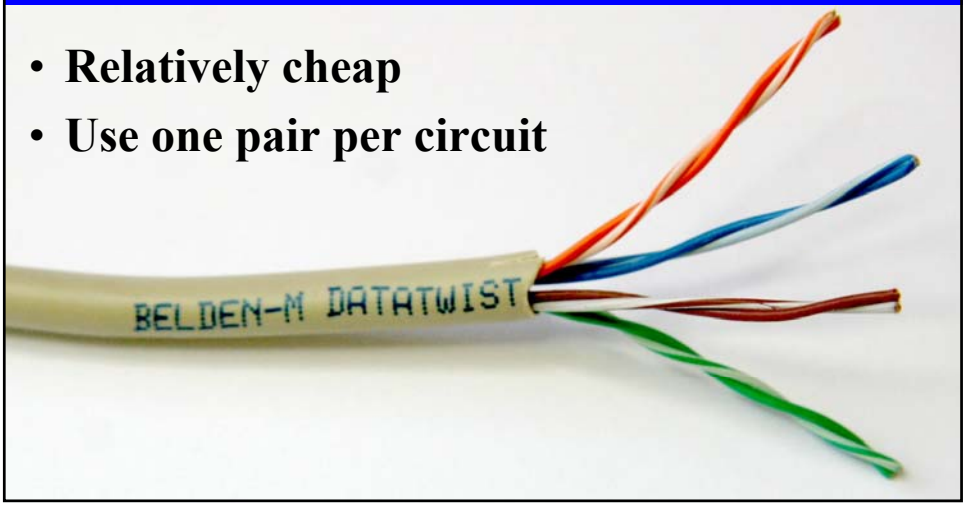
Description	Switchcraft	Neutrik
3-ckt male 1/8” plug	35HDNN	NYS231BG
2-ckt male 1/8” plug		NYS226BG
3-ckt female 1/8” jack		NYS240BG
Phono (RCA) male plug	3502	NYS352
Phono female jack	3503	

Cable Problems – Paired Cable

- **Parallel wires (zip cord) cause RFI**
- **Twisted pair cable rejects hum, buzz, RFI**
- **Replace zip cord with twisted pair**
  - **CAT5/6 for telephone wiring, security systems**
  - **#14 gauge between loudspeakers and power amp**
  - **CAT5/6 for RS232 cables, one pair per circuit**
  - **Improvements of 20-30dB (100-1,000X the power)**
- **Twisting is far more important than shielding**

CAT5 is 4 Very Good Twisted Pairs

- Excellent for audio, digital, telephone, control wiring, RS232
- Relatively cheap
- Use one pair per circuit



RFI to Telephones and DSL Modems

- Use only CAT5/6 for telephone wiring
- Use one pair for each circuit
  - Blue = hot, blue/white = return
- Tune DSL chokes to ~2 MHz
  - 30 turns on one #31 toroid
  - 22 turns on two #31 toroids
- Place choke very close to DSL modem
- Use add'l choke(s) if needed

RFI to Telephones and DSL Modems

- Choke every cable connected to phone or modem
- Try for at least 10k ohms
- Telephones are known RFI dogs
- For wireless phones, choke the cable(s) at the base station

Security Systems

- Very poor RF rejection
- Connections between sensor and main unit are usually a simple switch contact
  - Try a small cap (470-1000 pF) across the cable pair at the main unit
  - Replace wiring with twisted pair
  - Chokes may help, but are <u>not</u> the first thing to try

Security Systems

- When connections carry data
  - Do not use a capacitor
  - Replace wiring with CAT5
  - Add choke at both ends
- When data is carried on the power line
  - Use twisted triplet cable for power wiring
  - Put power in steel conduit if you can
  - Call the manufacturer and force them to fix it

The Other Half of the Problem – RFI to Ham Radio

RFI To Ham Radio

- RF noise is generated inside equipment
- The wires inside equipment, and cables that interconnect equipment, are antennas, and can transmit that RF noise
- The same problems that let RF into the box also let it out of the box
  - Pin One Problems
  - Poor shielding and poor circuit layout
- Our antennas receive it like any other signal

