RFI In Audio Systems
Pin 1 Problems, Poor Shielding, and Poor Input/Output Filtering

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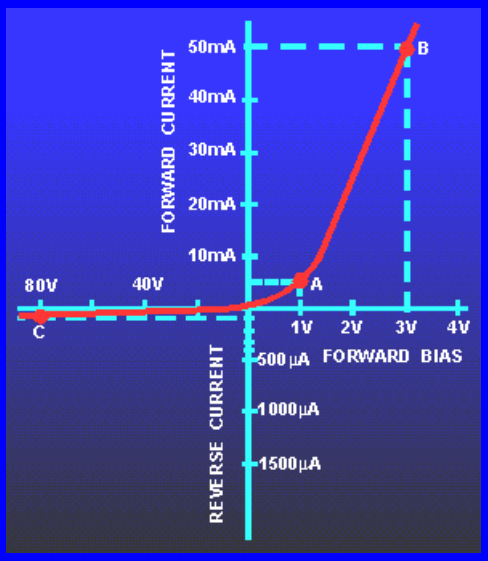
The Heart of the Problem

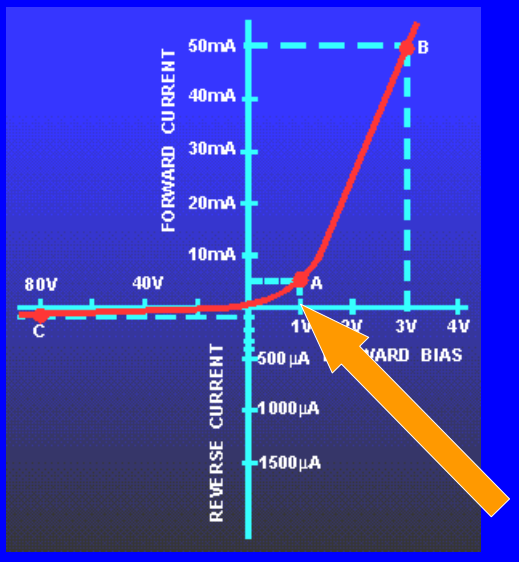
- Audio equipment can work as a radio receiver if we allow it to do so
- The wires inside our equipment, and cables that interconnect our equipment, are antennas, and can bring radio signals into our gear
- Some of our equipment is poorly designed

Square Law Detection



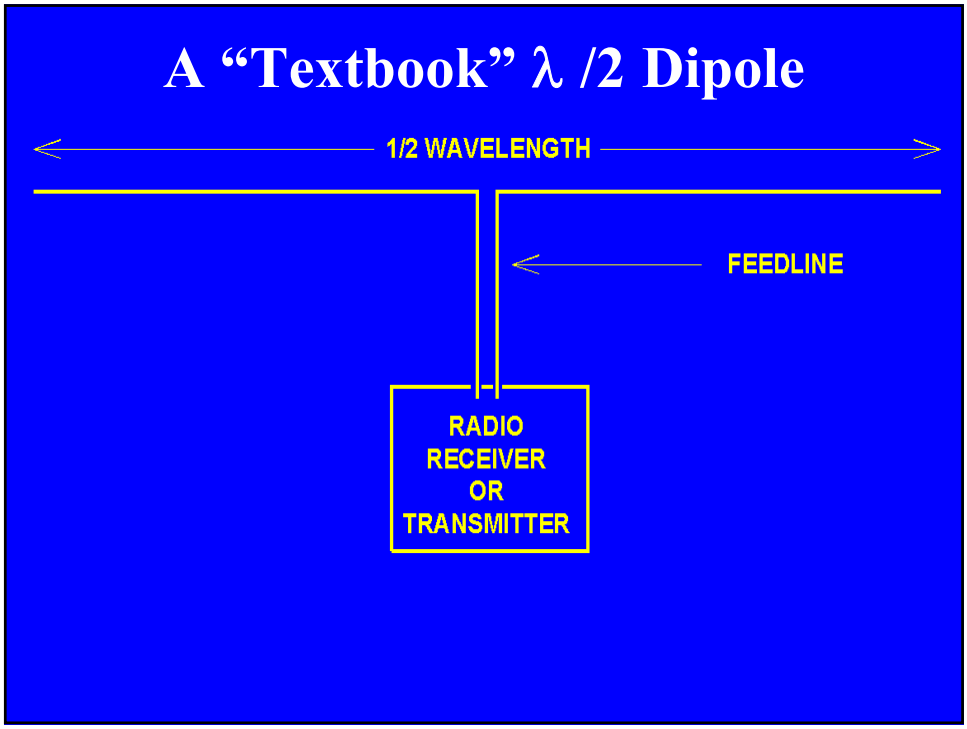
- Diodes
- Transistors
- IC's

Square Law Detection

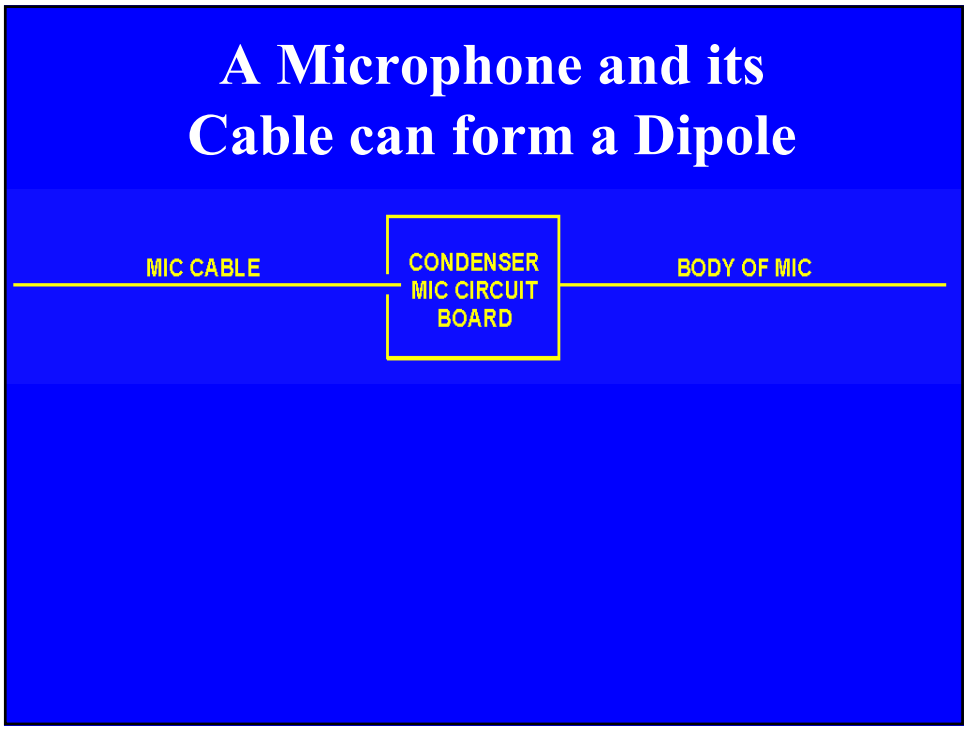


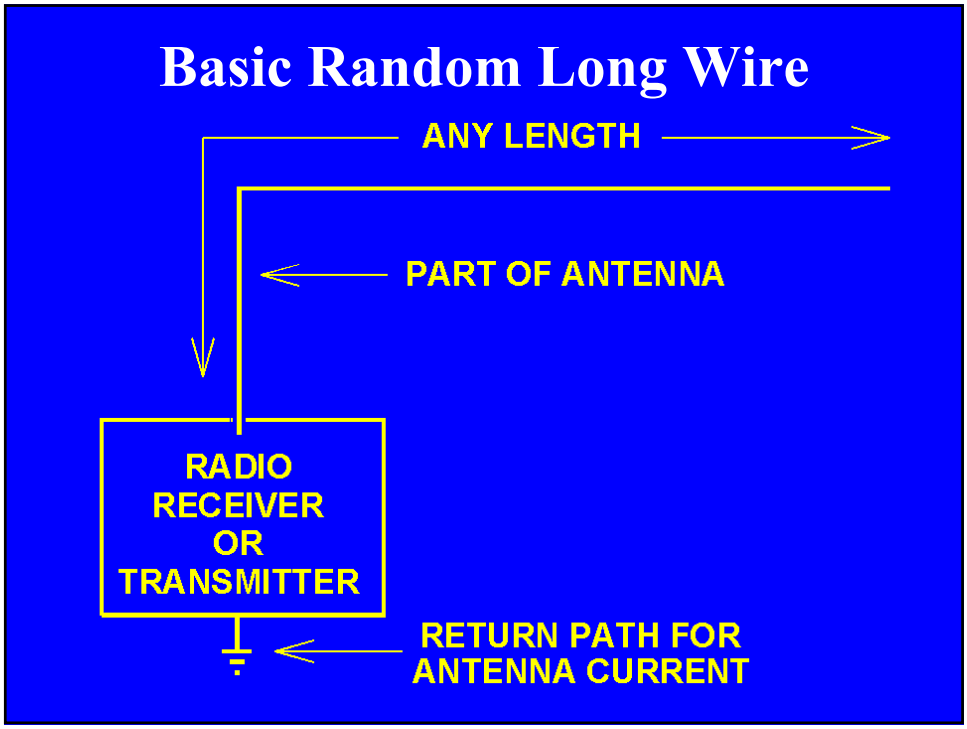
- Diodes
- Transistors
- IC's

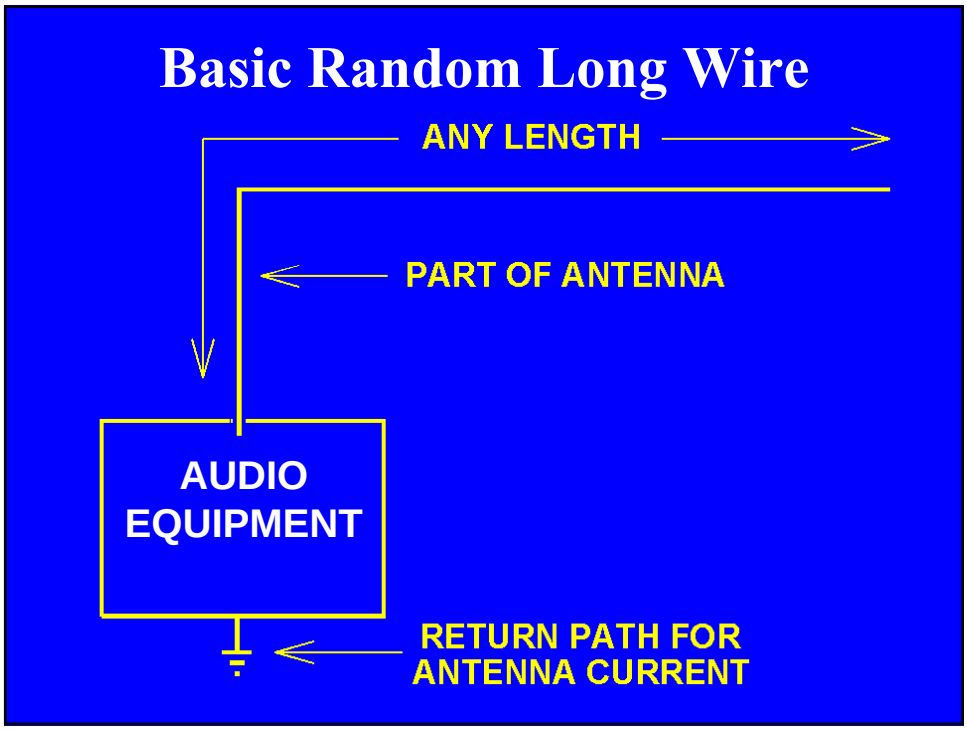
A "Textbook" λ /2 Dipole



A Microphone and its Cable can form a Dipole




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

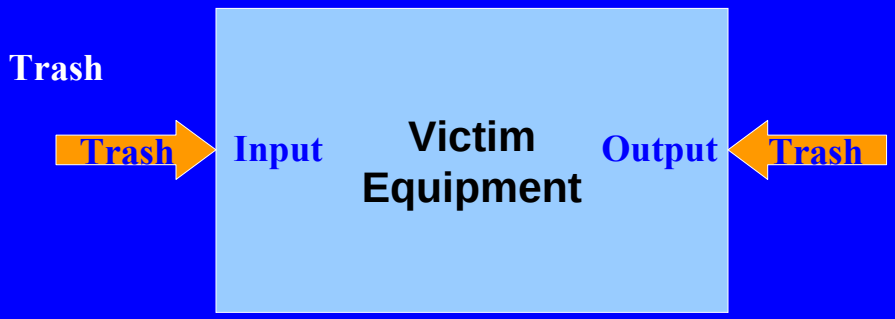

Basic Random Long Wire
ANY LENGTH
PART OF ANTENNA
AUDIO
EQUIPMENT
RETURN PATH FOR
ANTENNA CURRENT

Common Mode Coupling

- I/O wiring acts as long wire antenna

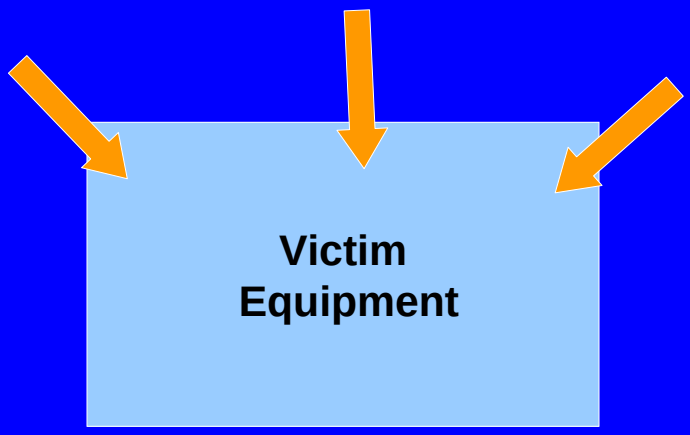
Differential Mode Coupling

- I/O wiring is not band-pass filtered



Poor Equipment Shielding

- Internal wiring is receiving antenna

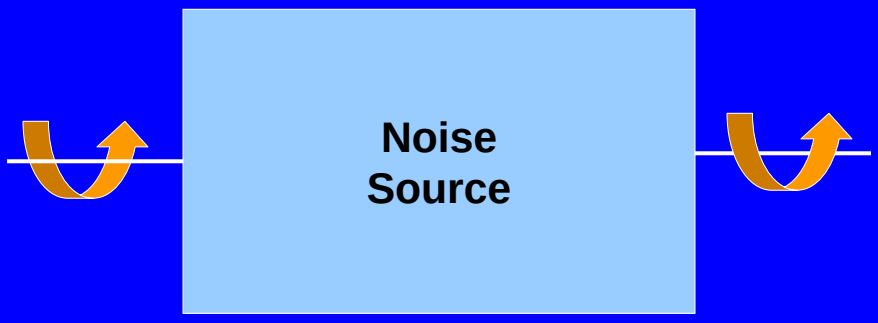


The Principle of Reciprocity – Coupling Works Both Ways

- If the coupling is passive, what helps minimize received interference will generally also help reduce transmitted noise
- Relative strength of coupling depends on impedances of the coupled circuit, and may not be equal in both directions

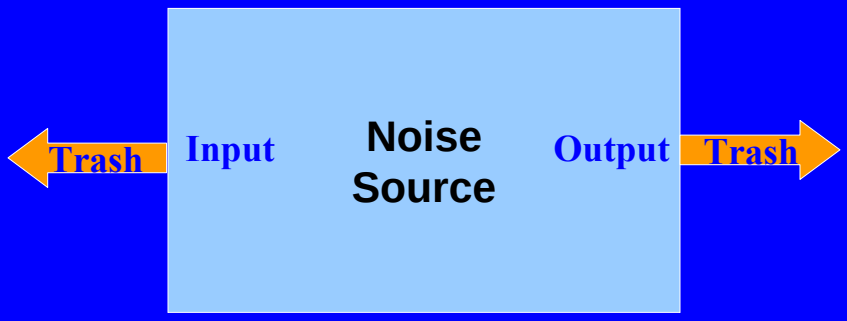
Common Mode Coupling

- I/O wiring acts as transmitting antenna



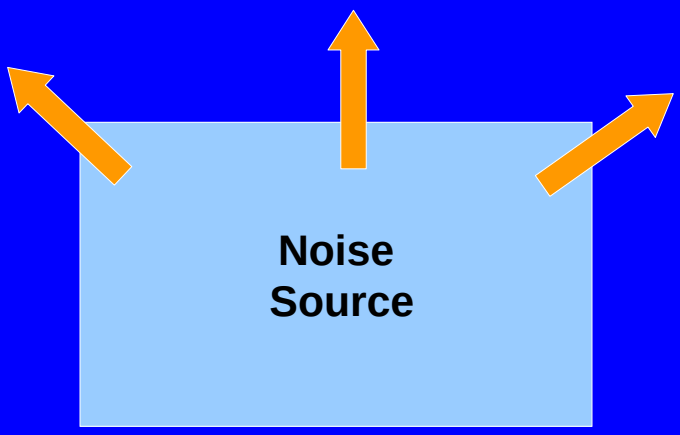
Differential Mode Coupling

- I/O wiring is not band-pass filtered



Poor Equipment Shielding

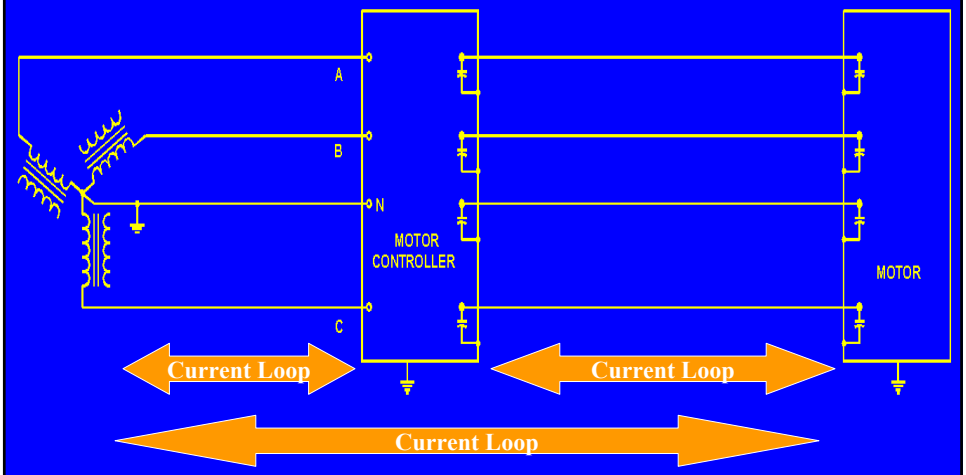
- Internal wiring is transmitting antenna



Radio Interference Sources

- AM Broadcast Transmitters
- FM Broadcast Transmitters
- Television Broadcast Transmitters
- Ham Transmitters
- Digital Wireless Mics
- Radiated Noise from Lighting, etc.
- Variable Speed Motors
- Cell Phones, Wireless PDA's

Variable-Speed Drive Motors



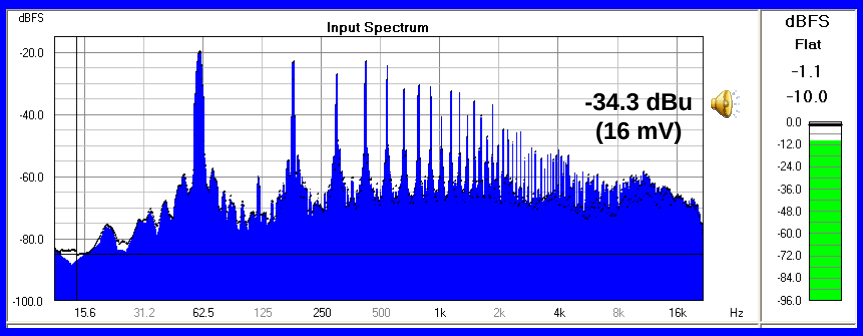
Variable Speed Drive Motors

- Operates by chopping DC to form a variable width pulse
  - 10-20 kHz typical switching frequencies
  - Harmonics extend to hundreds of kHz
- Stray capacitance (and filter capacitors) between motor and earth causes very large currents to flow on building structure
  - Establishes a very large current loop
- Controllers often widely separated from motors to make installation easier