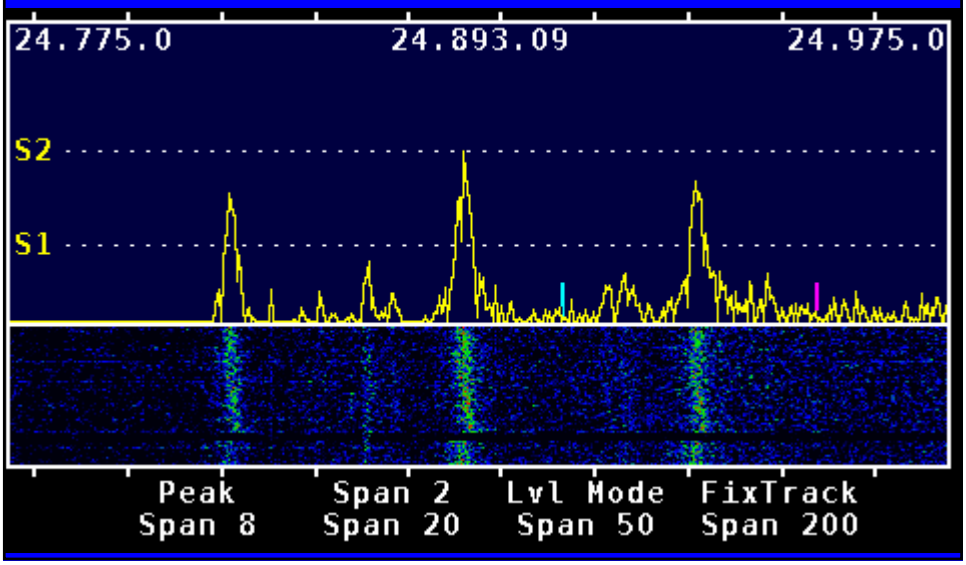
Sources of RF Noise

- Switching Power Supplies, including Battery Chargers
- Equipment with digital circuitry
  - Computers, audio and video gear, ham gear
- Plasma TV Sets
- Faulty Insulators in Power Systems
- Variable Speed Motors

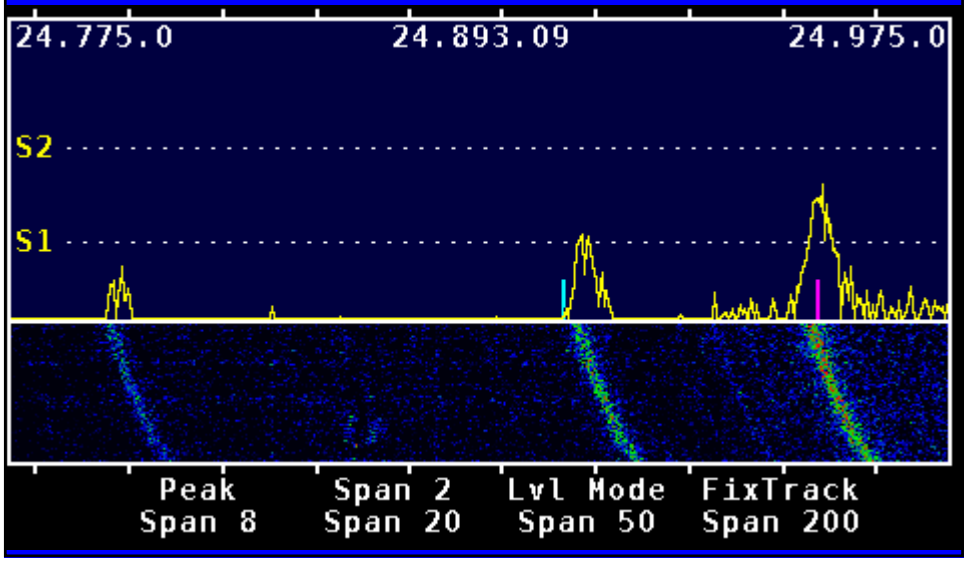
What is Digital Noise?

- Most digital noise results from oscillators or clocks that produce square waves
- Square waves have lots of harmonics
- Fast rise times = strong harmonics

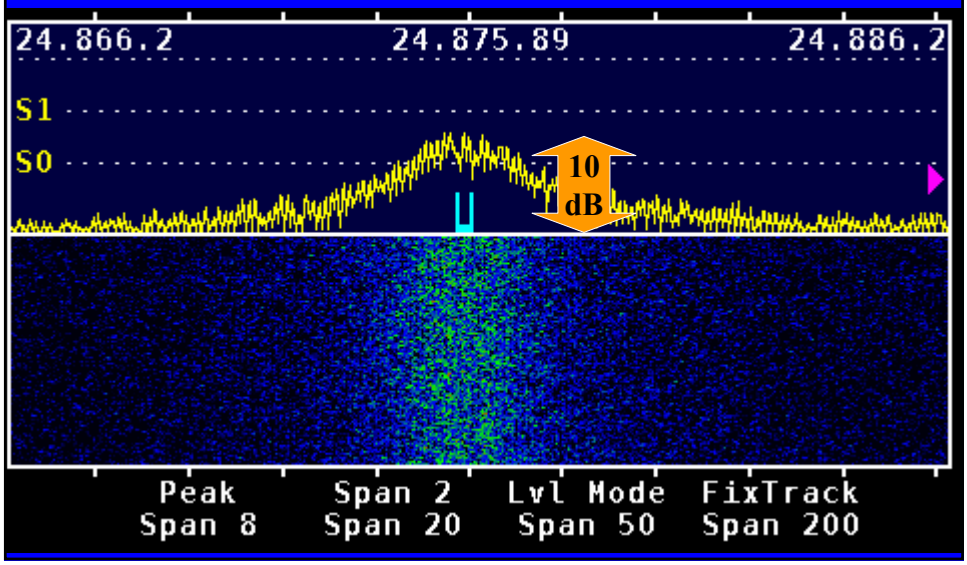
Typical noise signature of a switching power supply



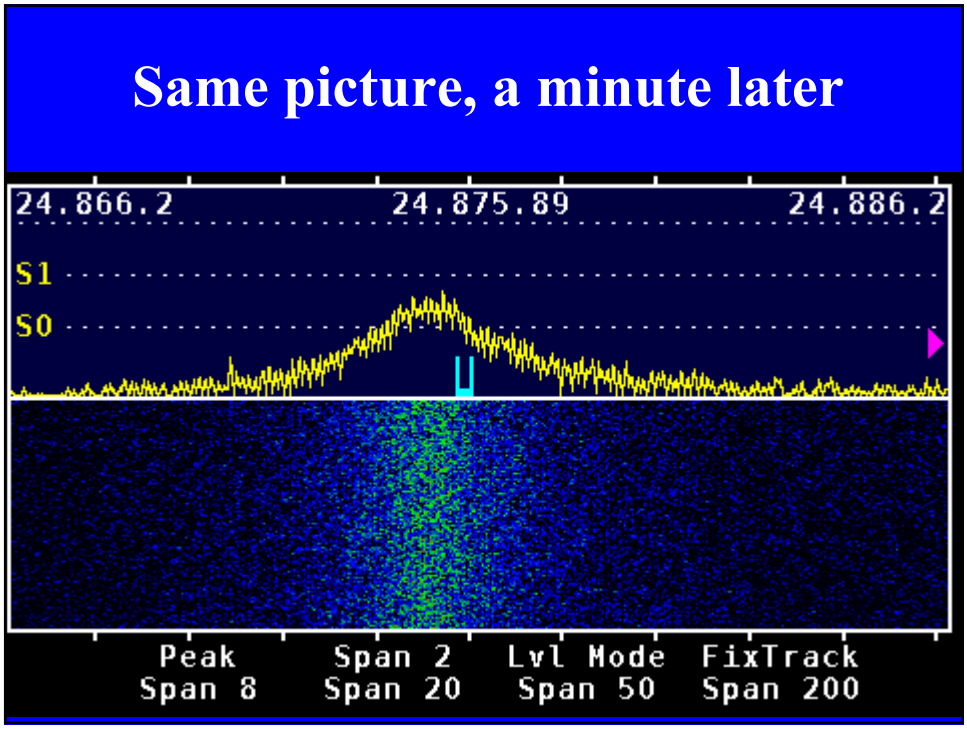
The same switching PSU drifting after being switched on