Variable Speed Drive Motor Solutions

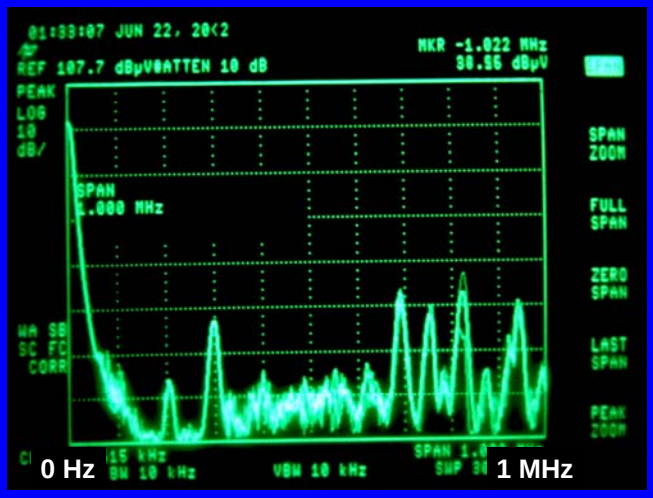
- Minimize the size of the current loops
  - Locate transformer, controller, and motor in closest possible proximity to each other
  - Transformer should have delta primary, wye secondary, bonded very close to motor
    - Prevents feeders to transformer from being part of the current loop
  - Twist neutral and phase conductors

Typical Audio Noise Spectrum on "Ground"



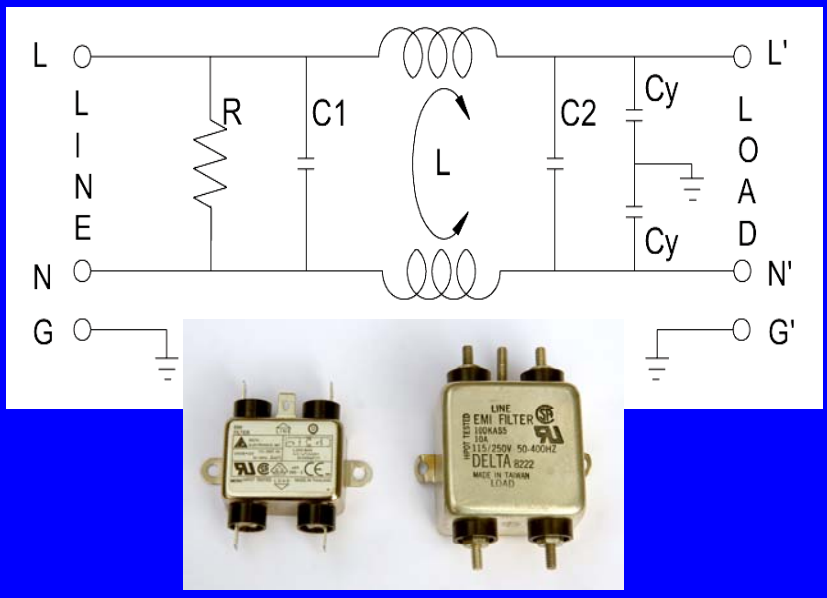
Measured between two outlets in my office

RF Spectrum Analyzer 0 – 1 MHz



Measured between two different outlets in my office, one a conventional outlet, and one an IG outlet, into a 75 ohm load

Line Filters Can Add Noise to Ground



Other Noise on "Ground"

- 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

Primary Coupling Mechanisms

- Pin 1 problems
  - Improper shield termination within equipment
- Differential noise on signal pair
  - Inductive imbalance between shield and signal conductors -- Shield-current-induced noise (SCIN)
  - Capacitance imbalance of cable
  - Inadequate low-pass filtering lets it in the box
- Common mode noise
- Inadequate shielding of internal wiring

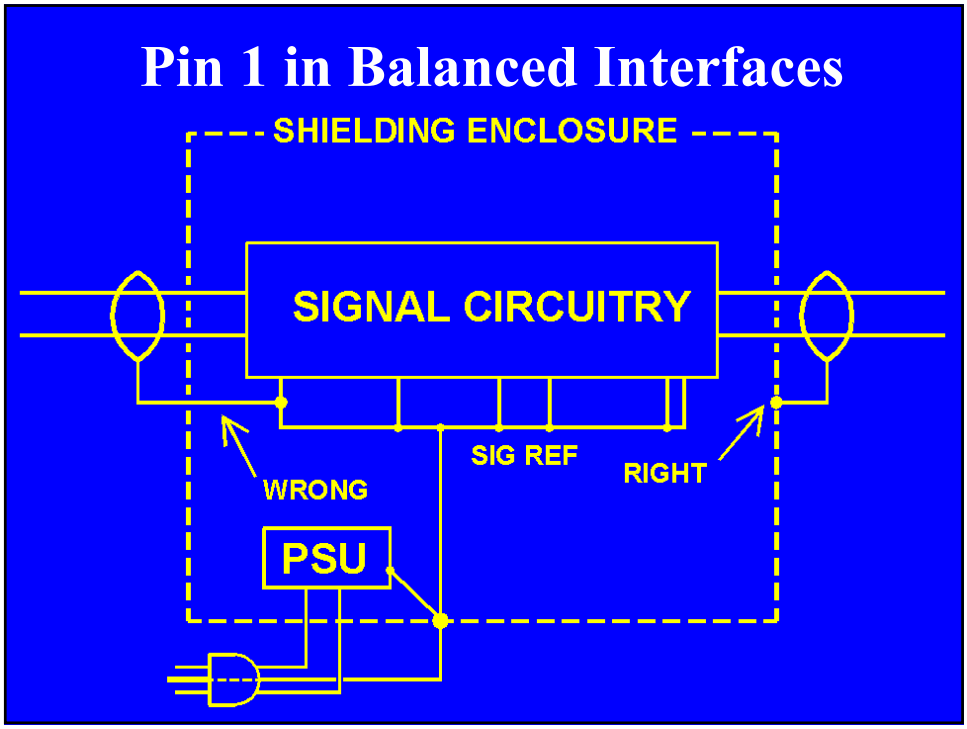
Pin 1 in Cable-Mounted Connectors

- Pin 1 is the shield contact of XL connectors (AES14-1992)
- No connection should be made to the shell of cable-mounted connectors

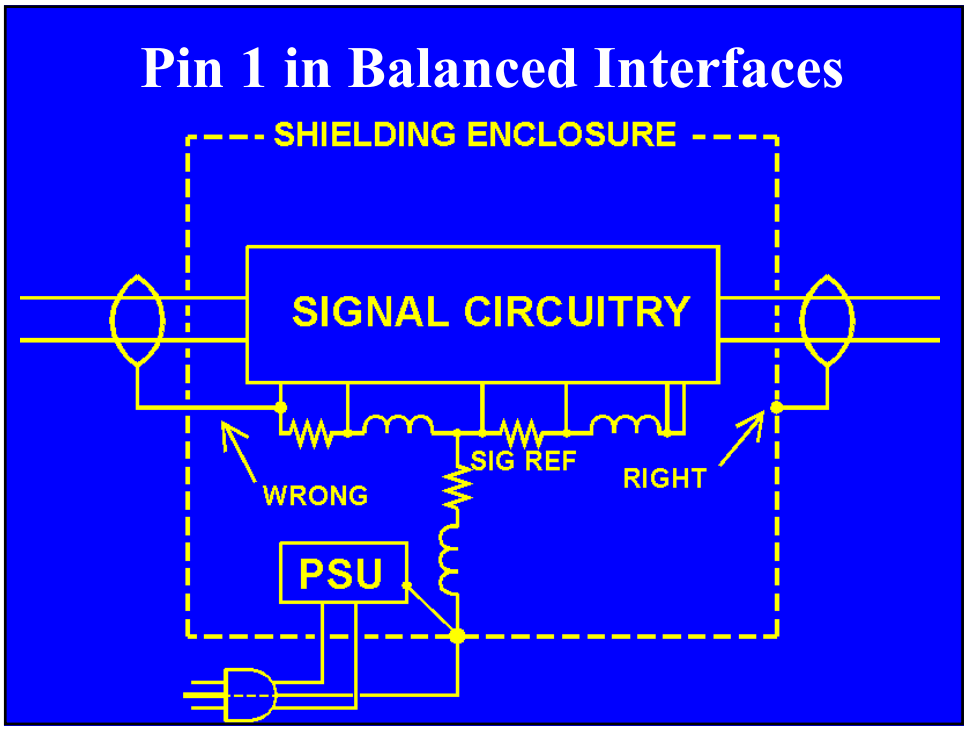
Pin 1 Within Equipment

- Pin 1 is the shield contact of XL connectors
- Cable shields must go to the shielding enclosure (and ONLY to the shielding enclosure) (AES48)
- If shields go inside the box first (to the circuit board, for example), common impedances couple shield current at random points along the circuit board!
- Noise is added to the signal

Pin 1 in Balanced Interfaces



Pin 1 in Balanced Interfaces

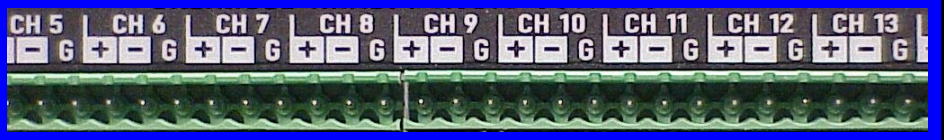


How Does It Happen?

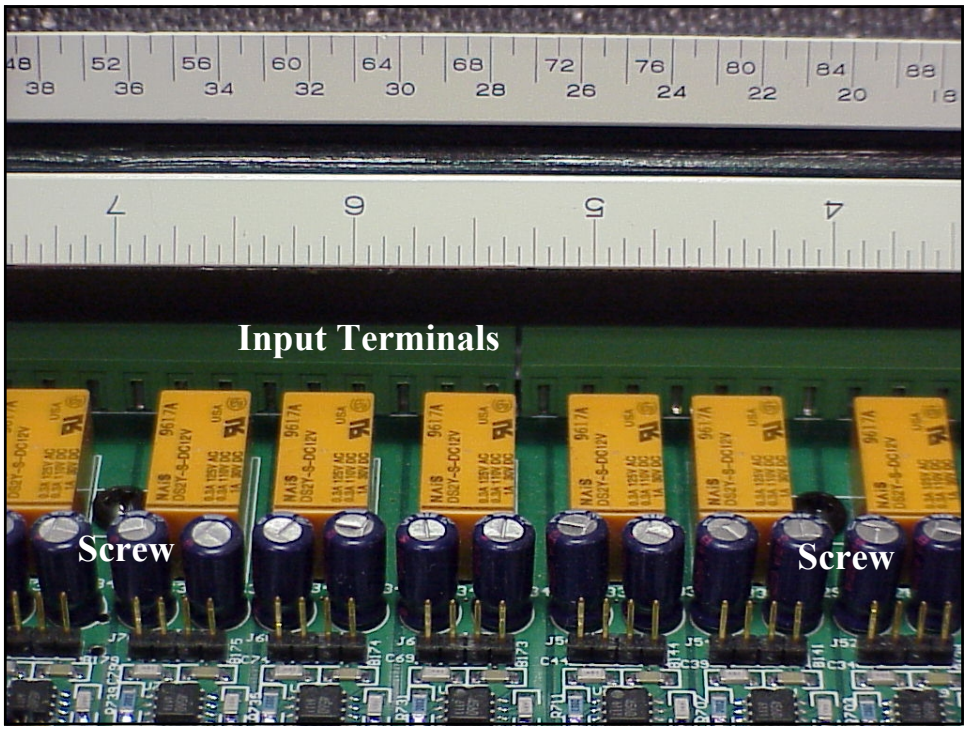
How Does It Happen?

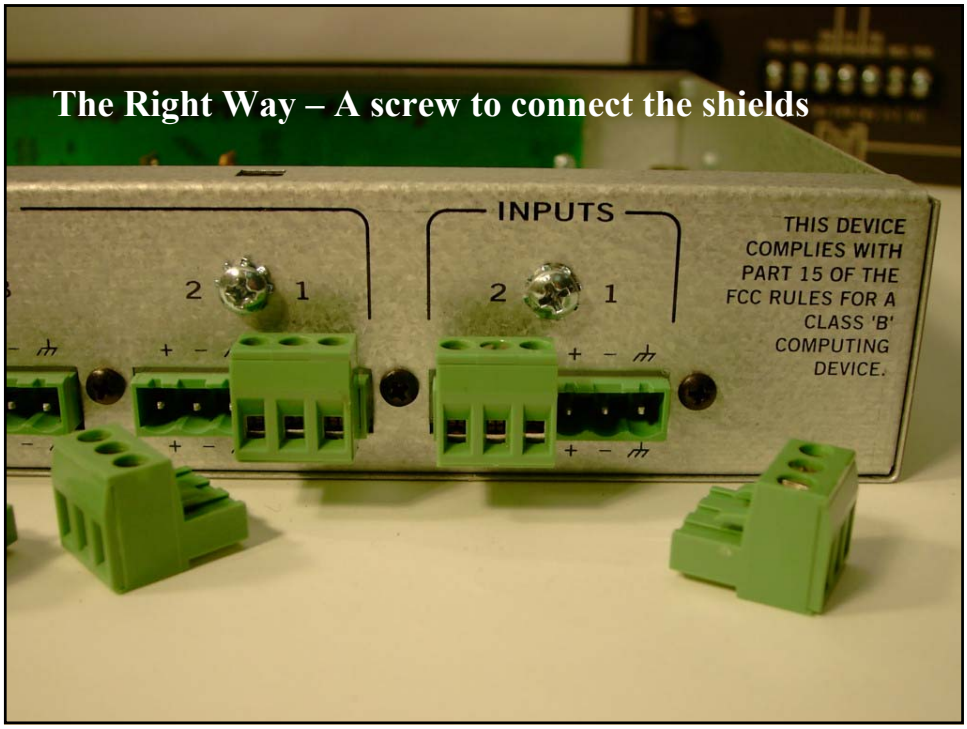
- Pin 1 of XL's go to chassis via circuit board and ¼" connectors (it's cheaper)
- XLR shell not connected to anything!
- RCA connectors not connected to chassis

The G terminal goes to the enclosure, right?



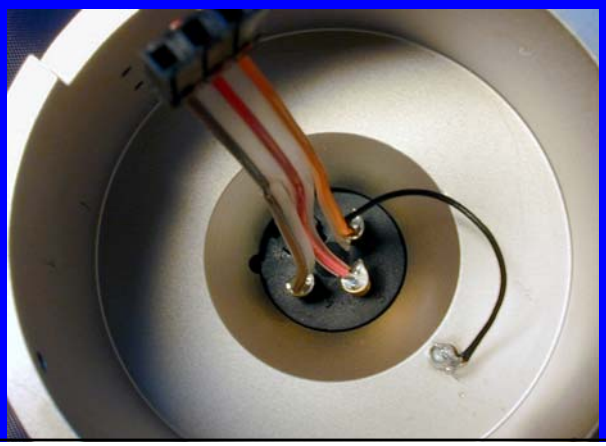
Well, sort of, but it's a long and torturous journey!



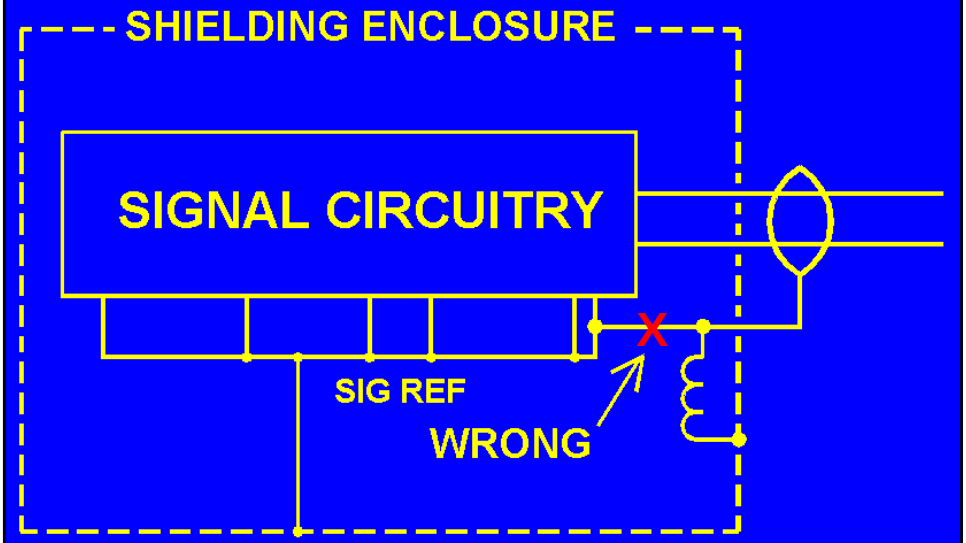


A classic RF pin 1 problem in a microphone

- Black wire goes to enclosure (good)
- Far too LONG - Inductance makes it high impedance
  - 7.5 Ω @ 100 MHz, 60 Ω at 850 MHz
- Orange wire goes to circuit board common
- Common impedance couples RF to circuit board

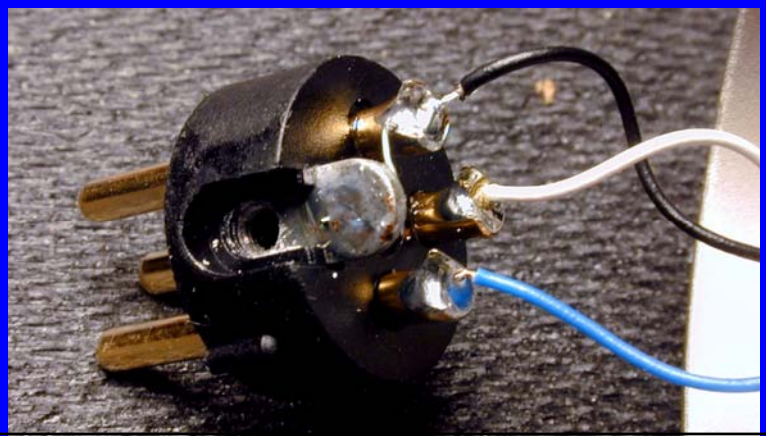


The Pin 1 Problem in Microphones



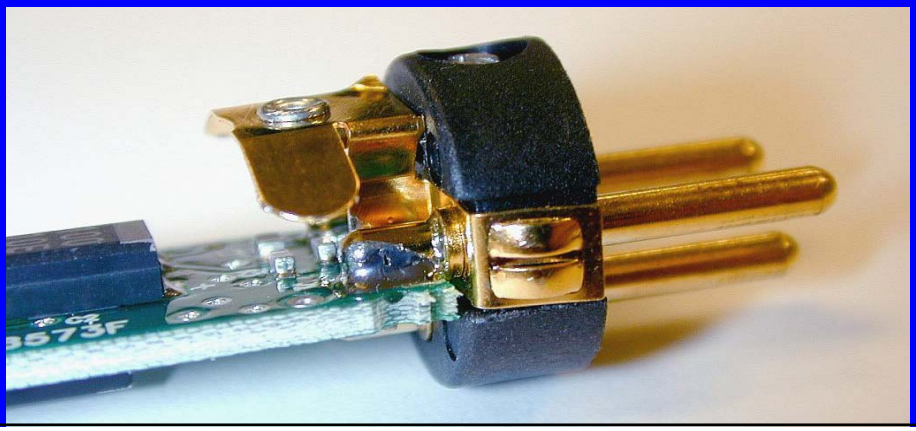
A pin 1 problem at RF

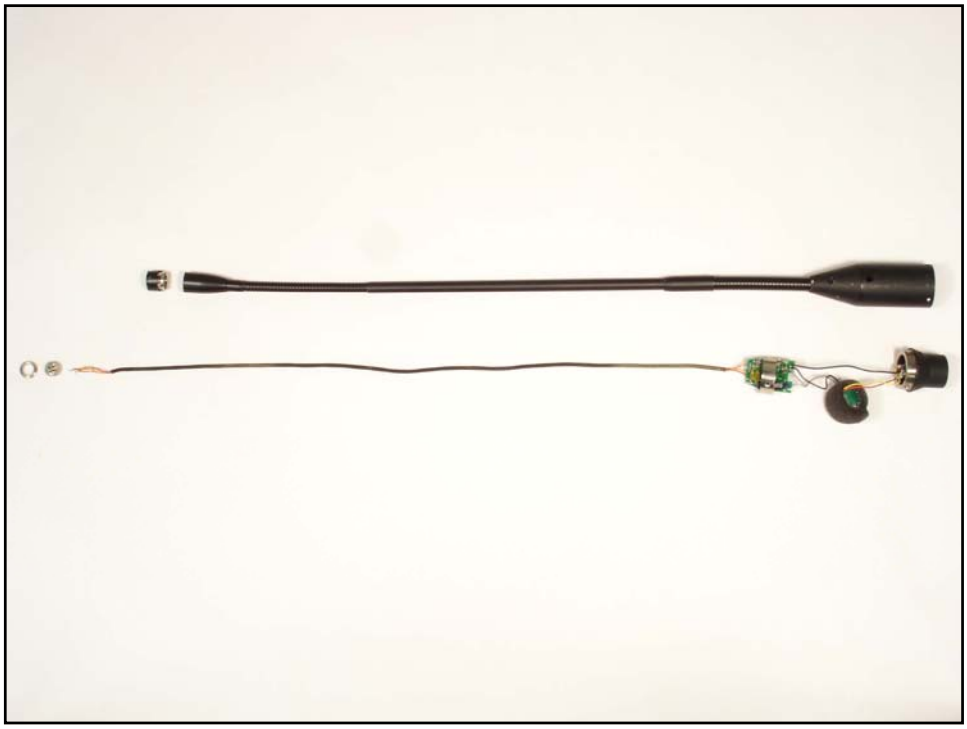
- Shield goes through connector retaining screw
  - 4 Ω @ 100 MHz, 30 Ω at 850 MHz
- Black wire is circuit board common
- Common impedance couples RF to circuit board
- This mic has RF problems

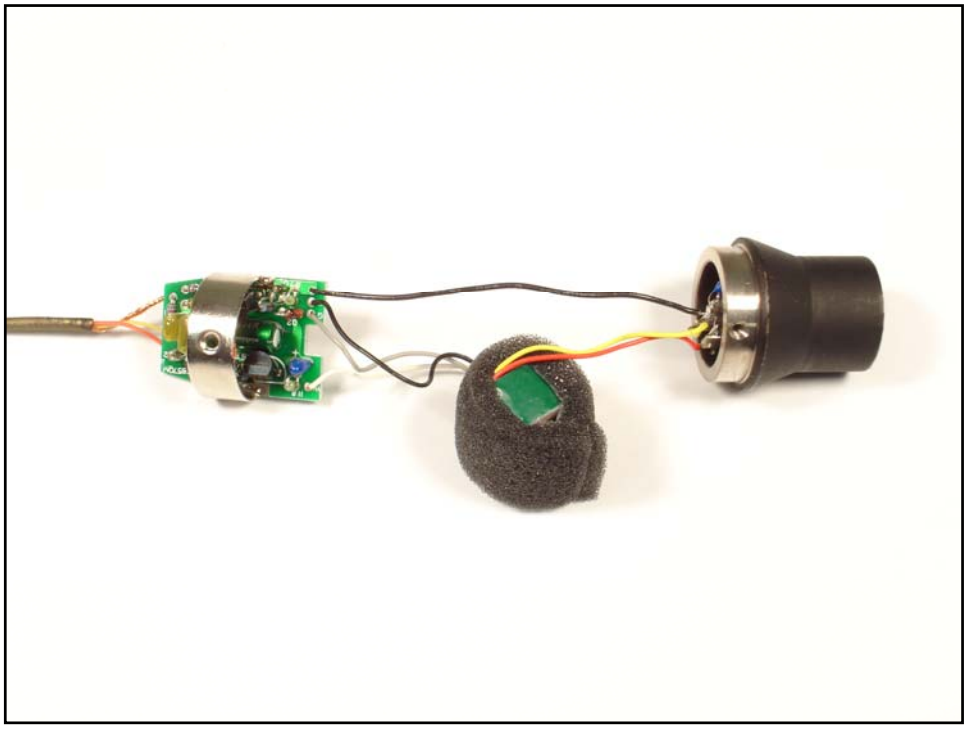


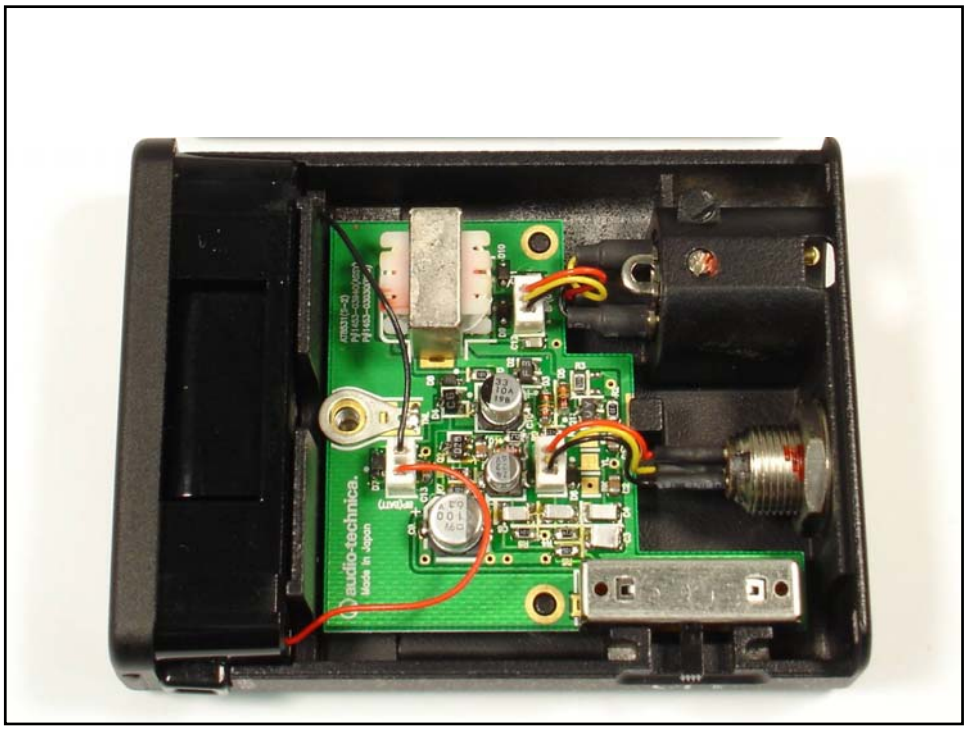
A better connection for pin 1

- Broad, short copper, pressure fit to enclosure
- Less inductance
- Still some common impedance to circuit board
- 100 pf capacitors, common mode choke
- Much better RF performance, still not perfect

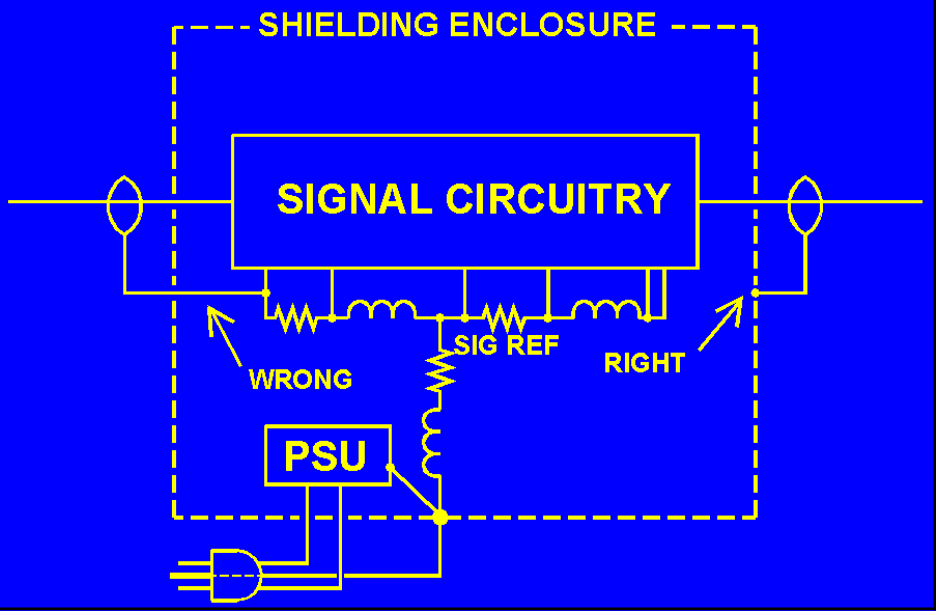







audio-technica
Made in Japan

Pin 1 in Unbalanced Interfaces



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

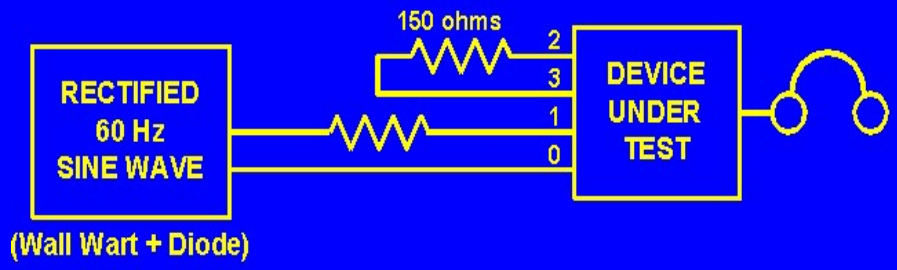
- Hint: It isn't an audio connector shell!
  - That metal is a shield, but not connected to connectors
  - And the cover is plastic too

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

Yes, it's the DB9 and DB25 shells!

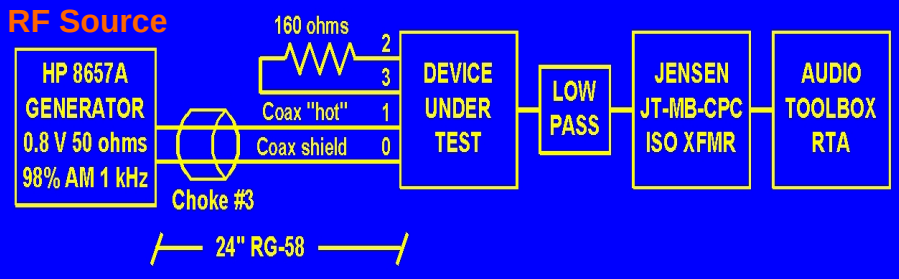
Testing for Pin 1 Problems

John Wendt's "Hummer" Test for Pin 1 Problems



- Drive pin 1
- Listen to the output
- If you hear it, you have a problem

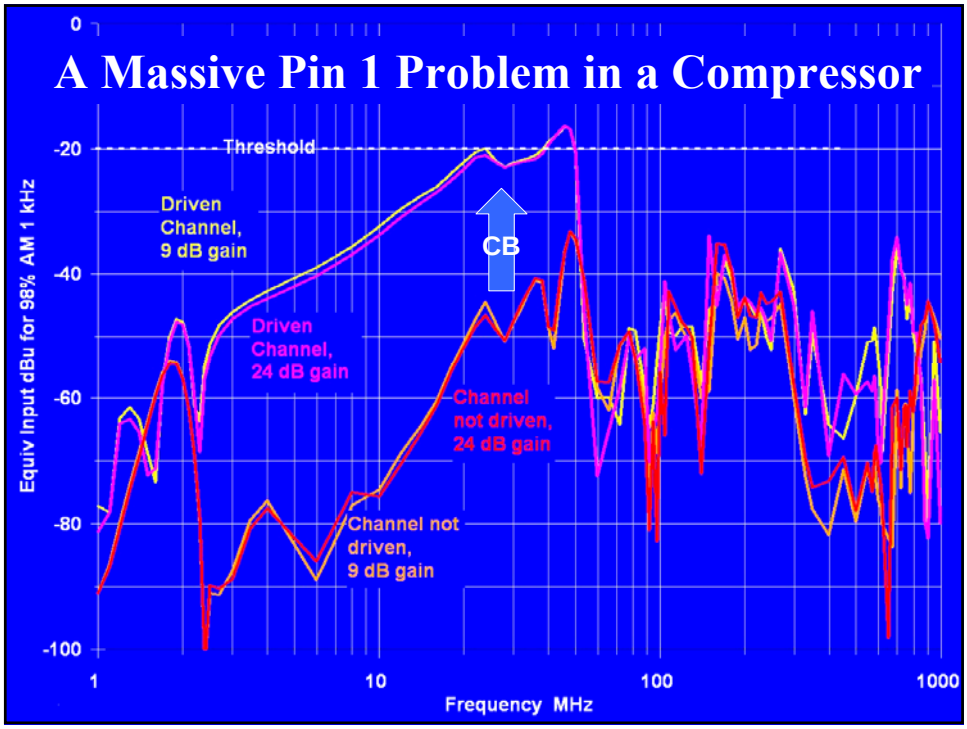
RF Pin 1 Test Setup for Equipment



Choke #3 - 4 turns around
2.4" OD type 43 toroid

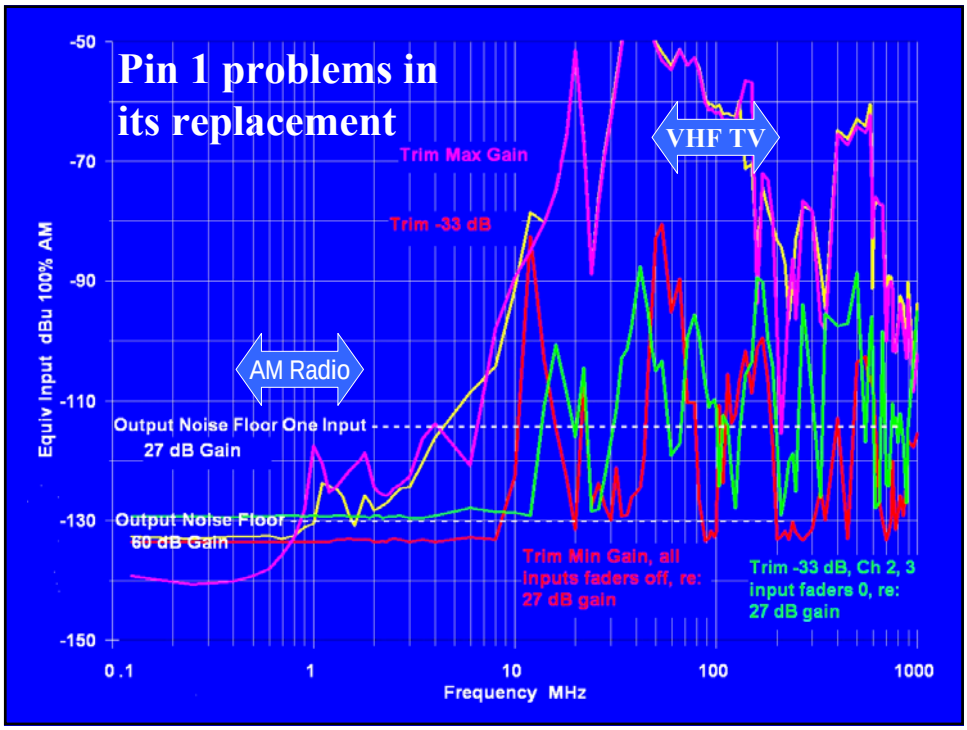
LOW PASS IS 2 - 475 OHMS
SERIES, 60 nF PARALLEL

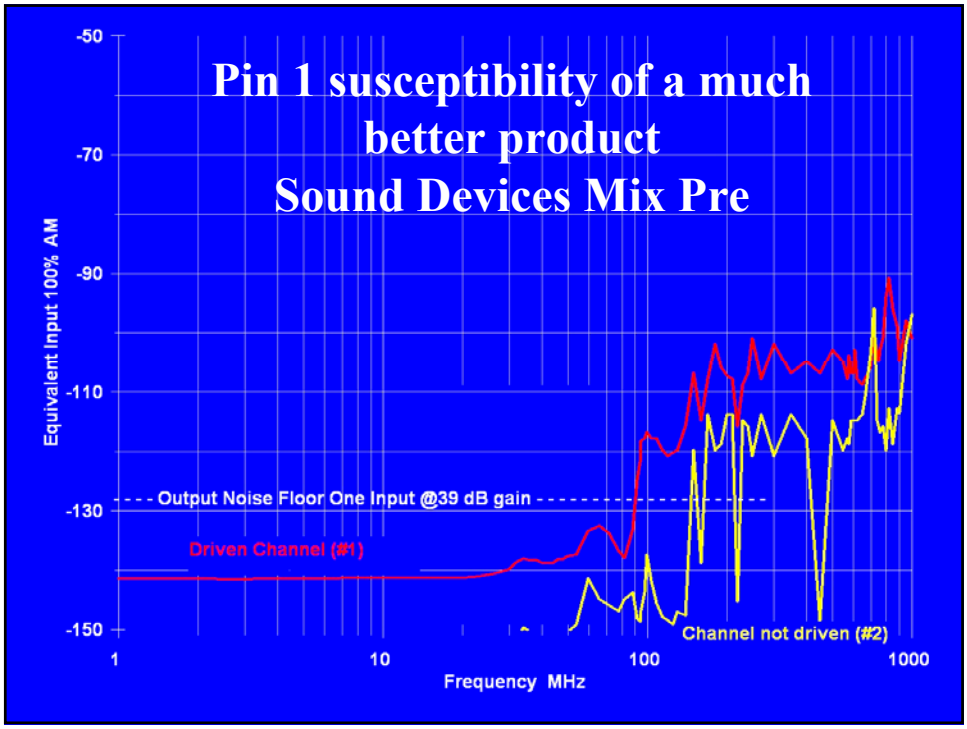
- Drive pin 1
- Listen to the output
- If you hear it, you have a problem