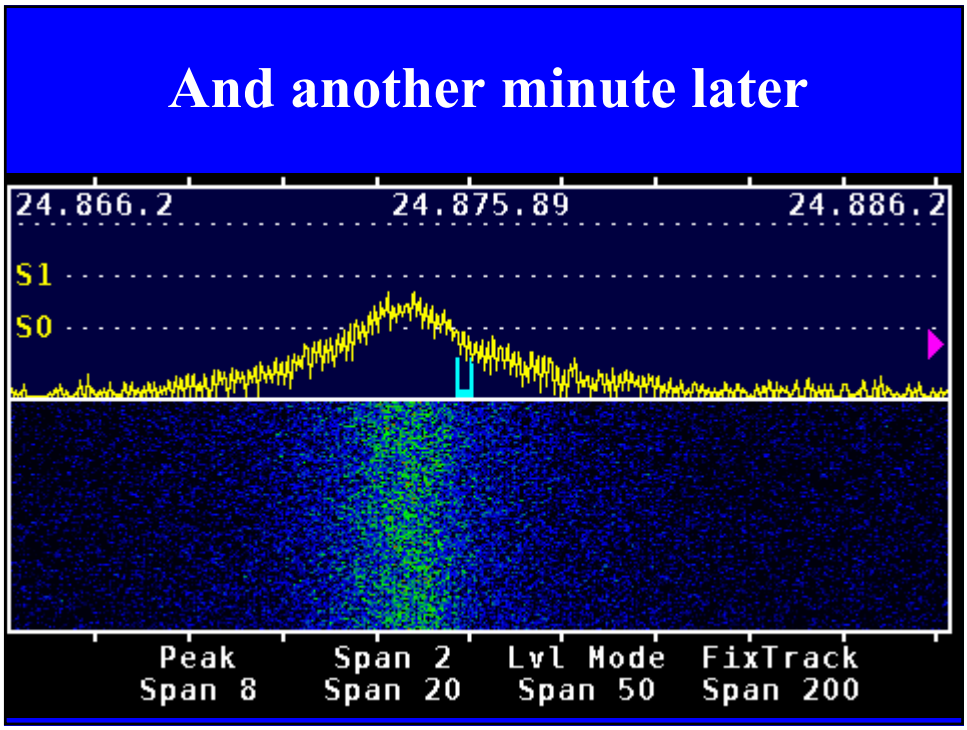
A closer look at one of the peaks



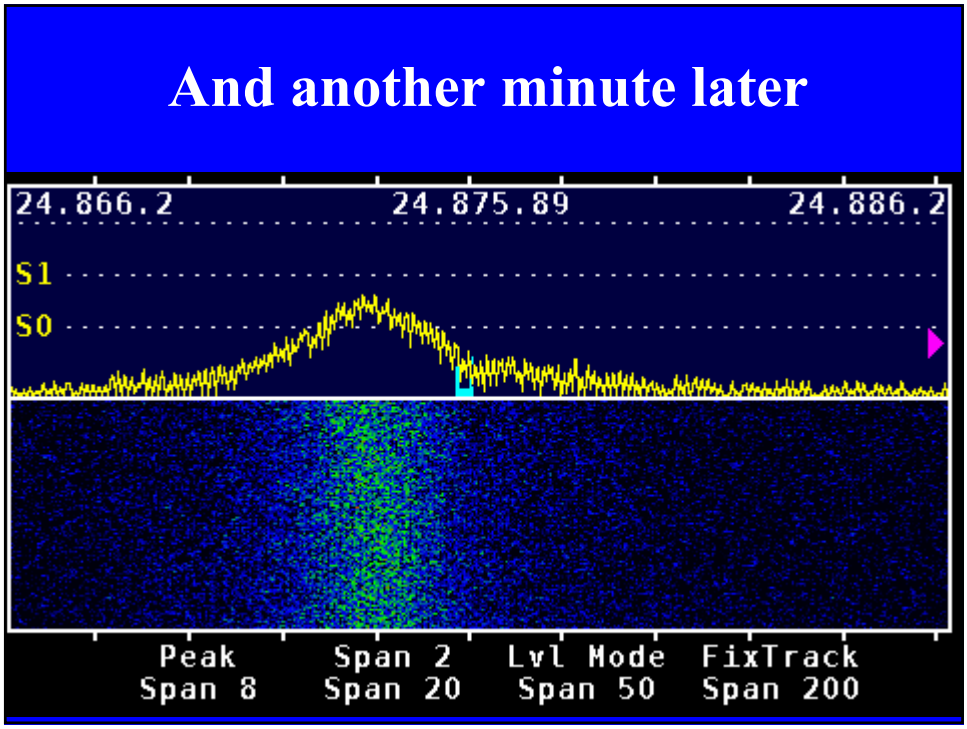
Same picture, a minute later



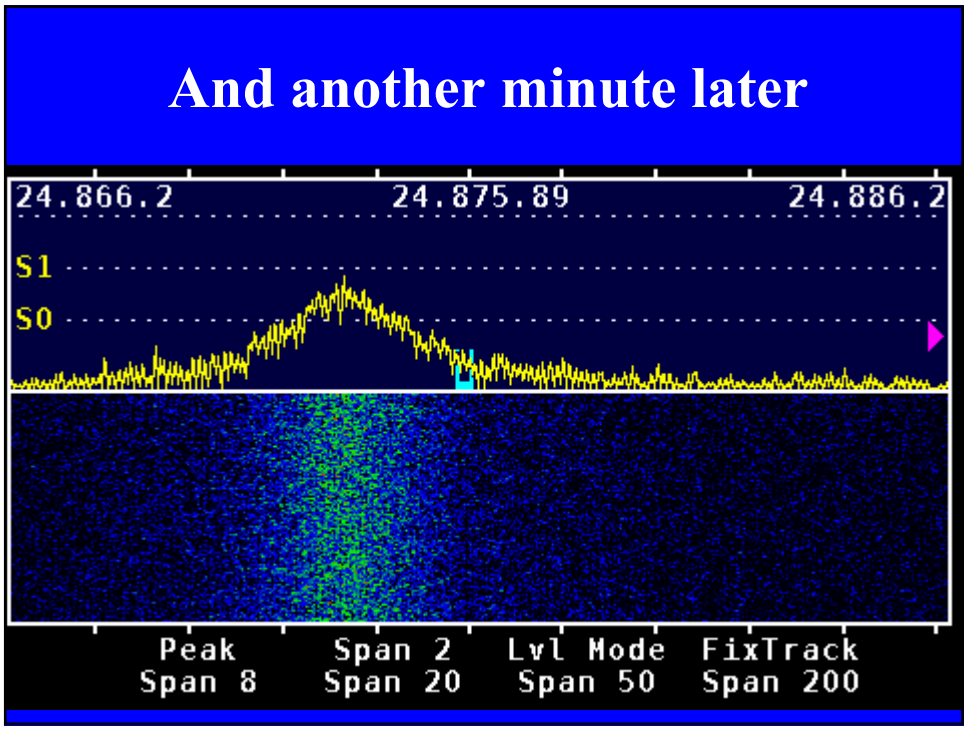
And another minute later



And another minute later



And another minute later



That's the PSU for my SteppIR

- I'd already suppressed the noise by more than 20dB before I took these pictures!
- I've worked a lot of guys who don't move my S-meter
- 10 dB of noise makes a 1kW signal seem like a 100W signal
- 20dB of noise makes 1kW seem like 1W
- You can't work 'em of you can't hear 'em!
- It's really worth it to chase and kill RX noise

Why a Hump Instead of a Steady Carrier?

- Oscillators are *dithered* (FM-modulated by noise) to skirt FCC RFI rules
- That noise causes them to wobble around in frequency or drift, and the modulation makes them broad
- FCC rules limit the strength of carriers, so the FM noise moves some of power from carrier to sidebands

The Principle of Reciprocity – Coupling Works Both Ways

- Problems that let RFI into the box also let it out of the box
  - Pin One Problems
  - Poor Shielding
  - Poor Filtering
  - Large magnetic loop area
  - Accidental Antennas

The Principle of Reciprocity – Coupling Works Both Ways

- Techniques that minimize received interference will generally also reduce transmitted noise
- Relative strength of coupling depends on impedances of the coupled circuits, and may not be equal in both directions

RFI To Your Station

- How bad is the problem?
- Band noise should increase when the band is open, quiet when it is dead
  - 10-20dB increase is typical