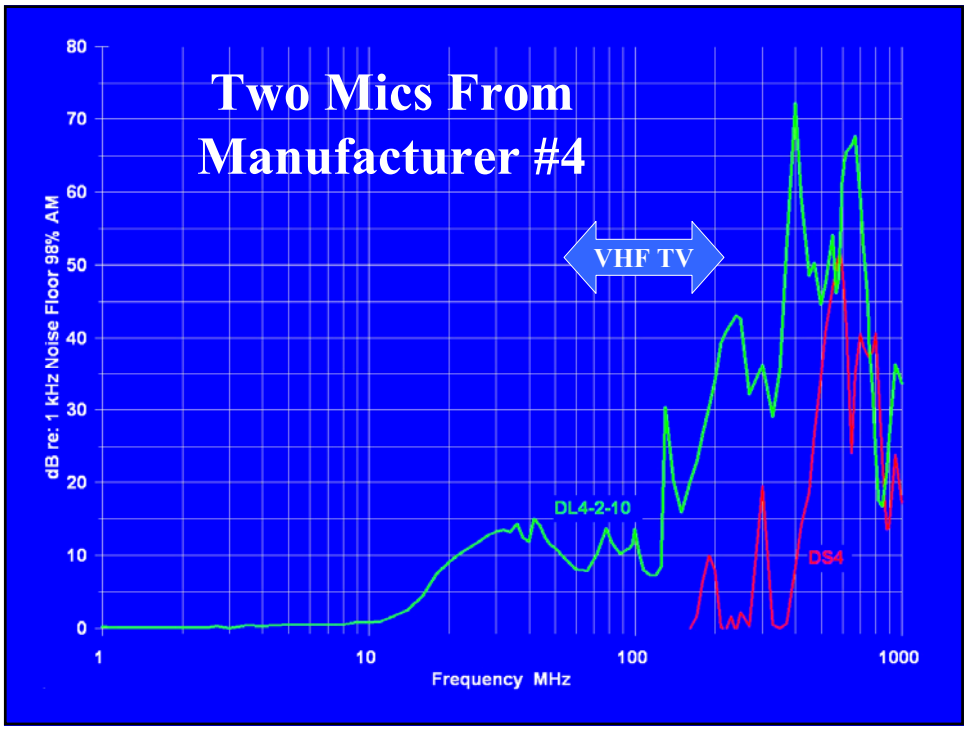


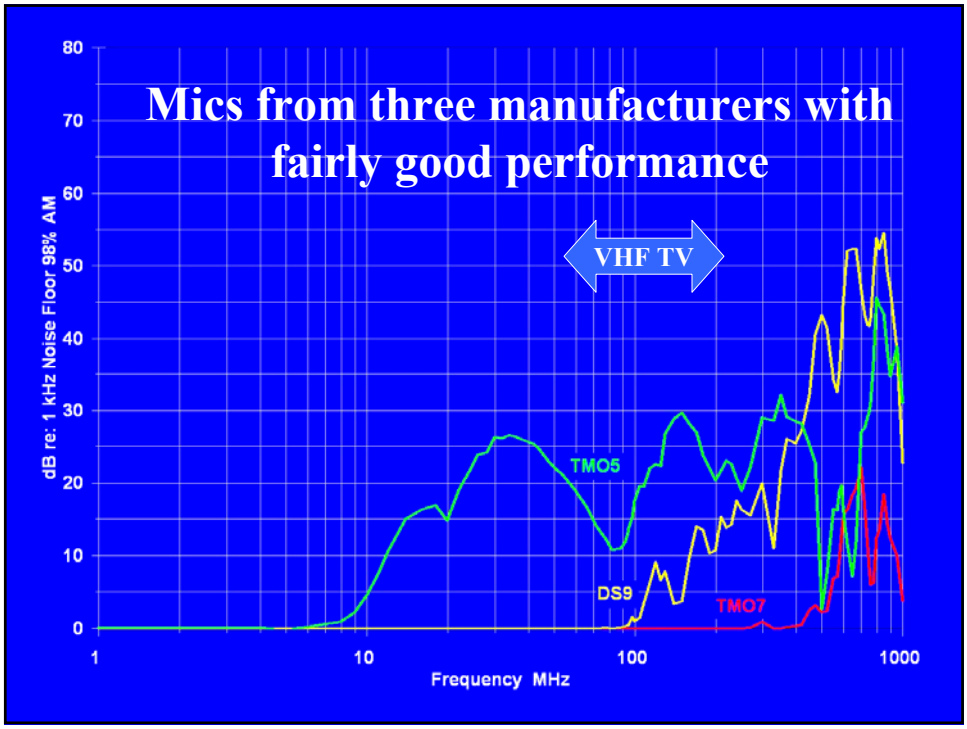
- Plastic body connectors not connected to chassis
  - Massive Pin 1 problem!
  - Pin 1 test hits threshold of compression 20-50 MHz!
- The CE sticker assures EMC? Not here!


Pin 1 problems in a 4-channel mixer
AM Radio
VHF TV
Trim Max
(63 dB Gain)
Trim -23 dB
(40 dB gain)
Noise Floor One Input
40 dB Gain
Trim Min Gain, all
inputs faders off,
re: 40 dB gain
Equivalent Input dBu 100% AM
-50
-70
-90
-110
-130
-150
0.1
1
10
100
1000
Frequency MHz

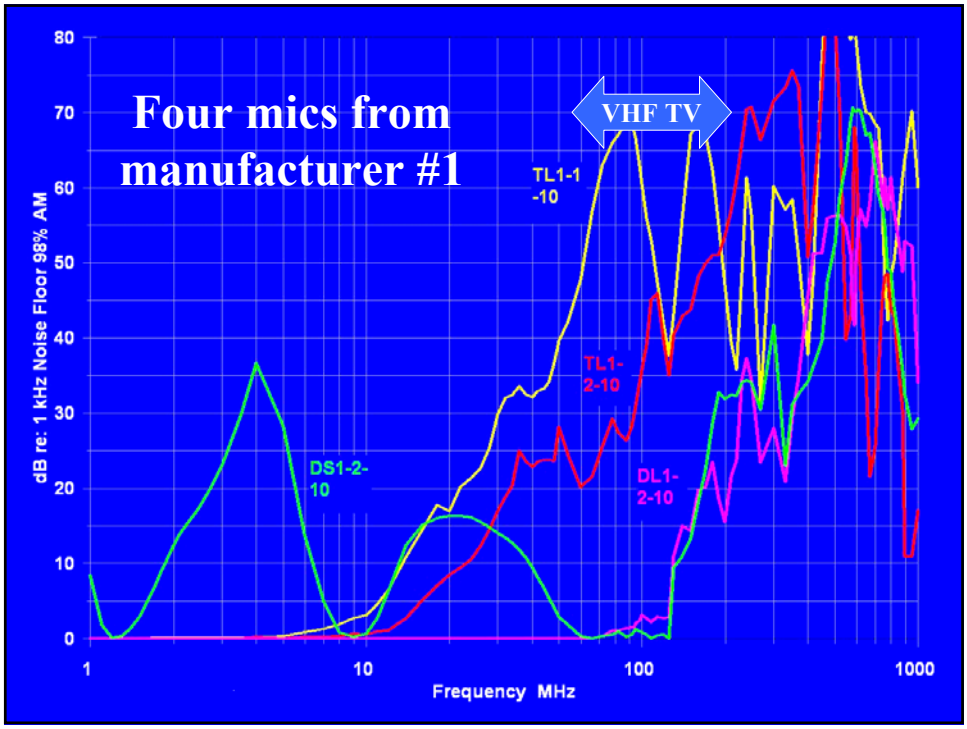

Pin 1 problems in
its replacement
Trim Max Gain
VHF TV
Trim -33 dB
AM Radio
Output Noise Floor One Input
27 dB Gain
Output Noise Floor
60 dB Gain
Trim Min Gain, all
inputs faders off, re:
27 dB gain
Trim -33 dB, Ch 2, 3
input faders 0, re:
27 dB gain
Equiv Input dBu 100% AM
-50
-70
-90
-110
-130
-150
0.1
1
10
100
1000
Frequency MHz


Pin 1 susceptibility of a much better product
Sound Devices Mix Pre
Equivalent Input 100% AM
-50
-70
-90
-110
-130
-150
Output Noise Floor One Input @39 dB gain
Driven Channel (#1)
Channel not driven (#2)
1
10
100
1000
Frequency MHz


Two Mics From Manufacturer #4
dB re: 1 kHz Noise Floor 98% AM
80
70
60
50
40
30
20
10
0
VHF TV
DL4-2-10
DS4
1
10
100
1000
Frequency MHz

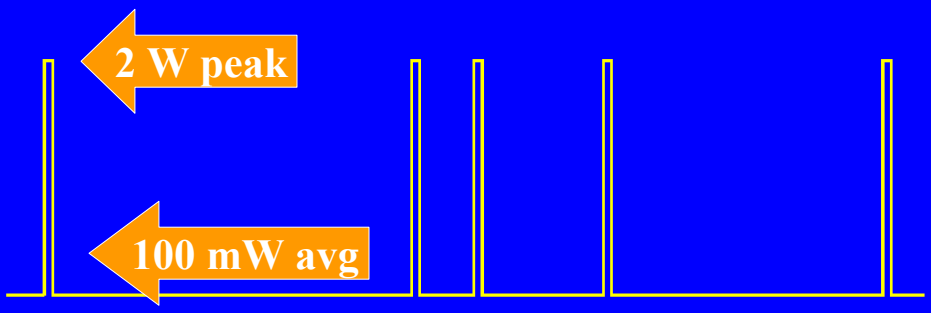

Mics from three manufacturers with fairly good performance
VHF TV
TMO5
DS9
TMO7
dB re: 1 kHz Noise Floor 98% AM
Frequency MHz
80
70
60
50
40
30
20
10
0
1
10
100
1000


Three mics from manufacturer #2
VHF TV
DS2-10
TS2-15
TL2-20
dB re: 1 kHz Noise Floor
Frequency MHz
80
70
60
50
40
30
20
10
0
1
10
100
1000



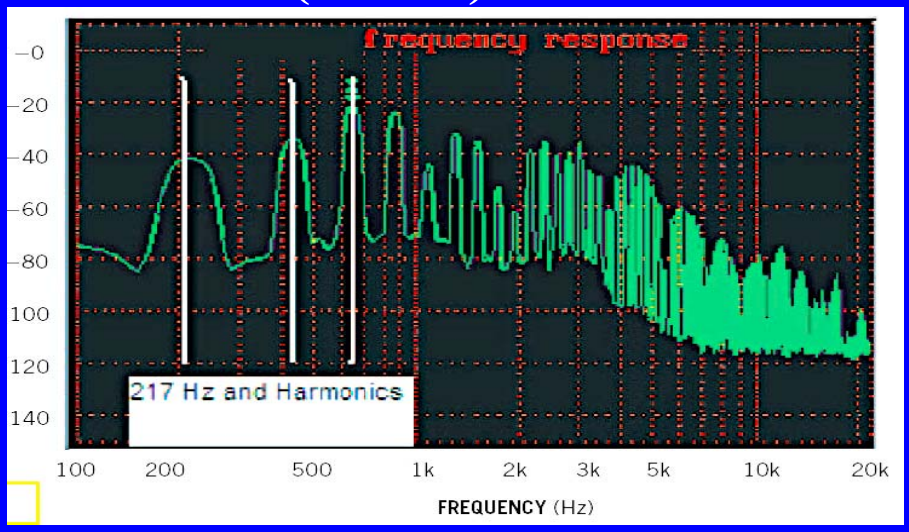
Why are Cell Phones Difficult?

- Very close to our equipment
- Ultra high frequency = very short wavelength
- Short wavelengths are difficult to filter
- Short wavelengths are difficult to shield
  - Small openings let RF in
- 100% AM, short square pulses



Low Duty Cycle Waveform of typical GSM and IDEN Cell Phone. Generically, it is Time Division Multiplex (TDMA)

Spectrum of detected GSM or IDEN (Nextel) Cell Phone



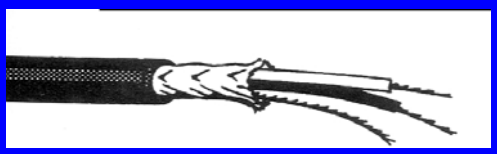
Why are Cell Phones Difficult?

- Very close to our equipment
- Short wavelengths are difficult to filter
- Short wavelengths are difficult to shield
- 100% AM, short square 217 Hz pulses
- 2 W peak power, 100 mW average
- Detected spectrum is midrange audio
- Equipment designers have ignored them

Cable construction is part of the problem!

- No cable is perfect
  - Inductive imbalance (SCIN)
  - Capacitive imbalance
  - Imperfect shielding (tiny openings in braid)
- Even small imperfections become more important at higher frequencies
  - No effect on audio
  - BIG effect on RFI

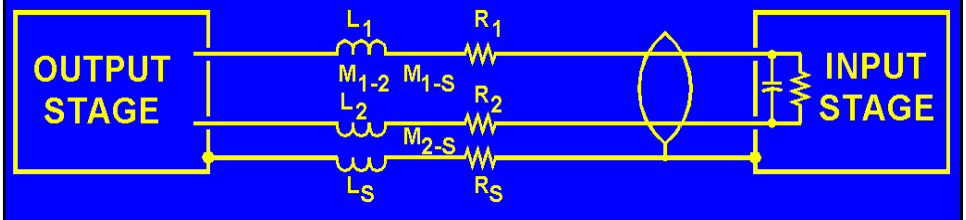
Foil/Drain Shield

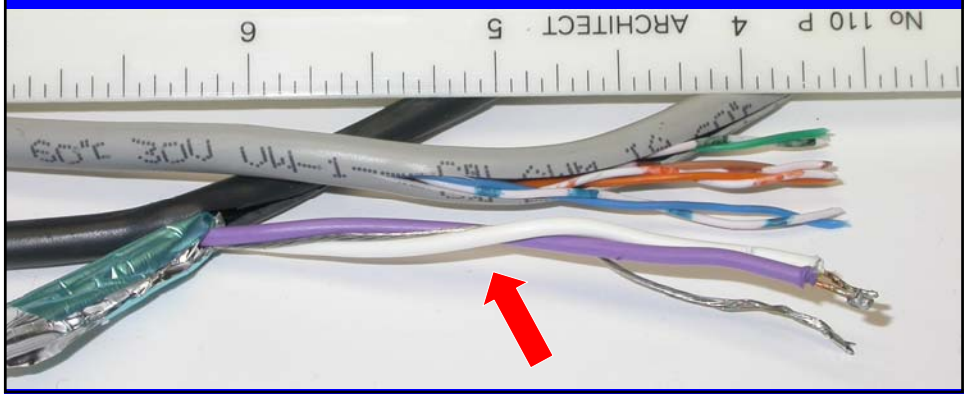


Braid/Drain Shield

Braid/Foil Shield

Inductive Imbalance

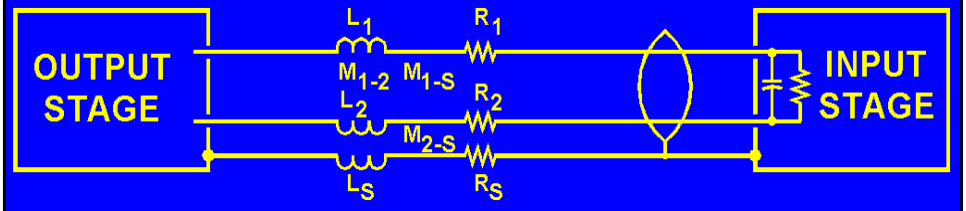




The drain wire is coupled more closely to the white conductor

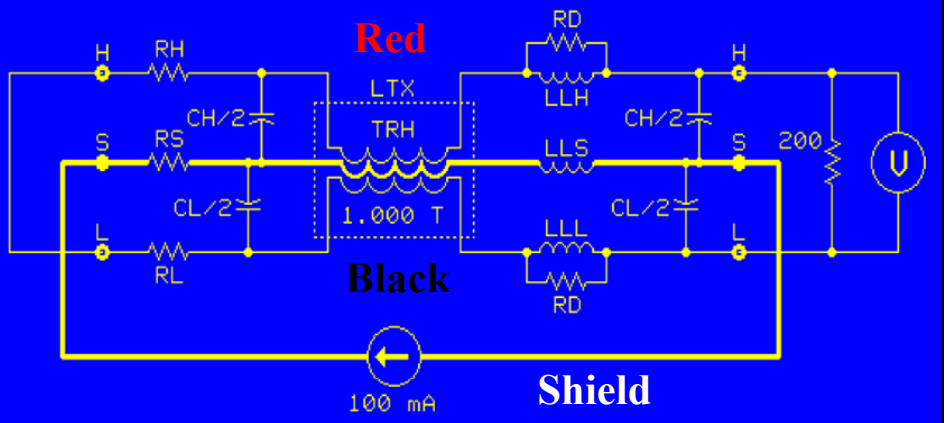
So shield current induces more voltage on white than violet

Inductive Imbalance



- Below about 5 MHz, most shield current in a foil/drain shield flows in the drain wire
- As a result of cable construction, the drain wire couples more closely to one signal conductor than the other
- That is, $M_{1\text{-}S}$ is not equal to $M_{2\text{-}S}$

It's a 3-Winding Transformer



So Equipment Needs RF Filtering!

- Antenna action induces common mode RF to equipment
  - Need <u>common</u> mode filtering
- Cable imbalances convert common mode to differential mode
  - Need <u>differential</u> mode filtering

Current Flows in Loops

- Where does the return current flow?
  - Large loop area = strong magnetic coupling
  - Long wires = better antennas

Antennas Work Without a Loop

- Most efficient if λ/4 or odd multiple of λ/4
- Start "kicking in" at λ/20
- Generally need something to be "the other half of the antenna"
- Current and voltage peak λ/4 apart, repeat at intervals of λ/2

Antennas Inside Equipment

- Wires and circuit traces are antennas too
- Shield the equipment
- Add a ground plane on a second layer
  - Turns each circuit trace into a transmission line
  - Return current flows on the ground plane under the trace
  - Minimizes the loop area
  - Minimizes antenna action
  - Microstrip (one ground plane)
  - Stripline (two ground planes sandwich the trace)

Enemies of Good Shielding

- Plastic cases
- Paint
- Openings in shielded cases
  - Slots


audio-technica

Is a Cable Shield Important for Balanced Audio Cables?

Shielded Twisted Pair

The bad:

- The shield provides no magnetic shielding
- The shield can cause SCIN, degrading noise rejection
- Unequal capacitances between conductors and the shield can degrade noise rejection
- Provides a current path to excite pin 1 problems

Shielded Twisted Pair

The good:

- A cable shield provides E-field shielding
  - Connection should by < λ/20
  - Can be important for crosstalk
- Connecting the shield minimizes common mode voltage at the point of connection

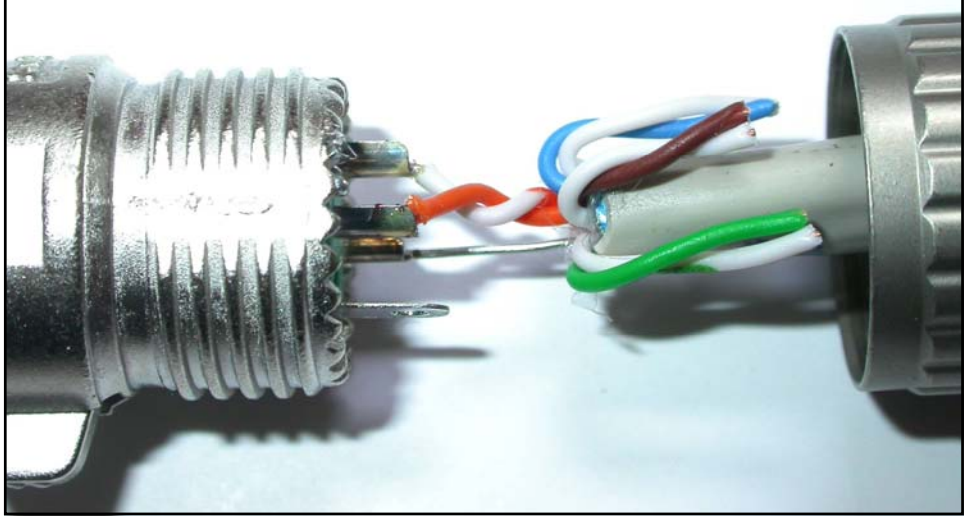
Twisting

- Twisting with good symmetry causes induced voltages and currents to be more closely balanced (equal) in the two conductors
- Most pronounced with near field sources
- A tighter twist ratio reduces coupling
  - Improves the balance in the presence of fields that vary along the cable
  - Improves the balance at higher frequencies

Twisting and Noise Coupling

- Cancellation of induced voltages occurs in the receiver, not in the cable!
- For magnetic fields and electromagnetic fields, helps in balanced or unbalanced circuits
- For low frequency electric fields, helps only in balanced circuits
- Loudspeaker cables should be twisted pairs to reject RF

Maintain Twisting Right Up to the Pins



An Experiment

Cable #1 – Belden 1800F –AES3, braid/drain

- **Conventional wiring, shield to pin 1**

Cable #2 – Belden 1752A – Unshielded CAT6

- **One pair connects pins 2 and 3 at each end**
- **One pair tied together to pin 1 at each end**

Test: Cable connects dynamic mic to mic preamp, gain set to very high level. Tape demagnetizer, Nextel phone, 5w VHF/UHF talkie are moved along cable to inject interference.

An Experiment

Results:

- **Neither cable coupled audible interference from demagnetizer – except at connector mating to an extension cable**
- **Neither cable coupled audible interference from the radios**

An Experiment

Repeat w/ condenser mics with RFI problems

- Mic #1 – RF interference with unshielded CAT6 cable was noticeably less audible than with shielded twisted pair! ~ 6-10 dB
- Mic #2 – RF interference was more audible with unshielded CAT6 3-6 dB
- Why the difference?
  - Common mode or differential mode susceptibility within the mic!
  - Impedance of mic at RF!

An Experiment

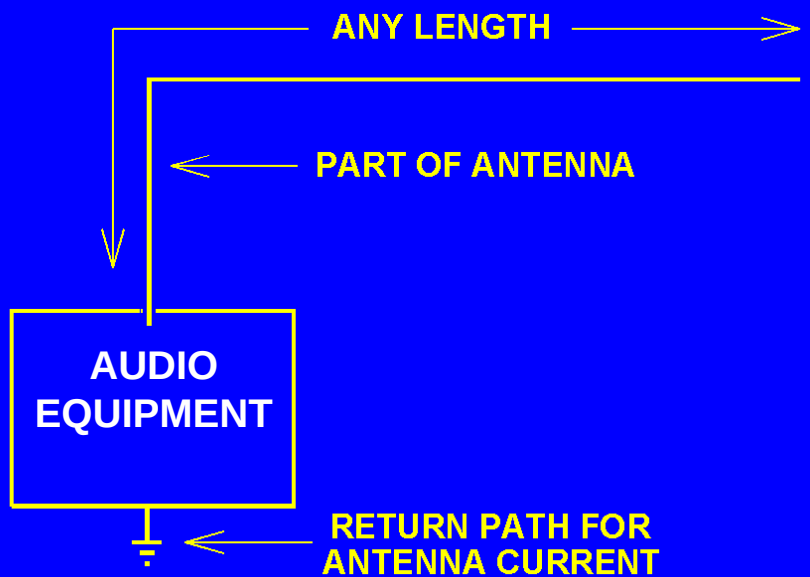
Conclusions:

While the experiment is neither rigorous or conclusive, it reinforces assertions that:

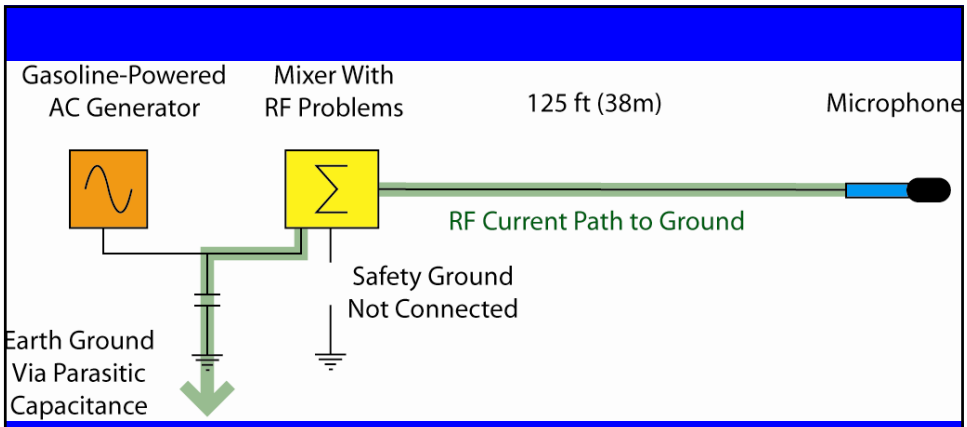
- Twisting is far more important than shielding
- A cable shield can degrade immunity

Using Ferrites to Tame the Antennas

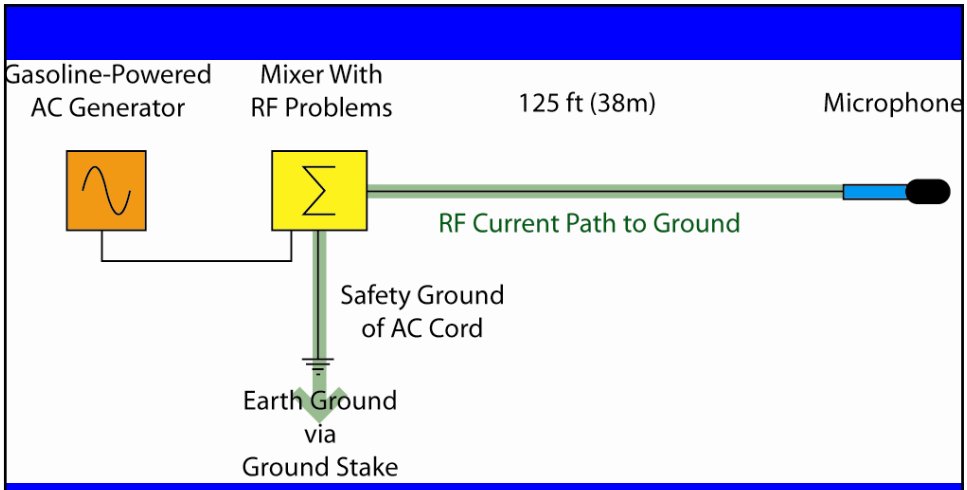
Basic Random Long Wire



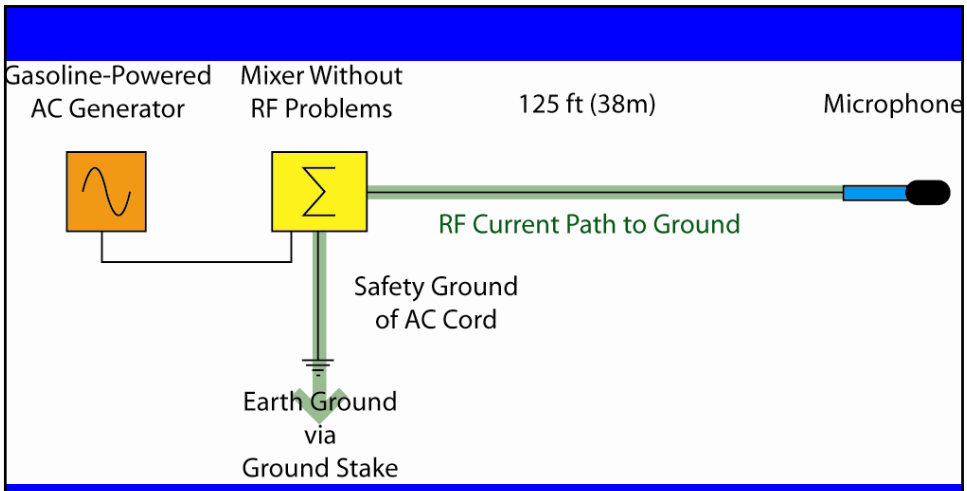
Testing mics and input gear for RFI
AM Radio – 50kW on 720 kHz



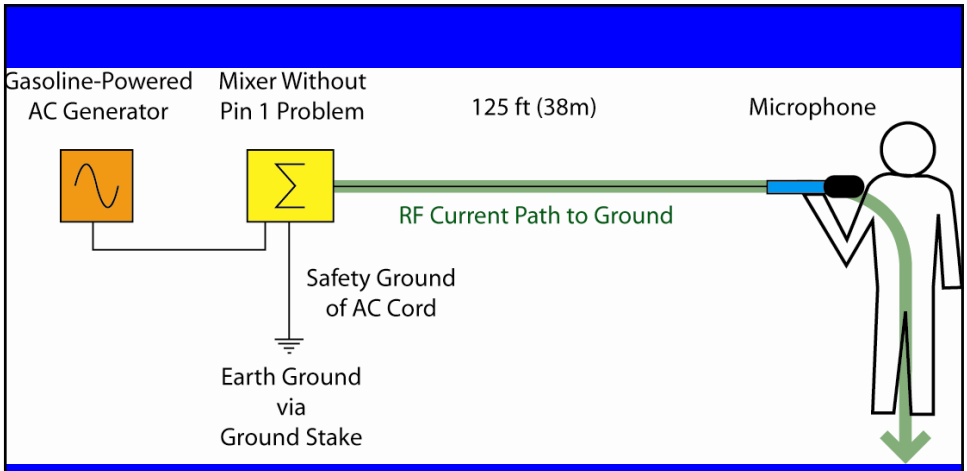
A poor RF ground (only the capacitance), so not much interference



A better RF ground (the ground stake), so much more interference



No RF ground for the mic, so no interference



But when my assistant held the mic in his hand, some mics had RFI

Ferrites can block the current!

Common Mode Current

- I/O wiring acts as long wire antenna
- Antenna current flows lengthwise on wiring

Ferrites “outside the box” can Help a Lot!

Common Mode Current

- Pin 1 Problems
- SCIN
- capacitive imbalance

Ferrites “outside the box” can Help a Lot!

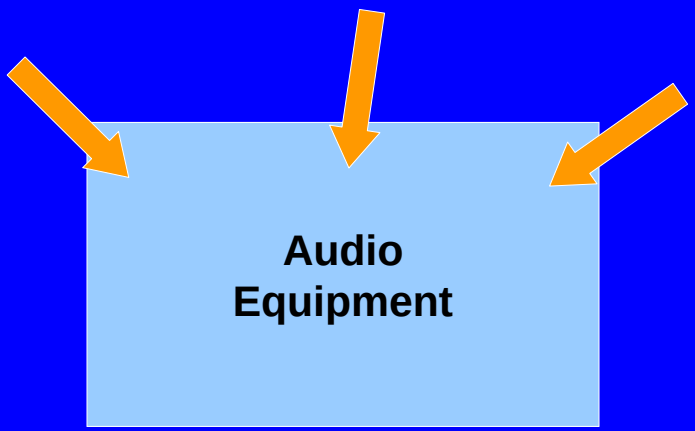
Differential Mode Current

- I/O wiring is not band-pass filtered
- Noise is between + and – terminals of wiring

Ferrites can be used inside the box as part of low pass filters

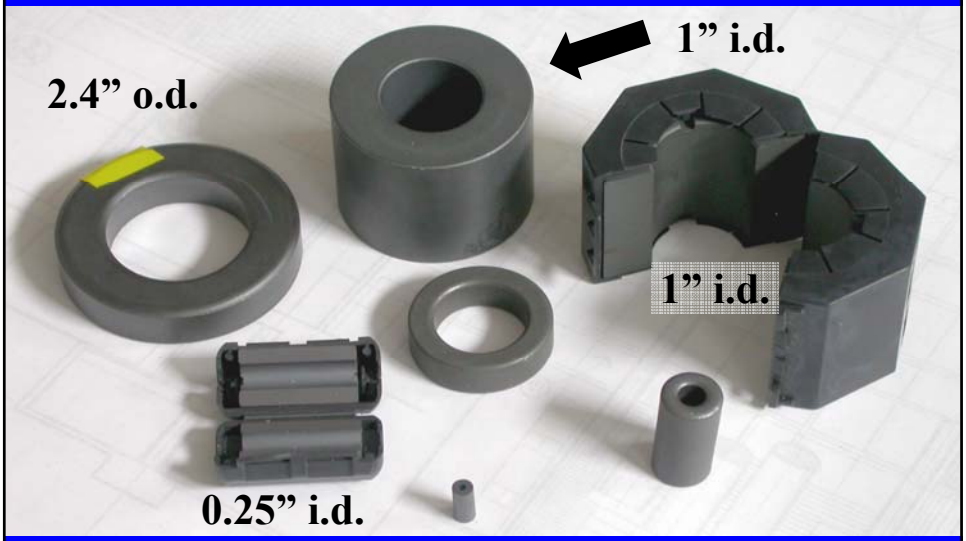
Poor Equipment Shielding

- Internal wiring is the receiving antenna



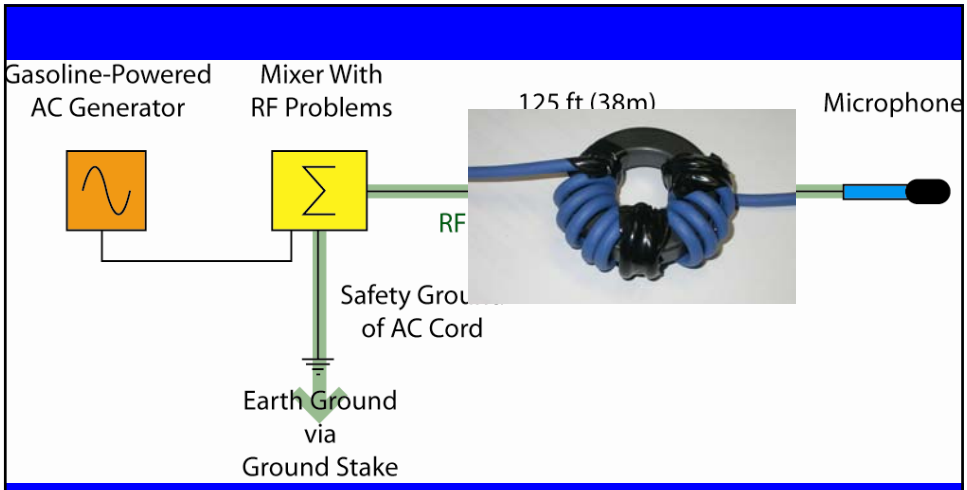
Ferrites don't help at all!

Different sizes and shapes



An AM Broadcast Choke

14 turns of mic cable around this ferrite can kill AM broadcast RFI



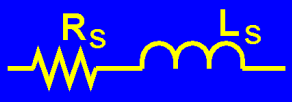
This choke reduced the current, and thus the RFI

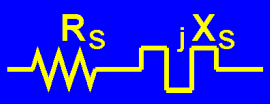
This "Clamp-On" forms a choke that can kill interference from FM and TV

What's a Ferrite?

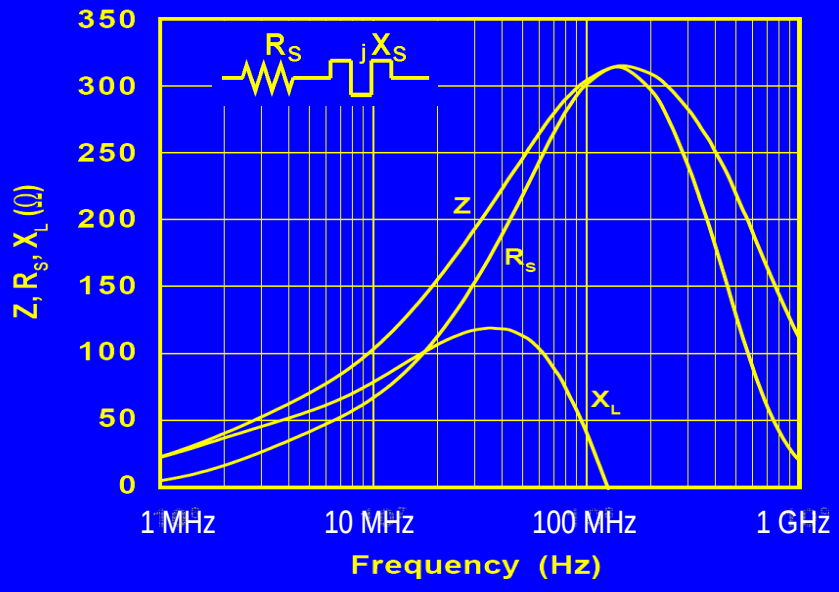
- A ceramic consisting of an iron oxide
  - manganese-zinc – 1-30 MHz (AM broadcast, hams)
  - nickel-zinc – 30 MHz-1 GHz (FM, TV, cell phones)
- Has permeability (μ) much greater than air
  - Better path for magnetic flux than air
  - Multiplies inductance of a wire passed through it
- Is very lossy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