  - Noise on 40, 80 and 160 should be low during the day, increase 10-20dB at night
  - Higher bands should also increase, but timing more complex

Measuring RFI To Your Station

- Most S-meters not very accurate
- One S-unit should be 6dB, but for most it's more like 3-4 dB
- A properly aligned K3 is accurate
- Our objective is to reduce local RX noise so that we see noise increase when the band is open

RFI To Your Station

- Start with your own home first
- Run your station on a battery and kill power to your home
  - Be sure to turn off any UPS units
- Any noise that goes away is your noise
- Restore power, and turn off one breaker at a time until noise stops (or gets weaker)

RFI To Your Station

- Start with your own home first
- Learn to locate and kill noise at home, so you don't look like a dummy if you can work on your neighbors' noise

RFI To Your Station

- Noise must be killed at the source
- You must find the source to kill the noise
- Exception – use antenna location and directivity to reduce noise
  - Move antennas away from noise sources
  - Use serious chokes on your feedlines at the feedpoint (that is, up in the air)

RFI From Digital Equipment

- What are the antennas?
  - Every interconnecting cable
  - The AC power line
- Wind multiple turns of AC cable through toroid to form choke
- Wind every interconnect cable through toroid to form choke

RFI From TV Sets, Cable Boxes

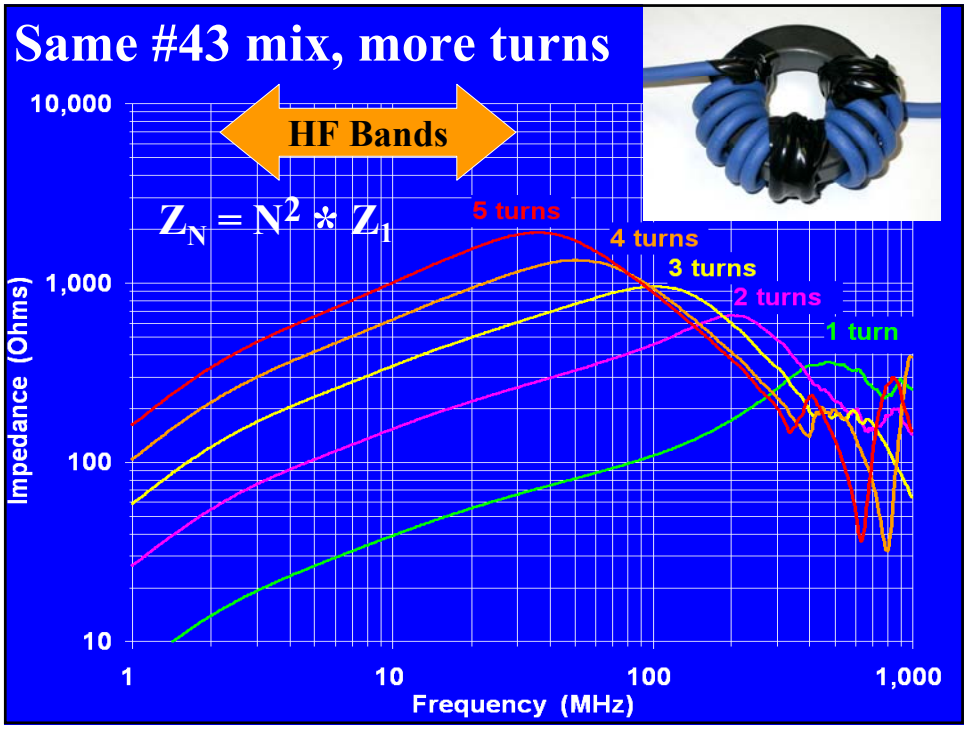
- What are the antennas?
  - Every audio/video cable
  - Coax from antenna, cable box, or DVR
  - The AC power line
- Wind multiple turns of AC cable through toroid to form choke
- Wind every interconnect cable through toroid to form choke