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

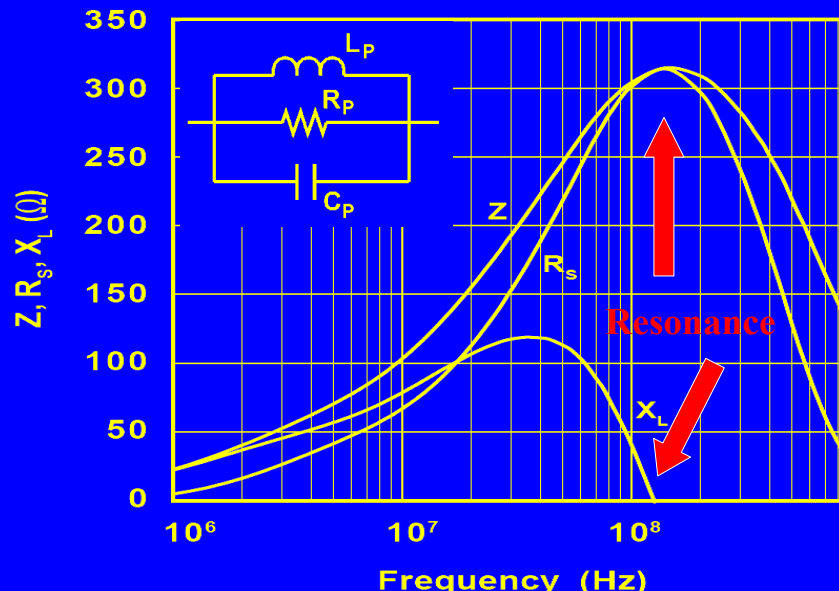




Impedance of Wire Through Ferrite



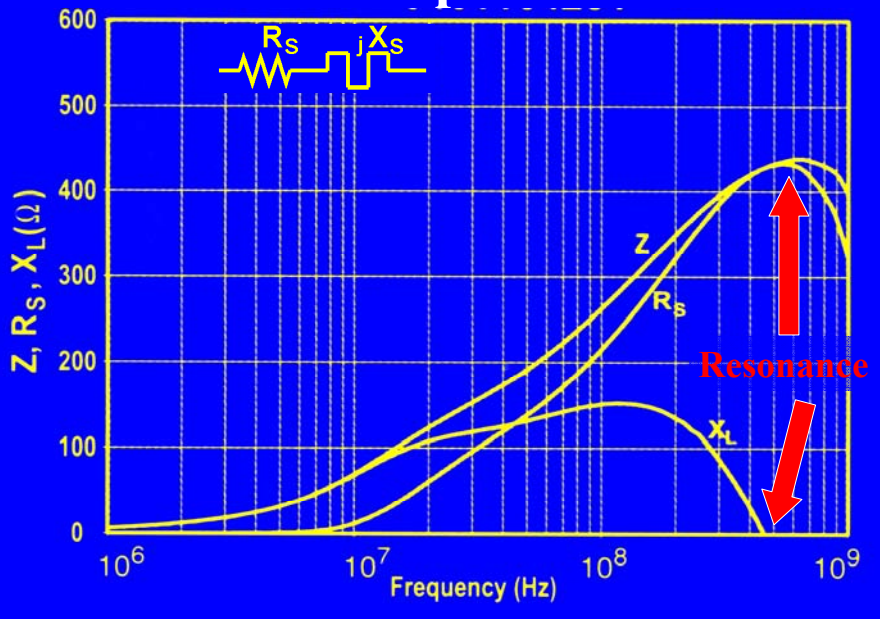
It's Really a Parallel Resonance

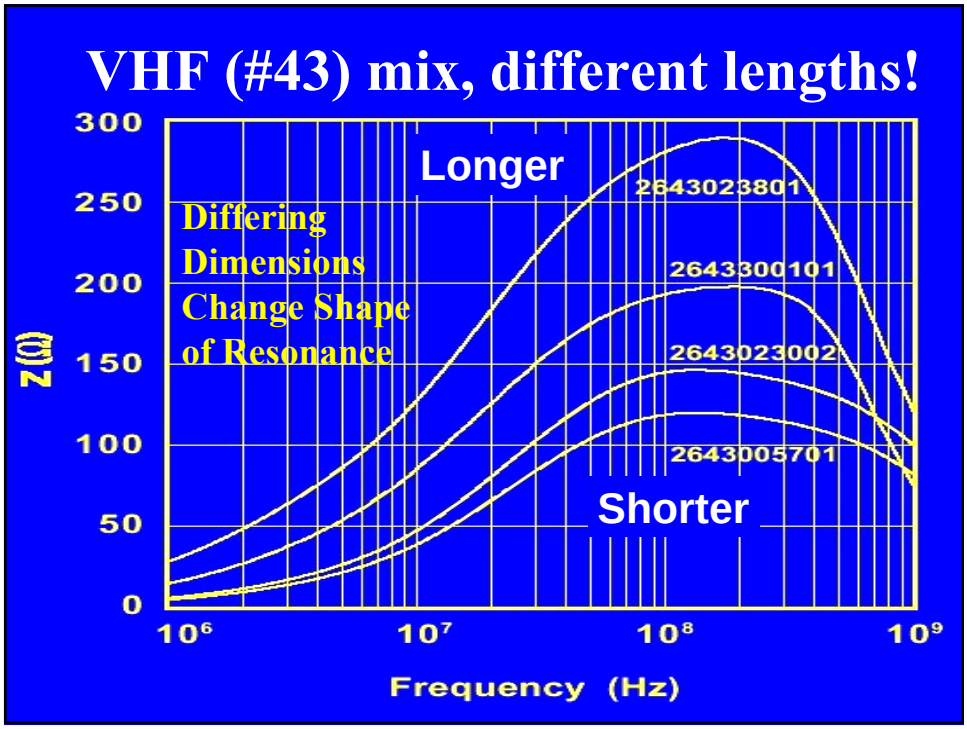


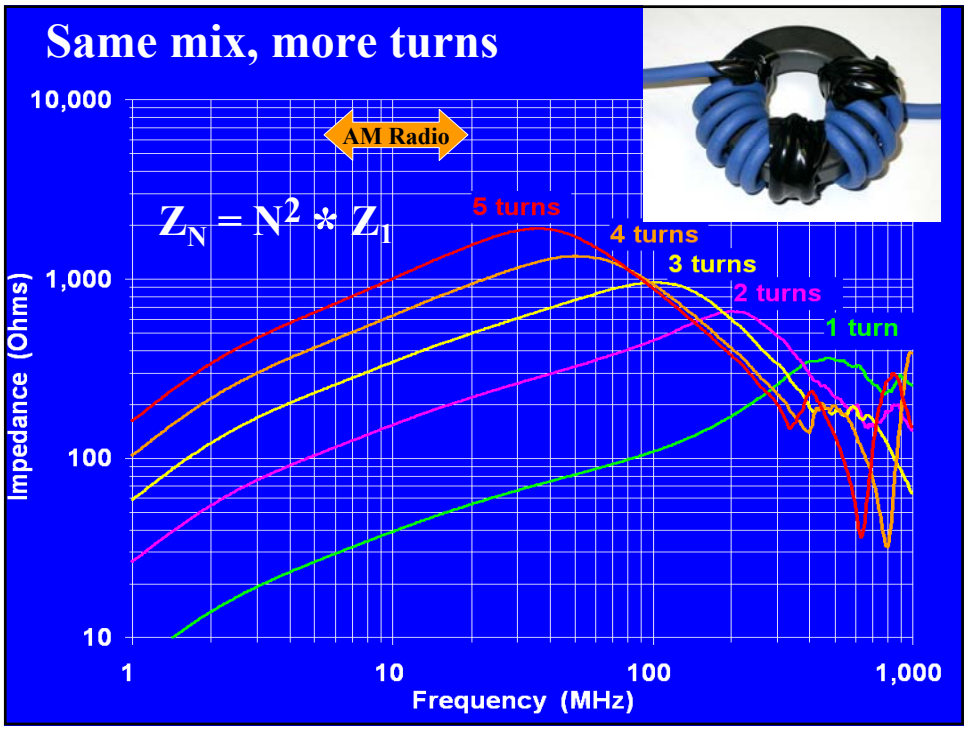
Where's the Capacitance here?

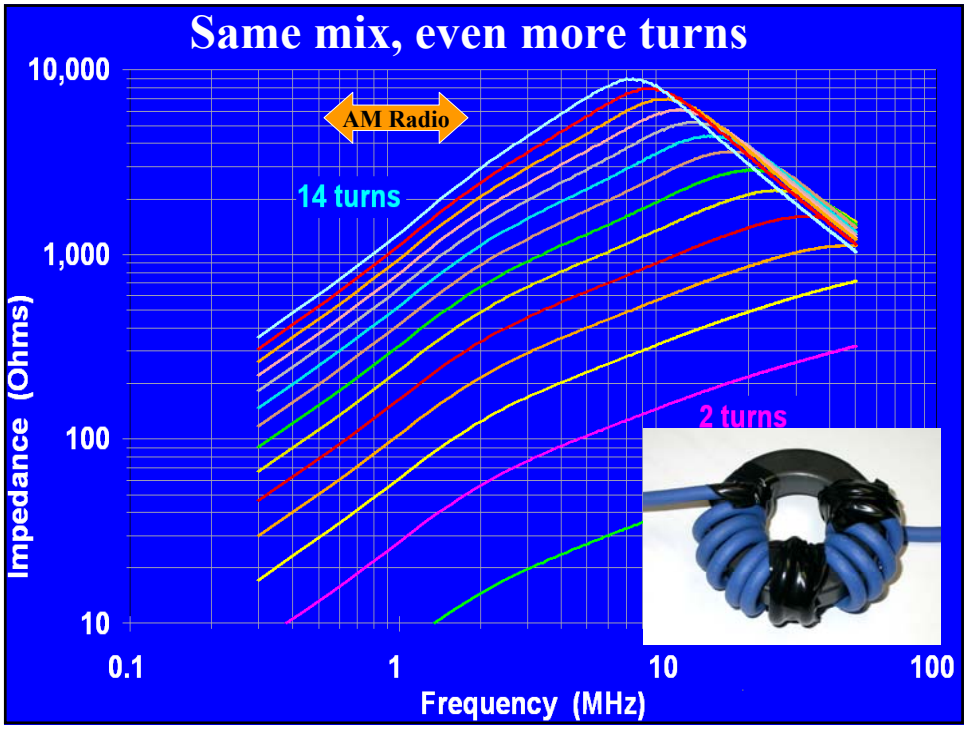
From one end of the choke to the other, through the permittivity of the ferrite (it is a dielectric!)

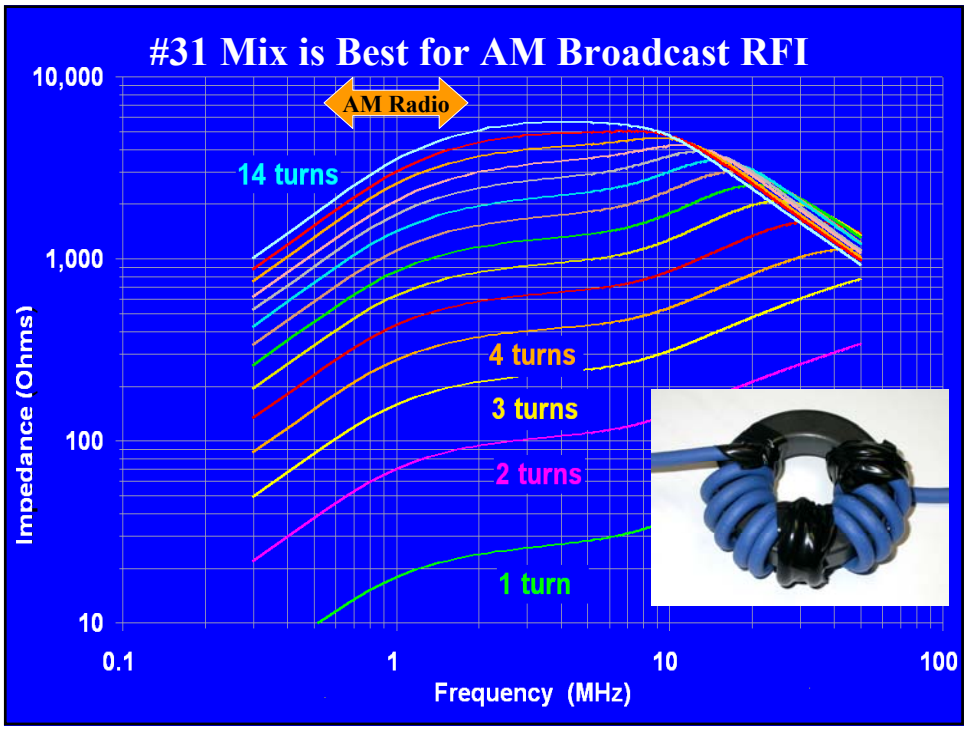
A Ferrite Mix Optimized for UHF

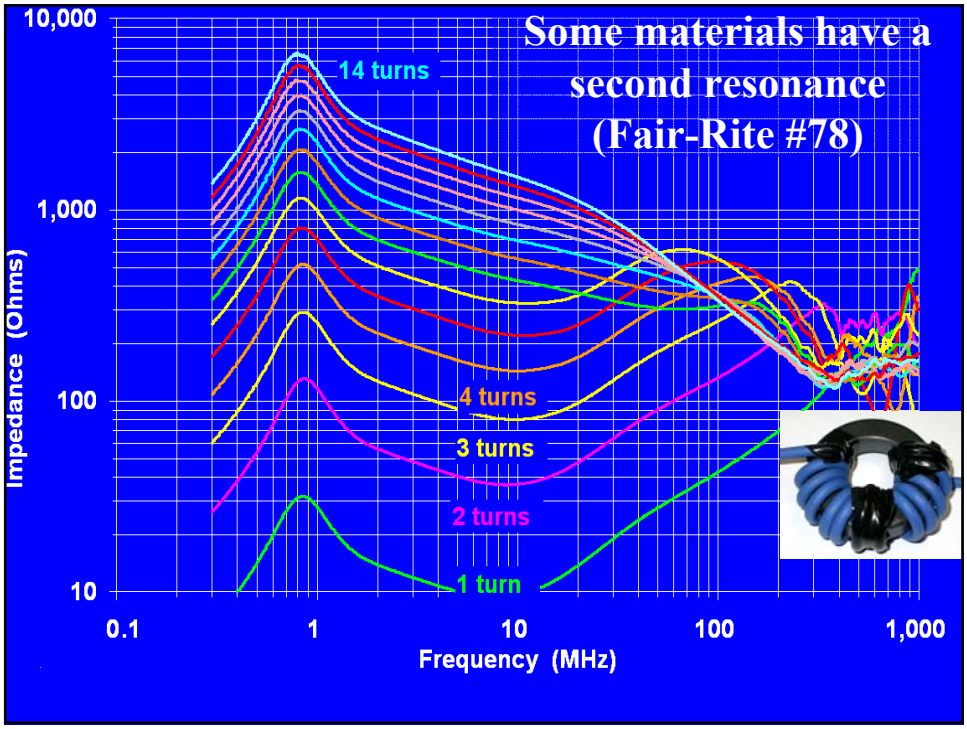


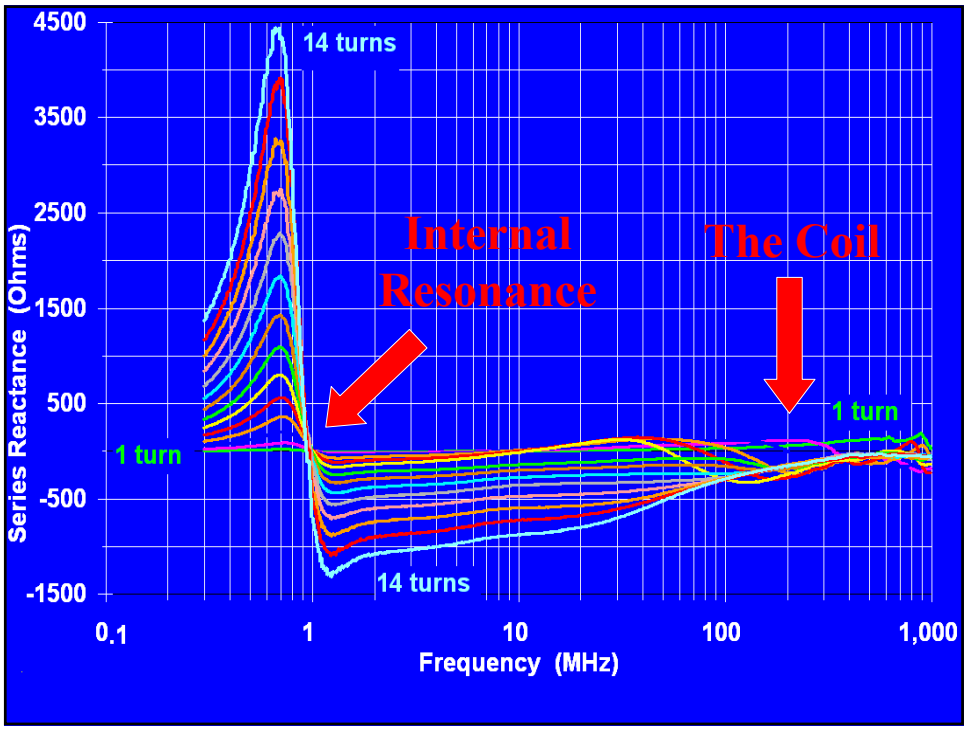

VHF (#43) mix, different lengths!
300
250
200
150
100
50
0
Z (Ω)
Longer
Differing
Dimensions
Change Shape
of Resonance
2643023801
2643300101
2643023002
2643005701
Shorter
10⁶
10⁷
10⁸
10⁹
Frequency (Hz)


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

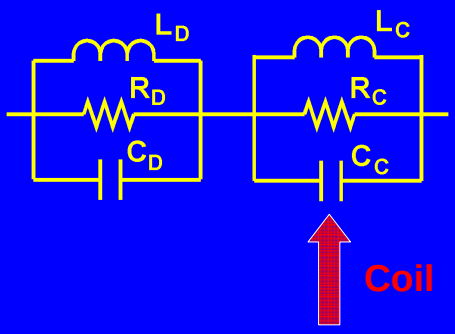

Same mix, even more turns
10,000
1,000
100
10
Impedance (Ohms)
AM Radio
14 turns
2 turns
0.1
1
10
100
Frequency (MHz)


#31 Mix is Best for AM Broadcast RFI
10,000
1,000
100
10
Impedance (Ohms)
AM Radio
14 turns
4 turns
3 turns
2 turns
1 turn
0.1
1
10
100
Frequency (MHz)


Some materials have a second resonance (Fair-Rite #78)
14 turns
4 turns
3 turns
2 turns
1 turn
10,000
1,000
100
10
Impedance (Ohms)
0.1
1
10
100
1,000
Frequency (MHz)


14 turns
Internal Resonance
The Coil
1 turn
1 turn
14 turns
4500
3500
2500
1500
500
-500
-1500
Series Reactance (Ohms)
0.1
1
10
100
1,000
Frequency (MHz)

A Better Equivalent Circuit



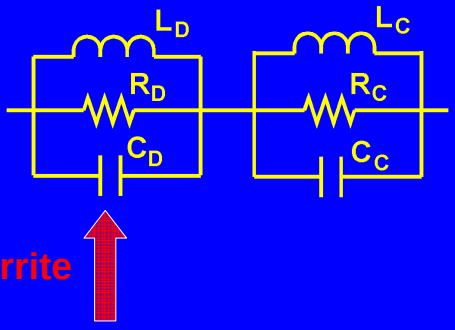
L_C is the inductance of the coil

C_C is the stray capacitance of the coil

R_C is the resistance of the wire.

L_C and C_C form the resonance that moves!

A Better Equivalent Circuit



L_D and C_D represent the *dimensional* resonance of the ferrite itself

R_D is the loss within the ferrite

What Causes this Resonance?

The ferrite material (called the "*mix*"), and

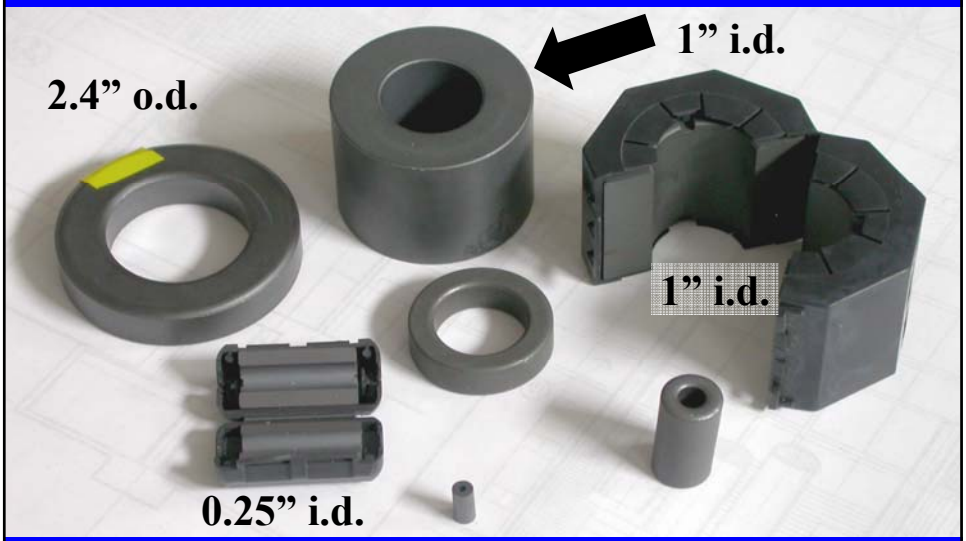
The physical dimensions of the ferrite core.