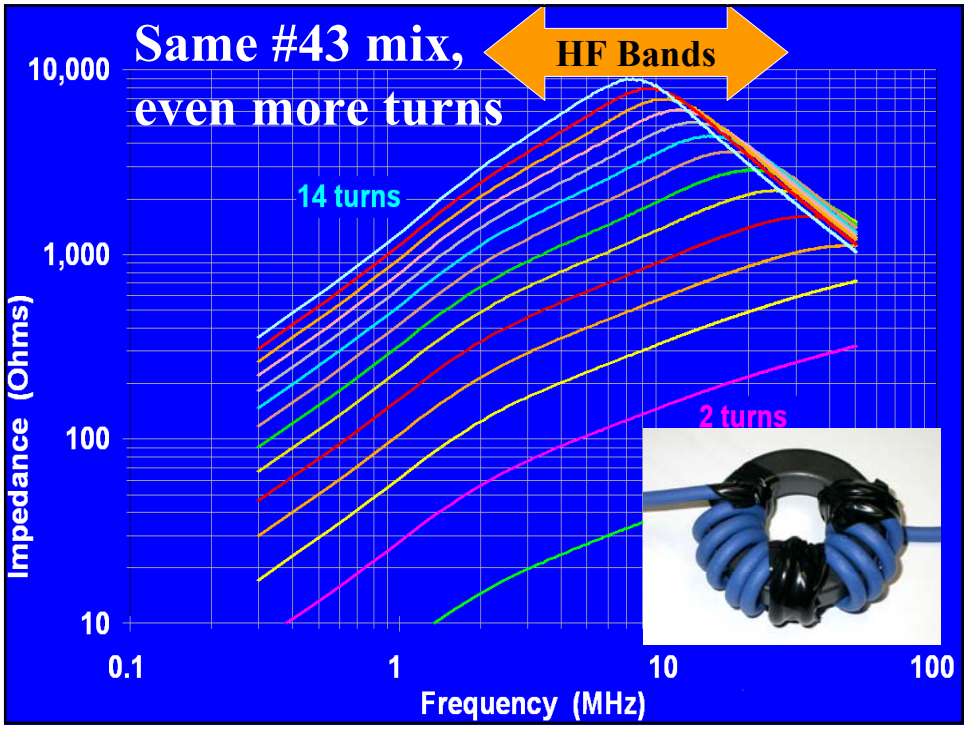
This 4-turn choke is about right for 15-30 MHz

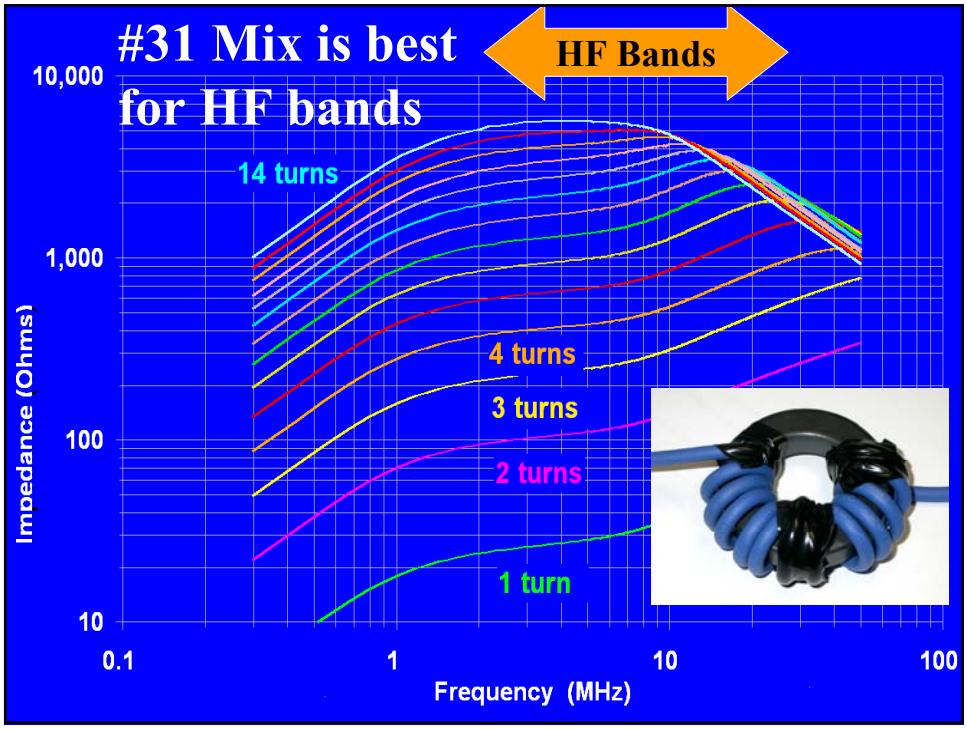
This 5-turn choke is about right for 10-30 MHz

An Effective Choke for 2-10 MHz

14 turns around a #31 core


Same #43 mix, more turns
HF Bands
$Z_N = N^2 * Z_1$
5 turns
4 turns
3 turns
2 turns
1 turn
10,000
1,000
100
10
Impedance (Ohms)
1
10
100
1,000
Frequency (MHz)


Same #43 mix,
even more turns
HF Bands
14 turns
2 turns
10,000
1,000
100
10
Impedance (Ohms)
0.1
1
10
100
Frequency (MHz)


#31 Mix is best for HF bands
HF Bands
10,000
1,000
100
10
Impedance (Ohms)
14 turns
4 turns
3 turns
2 turns
1 turn
0.1
1
10
100
Frequency (MHz)


If you can't easily remove the connector

RFI From Switching Power Supplies

- What are the antennas?
  - The DC cable
  - The AC power line

Noisy Equipment Solutions

RFI From Battery Chargers

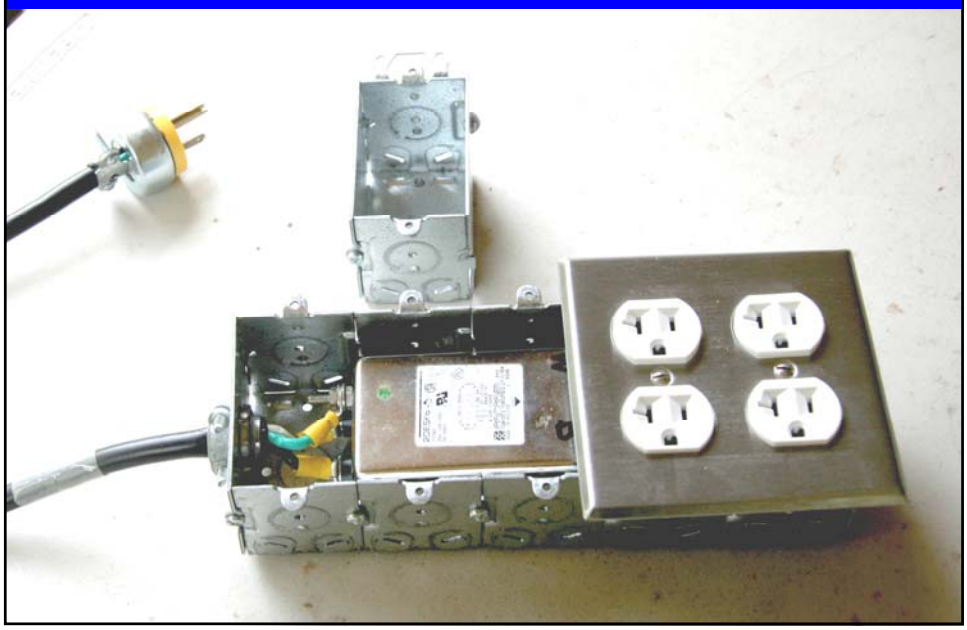
- What are the antennas?
  - The AC power line
  - The DC cable, if there is one
- Treat it like any other switching power supply – choke the antennas!