- **The velocity of propagation within the ferrite establishes standing waves within the core**

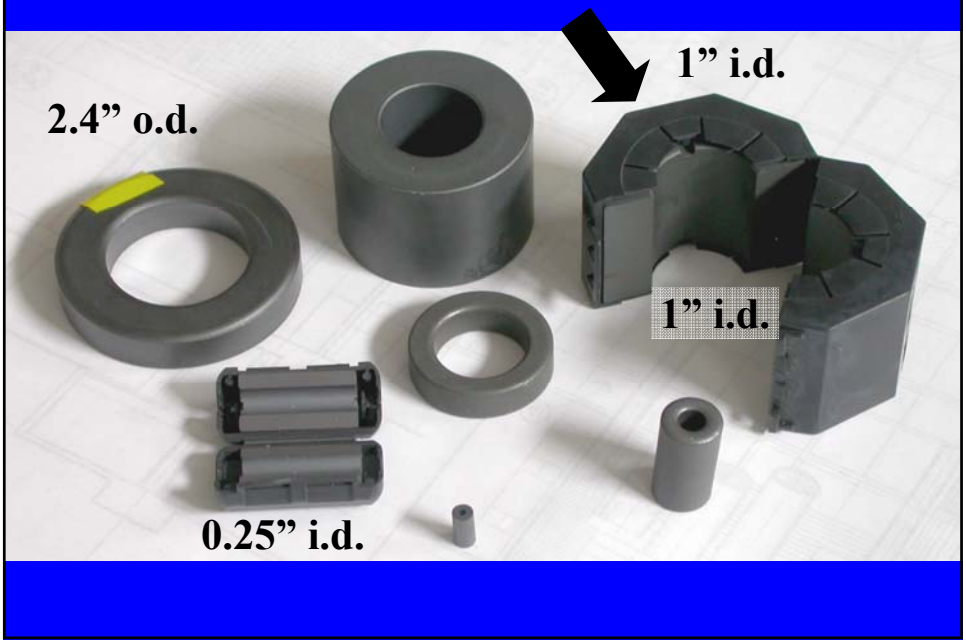
  $V_P = \mu\varepsilon$ **(that is, permeability * permittivity)**

- ***Dimensional resonance* occurs when the cross-section is a half-wavelength**
- **Frequency of the resonance depends on:**
  - **Velocity of propagation (depends on the "mix")**
  - **Dimensions of the cross-section of the flux path**

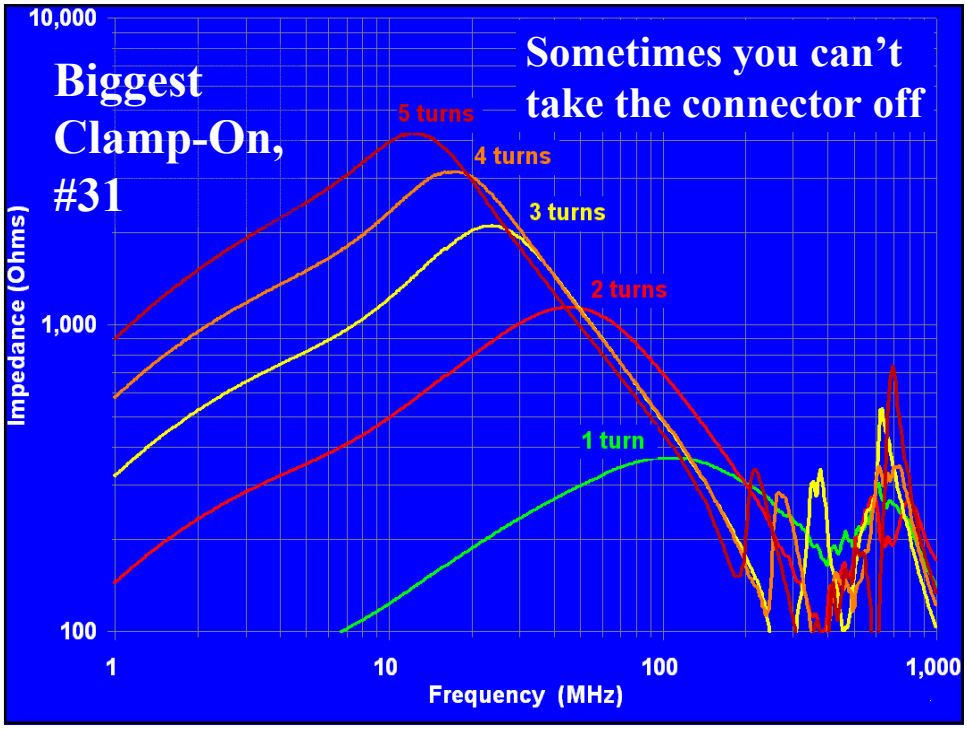
How About Mic Snakes?

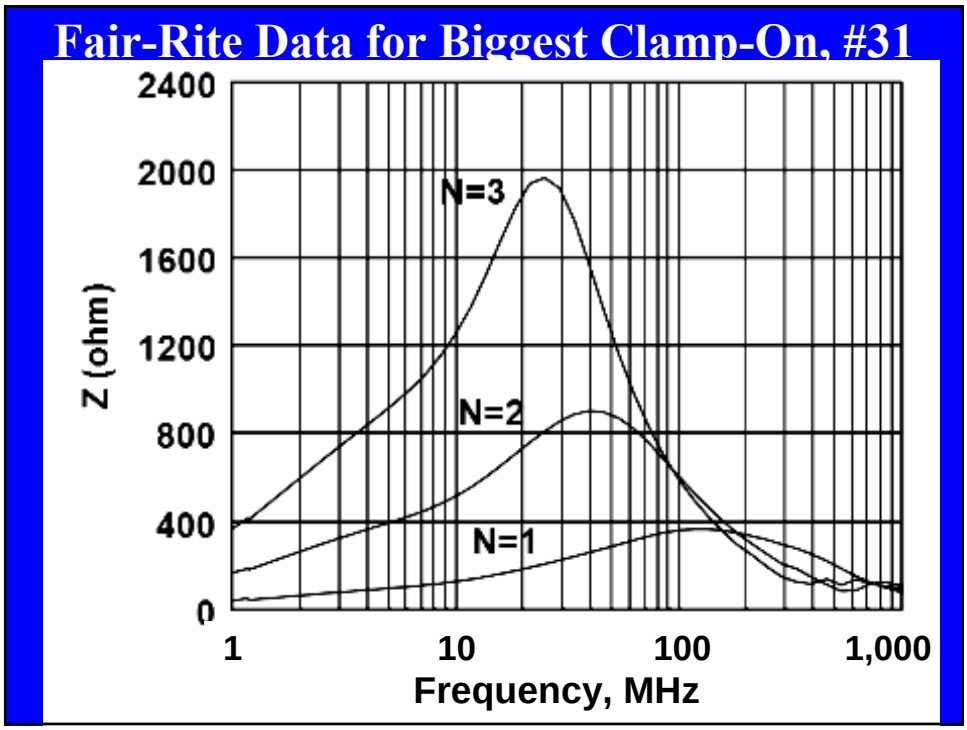


If You Can't Remove the Connector



If you can't easily remove the connector


Biggest Clamp-On, #31
Sometimes you can't take the connector off
5 turns
4 turns
3 turns
2 turns
1 turn
10,000
1,000
100
Impedance (Ohms)
1
10
100
1,000
Frequency (MHz)

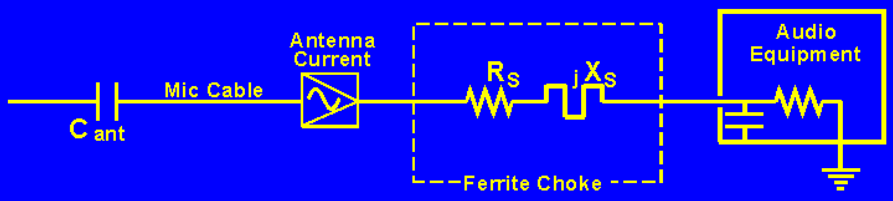

Fair-Rite Data for Biggest Clamp-On, #31
2400
2000
1600
1200
800
400
0
Z (ohm)
N=3
N=2
N=1
1
10
100
1,000
Frequency, MHz

Techniques for Suppression

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

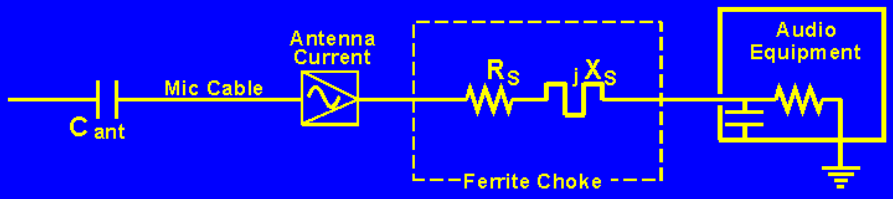
Without the choke, the total antenna circuit is $300\angle -60°\Omega$,

and we add a choke that is $300\angle 60°\Omega$,

$$Z_T = (150 - j260) + (150 + j260) = 300\ \Omega$$

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.

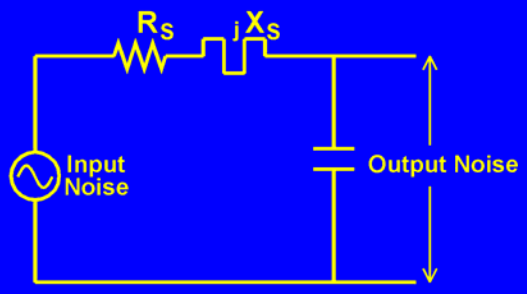
Increasing R_T to 425Ω (3 dB) reduces detected RF by 6 dB, and increasing R_T to 600Ω (6 dB) reduces detected RF by 12 dB (assuming no change in X_S).

Threshold Effect

- For "brute force" suppression, 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.

Capacitance Can Help a Lot

- Outside the box, we're stuck with what the designer provided, so a big ferrite is needed
- Inside the box, we can use a much smaller ferrite part if we provide the capacitor



Criteria for Good Suppression

- Choke should be predominantly resistive
- With voltage divider (capacitor across input)
  - A few hundred ohms can be very effective
- No voltage divider (brute force)
  - 500–1,000 ohms typically needed to hit threshold
  - More is better
- 1,000 ohms R_S is a <u>minimum</u> design goal
- More is better

Saturation

- Ferrites saturate at high power levels, reducing μ
- If both conductors of high power circuits are wound through core, the fields cancel, so only the common mode current contributes to saturation
  - This allows ferrites to be effective on loudspeaker and power wiring

They can look alike, but be very different

They're brittle!

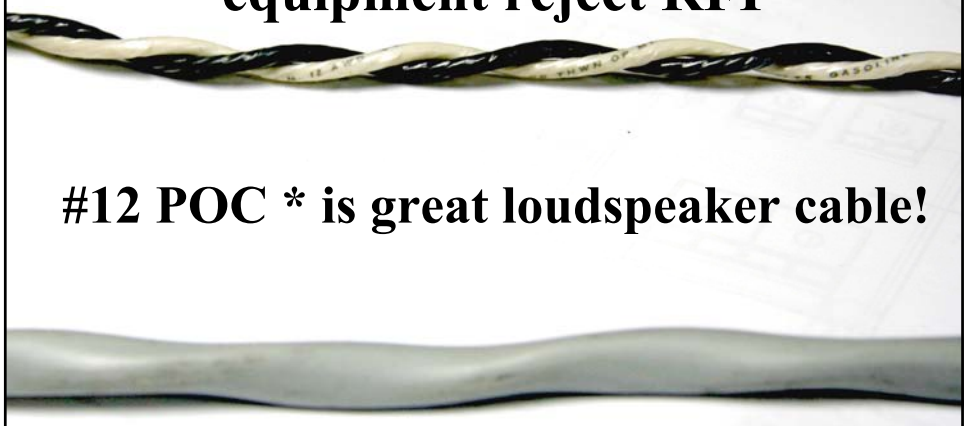
Golden Rules to Avoid RFI

- Loudspeaker Cables
  - Always use TWISTED PAIR
  - Shielding is <u>not</u> important
  - Exotic cable is a waste of money

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

Golden Rules to Avoid RFI

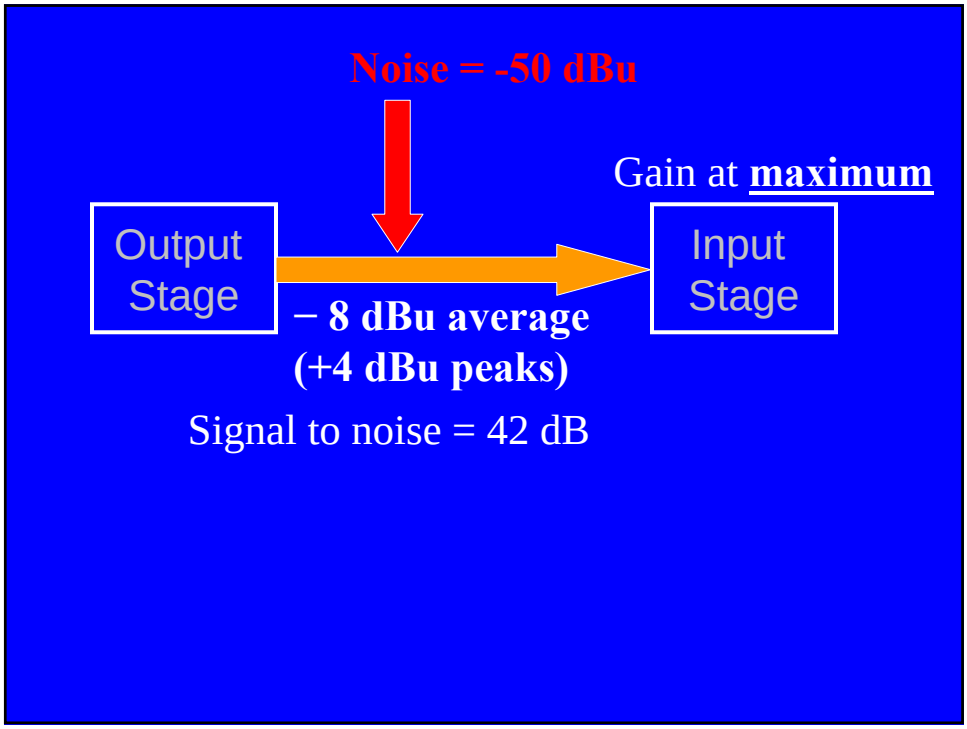
- **Mic and Line level Cables**
  - **<u>Avoid</u> drain wires in shields**
  - **Use braid shielded cable**
  - **Use twisted pair (tighter twist helps too)**

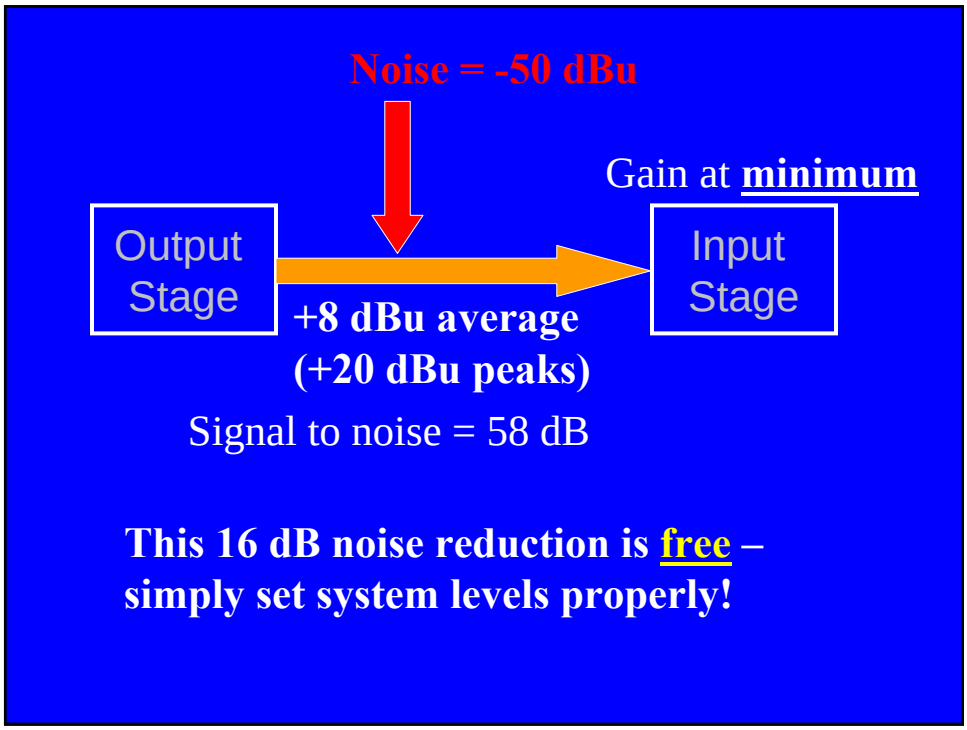
Golden Rules to Avoid RFI

- Maximize audio levels on cables
  - Run line level outputs near their maximum levels
  - Set inputs near their minimum gain
- 15-20 dB of noise rejection for free!

Critical Product Specifications

- Maximum input level
  - How much signal does it take to clip the input stage?
- Maximum output level
  - How much can the box produce cleanly?


Noise = -50 dBu
Gain at maximum
Output Stage
Input Stage
– 8 dBu average
(+4 dBu peaks)
Signal to noise = 42 dB

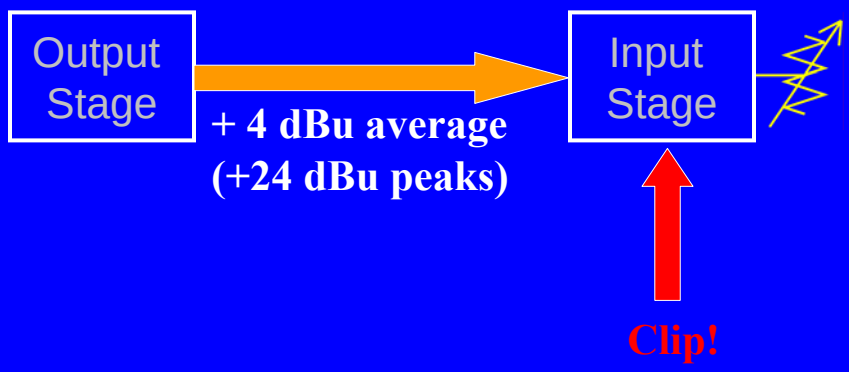

Noise = -50 dBu
Gain at minimum
Output Stage
Input Stage
+8 dBu average
(+20 dBu peaks)
Signal to noise = 58 dB
This 16 dB noise reduction is free –
simply set system levels properly!

What is Professional Level?

- Average level of Program: +4 dBu
- RMS value of Program Peaks: +24 dBu

A product that does not support these levels is <u>not</u> a professional product!

A Poorly Designed Input Stage

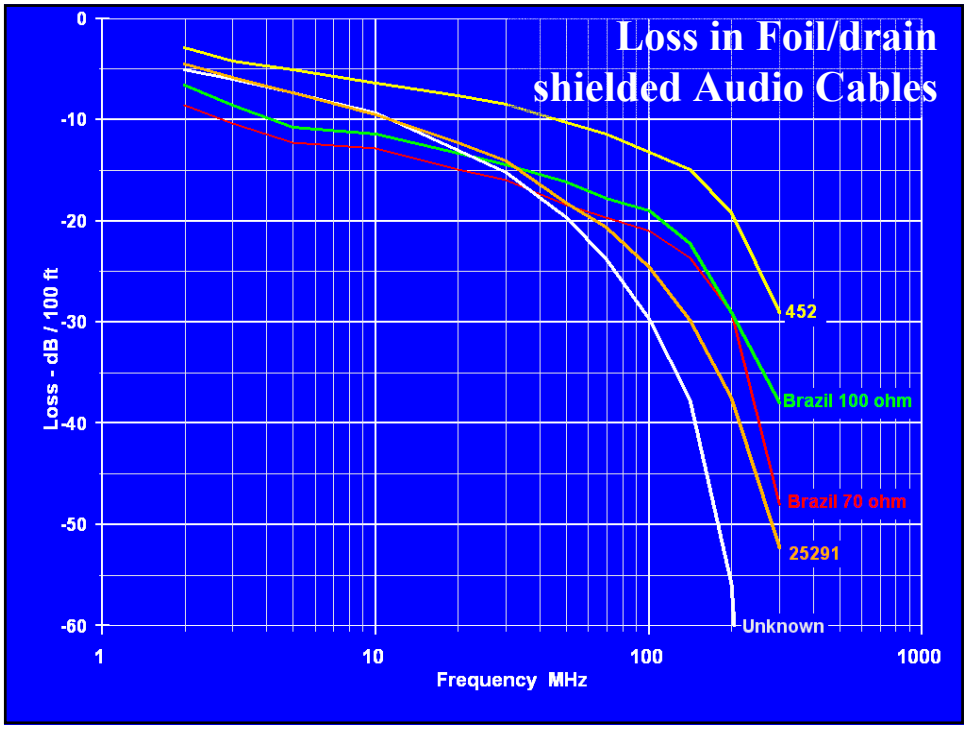


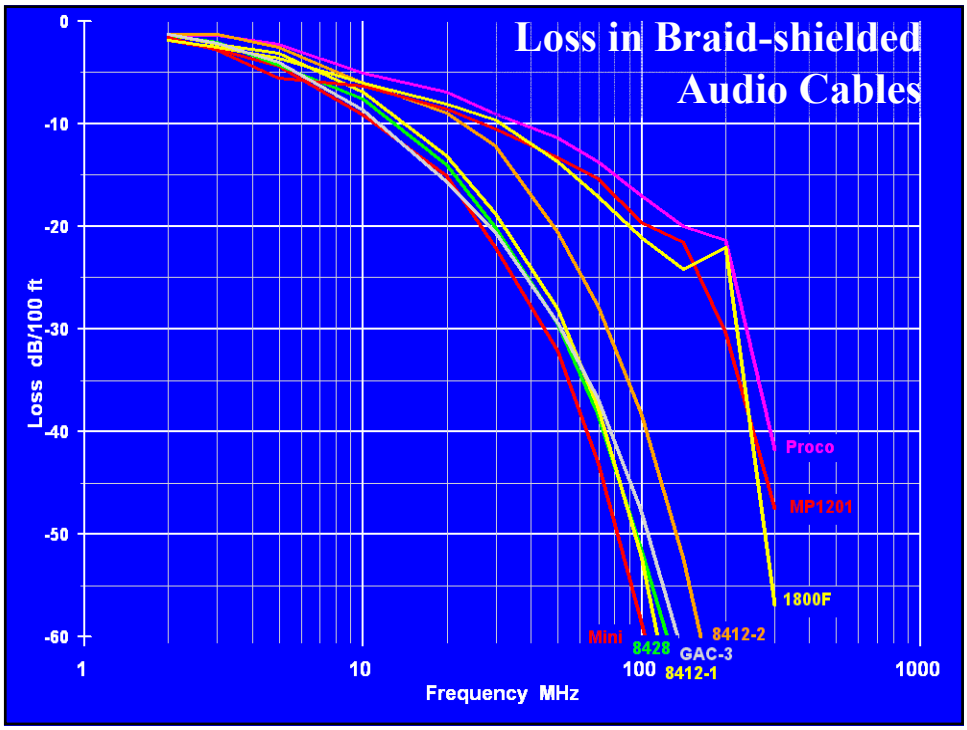
Golden Rules to Avoid RFI

- Don't overlook output stages
  - Feedback networks
  - Pin 1 problems
- Power amplifiers
- Headphone amplifiers
  - Twisted pair

Golden Rules to Avoid RFI

- RFI often enters equipment (and systems) by more than one path.
- Always assume that there are other paths!
- 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!