RFI From Switching Power Supplies

- Wind each DC cable through a ferrite core to form a choke
- Plug supplies into multi-outlet boxes and wind AC power cable through toroids to form chokes
- If you can, replace switching power supplies with linear power supplies
  - Rewire with Anderson Power Poles
  - Be sure to get the voltage right

Plug Noisy Power Supplies Into Filtered Power Outlets

A Field Day Generator RFI Filter



Field Day Generator RFI Filter Also Needs Ferrite Choke

RFI To Your Station

- Identifying Ethernet birdies
  - Crystal controlled, wide tolerance, modulated
  - Around 14,030 kHz, 21,052 kHz, low end of 10M CW, low end of 6M
  - Multiple signals – you will hear your neighbors too, each on a slightly different frequency
  - Kill power to your router to see if birdies go away, work on those carriers
  - Wind each ethernet cable around toroid
  - 6-8 turns usually about right
  - Some trash due to poorly shielded box

RFI To Your Station

- Killing Ethernet birdies
  - Wind each cable around toroid
  - 6-8 turns usually about right
  - Don't forget power supply cable
  - Some trash due to poorly shielded box
- Use shortest cables possible
  - Longer cable is better antenna

Two More Equipment Design Issues

- Magnetic Coupling
- Fast Rise Times

Magnetic Coupling

- A problem often overlooked by circuit and system designers
- A very potent coupling mechanism
- Strongly couples any large currents
  - Switching power supplies
  - Battery chargers
  - Variable speed motor controllers
  - Lighting controllers
  - Solar power systems and regulators

Current Flows in Loops

- Where does the return current flow?
  - Large loop area = strong magnetic field
  - Large loop area = more magnetic reception
  - Long wires = better antennas
- Good RFI design = very small loop areas and short antennas (or no antennas)
  - Place RF bypass cap directly between C and E of switching transistor, zero length leads
  - Keeps the loop area small for RF current

Rise Time

- RF trash proportional to switching speed
- Good RFI design = slow down the rise times of large pulsed currents
- Fast switching = lower power dissipation
- These are conflicting requirements
- Small rounding of waveform can greatly reduce RFI with little effect on dissipation

Troubleshooting RFI

- RFI often enters equipment (and systems) by more than one path.
- **When you find one path, always assume that there may be others!**
- Take a methodical approach. Don't give up when one "right" technique doesn't fix it – keep on doing other "right" things. The "right" techniques really are right!

Troubleshooting RFI

- It usually helps to have an assistant
- You operate your station while your assistant watches/listens for RFI in your living room (or your neighbor's)
- Your assistant listens to your station while you kill breakers one at a time to find noise sources, then add chokes as needed
- Use talkies to communicate

The Biggest Myths

Myth: "I need a better ground"

Fact: A connection to earth almost never reduces noise or RFI, and it will often make it worse, because the "ground wire" can act as an antenna.

Fact: A connection to earth is very important for lightning protection.

The Biggest Myths

Myth: "I need a separate RF ground"

Fact: Separate grounds are unsafe – they can kill someone, increase lightning damage, even start a fire.

Fact: Separate grounds are more likely to cause problems than to fix them.

Fact: BY LAW, all grounds must be bonded together

Definitive Text On RFI

***Electromagnetic Compatibility Engineering*, Henry Ott, Wiley, 2009**

References

- Henry Ott, *Electromagnetic Compatibility Engineering,* Wiley Interscience, 2009
- E. C. Snelling, *Soft Ferrites, Properties and Applications,* CRC Press, 1969
- E. C. Snelling and A. D. Giles, *Ferrites for Inductors and Transformers,* Research Study Press, 1983
- *Fair-Rite Products Catalog* This 200-page catalog is a wealth of product data and applications guidance on practical ferrites. http://www.fair-rite.com
- *Ferroxcube Catalog and Applications Notes* More online from another great manufacturer of ferrites. http://www.ferroxcube.com

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- ***Noise Susceptibility in Analog and Digital Signal Processing Systems***, **N. Muncy**, JAES, June 1995
- ***Radio Frequency Susceptibility of Capacitor Microphones,*** **Brown/Josephson** (AES Preprint 5720)
- ***Common Mode to Differential Mode Conversion in Shielded Twisted Pair Cables (Shield Current Induced Noise)***, **Brown/Whitlock** (AES Preprint 5747)
- ***Testing for Radio Frequency Common Impedance Coupling in Microphones and Other Audio Equipment***, **J. Brown** (AES Preprint 5897)
- ***A Novel Method of Testing for Susceptibility of Audio Equipment to Interference from Medium and High Frequency Broadcast Transmitters***, **J. Brown** (AES Preprint 5898)

References

- ***New Understandings of the Use of Ferrites in the Prevention and Suppression of RF Interference to Audio Systems*** , **J. Brown** (AES Preprint 6564)
- ***Understanding How Ferrites Can Prevent and Eliminate RF Interference to Audio Systems*****, J. Brown** Self-published tutorial (on my website)
- ***A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing*****, J. Brown** Self-published tutorial (on my website)

Applications notes, tutorials, and my AES papers are on my website for free download

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