Loss in Foil/drain shielded Audio Cables
0
-10
-20
-30
-40
-50
-60
Loss - dB / 100 ft
1
10
100
1000
Frequency MHz
452
Brazil 100 ohm
Brazil 70 ohm
25291
Unknown


Loss in Braid-shielded Audio Cables
0
-10
-20
-30
-40
-50
-60
Loss dB/100 ft
1
10
100
1000
Frequency MHz
Proco
MP1201
1800F
Mini
8428
GAC-3
8412-1
8412-2

Digital Equipment

- Any equipment with digital circuitry, a clock, or a switching power supply can cause RFI as well as receiving it
  - Unlikely to interfere with audio
  - Is likely to interfere with wireless mics

Reciprocity

- In general, shielding and filtering that reduces emissions will also reduce susceptibility
- Passive networks, shielding, and antennas work in both directions

  BUT:

- If impedances on either side are different, they may not work equally in both directions

Common Bear Traps

- Watch out for coherent addition
  - RF at multiple inputs will have random phase at each input
  - Detected audio is precisely in phase at multiple inputs (maybe out of polarity)
- RFI can build by 3 dB per doubling
  - 6 dB for four inputs
  - 12 dB for 16 inputs
  - 15 dB for 32 inputs

The Biggest Myths

Myth: "I need a better ground"

Fact: A connection to earth will almost never reduce 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 audio 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.

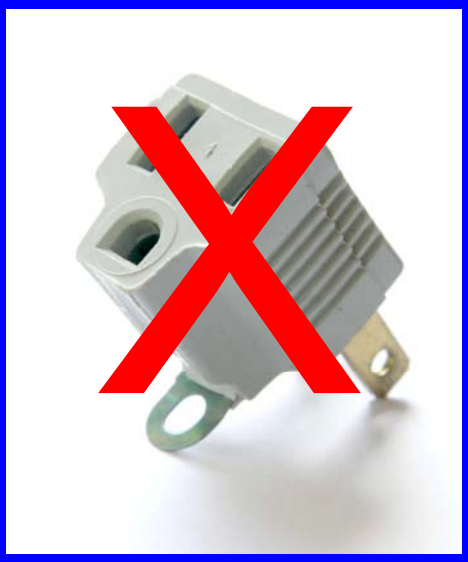
Fact: For safety, all grounds must be bonded together

The Biggest Myths

Myth: "I can fix these ground loops with a ground lifter"

Fact: AC ground lifts are unsafe – they can kill someone or start a fire.

Ground Lifts – Bad Medicine



- Breaks equipment ground path
- Prevents breaker from blowing if chassis becomes "hot"
- **Can KILL someone**

Ground Lifts – Bad Medicine

- Breaks equipment ground path
- Prevents breaker from blowing if chassis becomes "hot"
- **Can KILL someone**

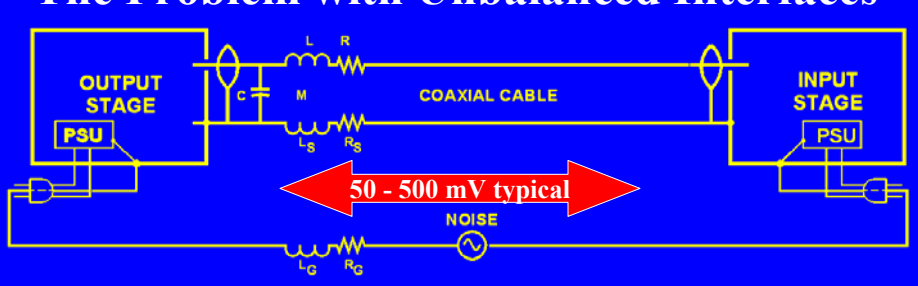
The Biggest Myths

Myth: "I need a power conditioner"

Fact: "Dirty power" is rarely the cause of hum, buzz, RFI, or bad sound.

Fact: The greatest effect of power conditioners is to transfer money from the pocket of the buyer to the pocket of the seller.

The Problem with Unbalanced Interfaces



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

- **Use a "beefy" cable shield**
  - **Minimizes the drop**
- **Reduce the noise voltage between the ends of the cable**

For Unbalanced interconnections, shield resistance is important!

- Shield current (noise) creates IR drop that is added to the signal
- $E_{NOISE} = 20 \log (I_{SHIELD} * R_{SHIELD})$
- Coaxial cables differ widely
  - Heavy copper braid (8241F) 2.6 Ω /1000 ft
  - Double copper braid (8281) 1.1 Ω /1000 ft
  - Foil/drain shield #22 gauge 16 Ω /1000 ft

IR Drop on Cable

Noise reduction = $20 \log (R_1/R_2)$

Typical "hi-fi" cable = 16 ohm/ft

Belden 8241F coax = 2.6 ohm/ft

$20 \log (2.6/16) = -16$ dB

RF noise voltage reduced by 16 dB

Because detection is square law, detected RF is reduced by 32 dB

Make the Cable Shorter

Resistance is proportional to length, so for the same current,

Noise reduction = 20 log (L_1/L_2)

20 log (3/6) = -6 dB

RF noise voltage reduced by 6 dB

Because detection is square law, detected RF is reduced by 12 dB

Make the Cable Shorter

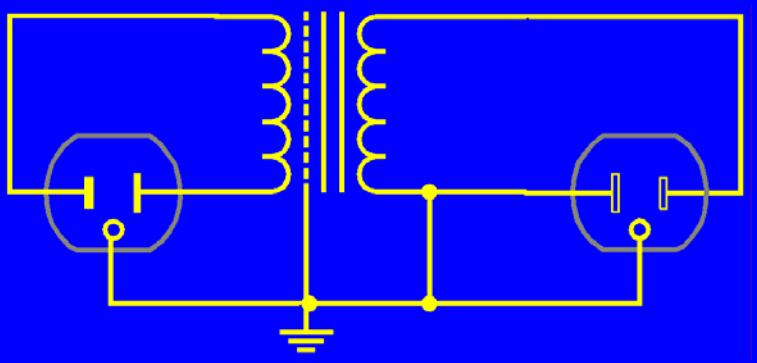
- It may <u>also</u> reduce the antenna current, so RF noise voltage may be reduced by <u>more than</u> 6 dB
- Because detection is square law, detected RF may be reduced by <u>more than</u> 12 dB

Snake Oil and other Bad Medicine

- AC Ground Lifts can KILL
  - Broken off ground pins
  - Ground lift adapters
- AC Ground Isolator can KILL
  - Delays breaker operation when a fault occurs
- Separate ground rods that are not bonded together can KILL
  - Can defeat the equipment ground
  - Make lightning damage more likely
- Exotic power cords are a waste of money

Power Isolation Transformer

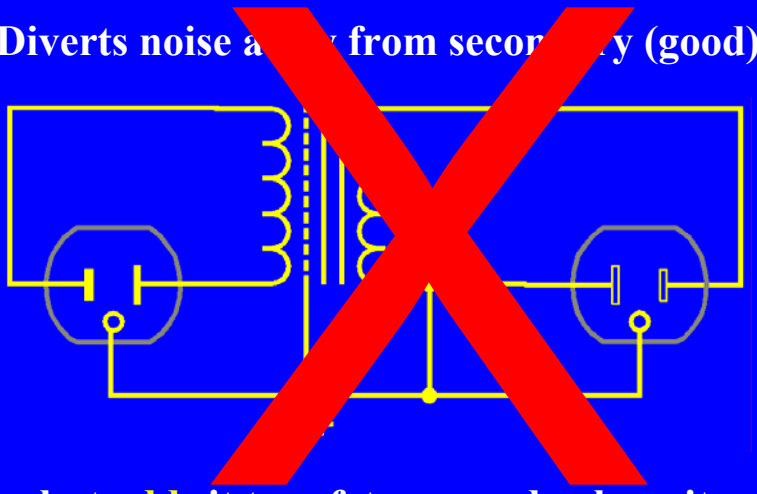
Diverts noise away from secondary (good)



but **adds** it to safety ground, where it increases leakage currents (bad)

Power Isolation Transformer

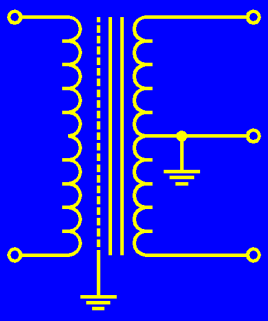
Diverts noise a[illegible] from secor[illegible]y (good)



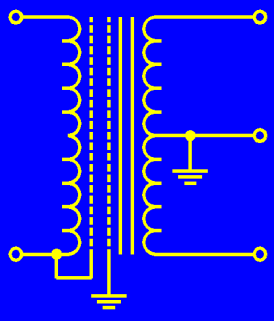
but **adds** it to safety ground, where it increases leakage currents (bad)

Power Isolation Transformer

Use a good one <u>only</u> to establish the technical power system, but not downstream



Single Faraday Shield



Two Faraday Shields

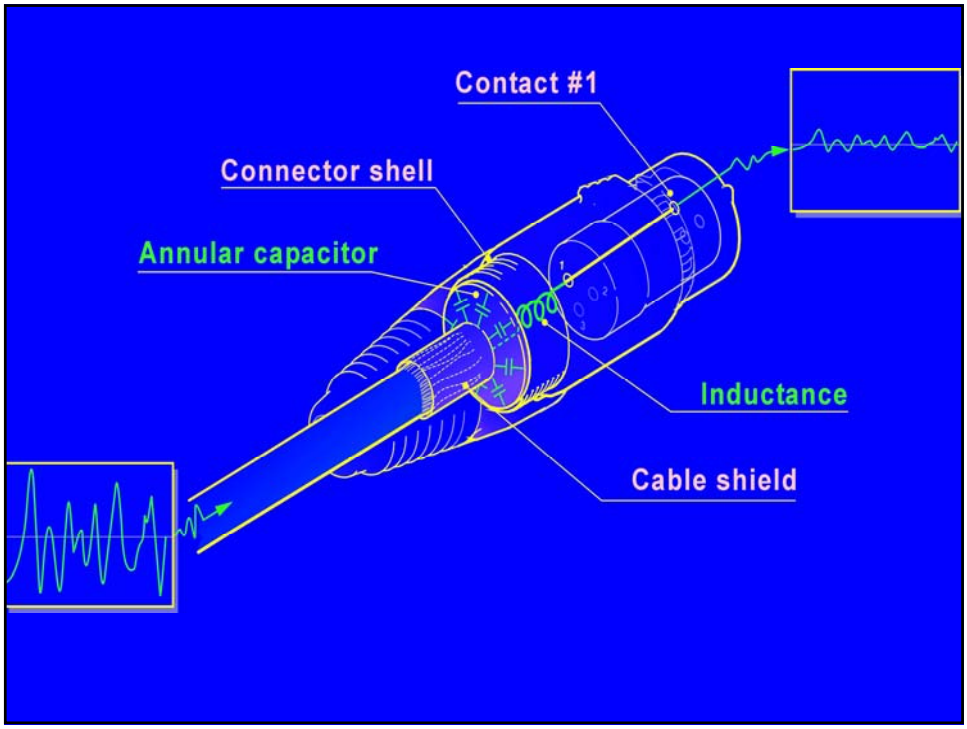
Ralph Morrison, *"Grounding and Shielding Techniques"*

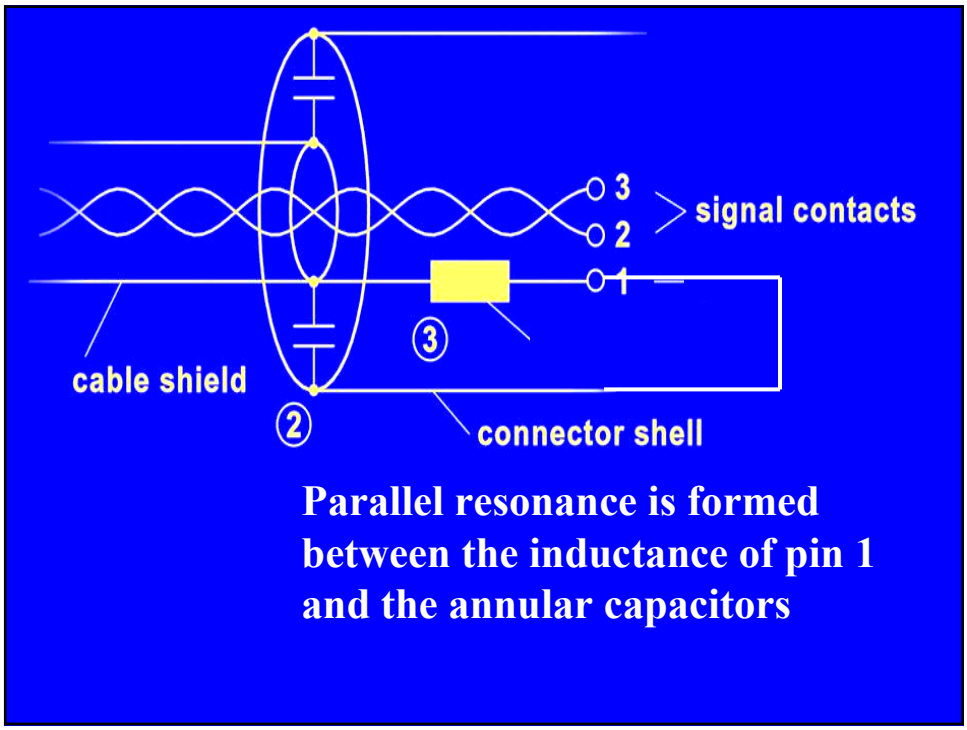
New EMC Connectors

- Annular ring of capacitors connects shield to shell
  - Low inductance – good connection > 1 GHz
  - More continuous shielding
  - Ferrite bead on pin 1

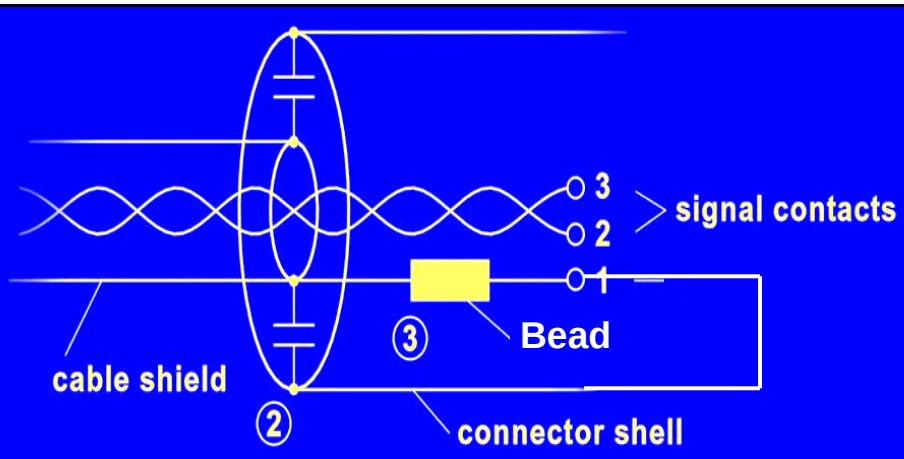
New EMC Connectors

- Female has same internal construction
  - Additional spring improves shell contact with mating connector





Parallel resonance is formed between the inductance of pin 1 and the annular capacitors



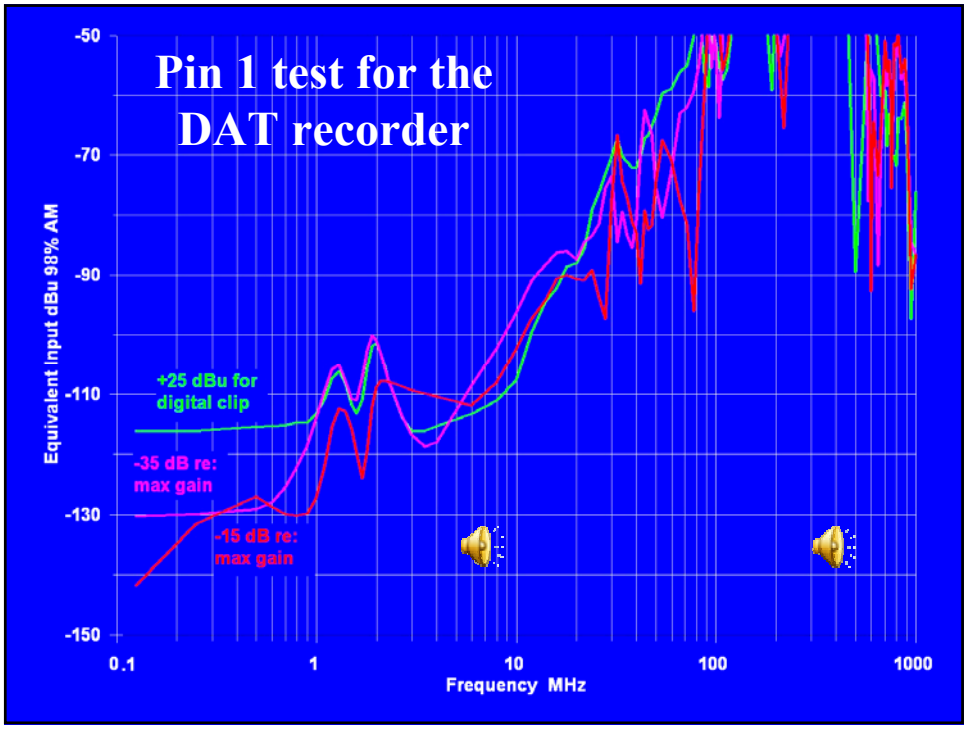
Bead lowers frequency and Q of the resonance

An Unexpected Side Benefit – A "band-aid for pin 1 problems!

- A low inductance capacitive bond from shield to shell makes the right connection
- The ferrite bead disconnects the shield from the wrong connection
- But – the shells must make good contact on the equipment, and the shell must be bonded to the chassis.

Benefits of the EMC Connector

- Better VHF/UHF Shield connection to enclosure
  - Reduces common mode voltage on pins 2 and 3
- "Fixes" VHF/UHF pin 1 problems
  - Removes shield connection from Pin 1 at VHF/UHF
  - Connects the shield to enclosure
- No Benefit if XL Shells Not Connected to Enclosure inside Equipment



Acknowledgements

- Ron Steinberg
- Neil Muncy
- David Josephson
- Dr. Leo Irakliotis
- Steve Kusiceil
- Fair-Rite Products

Excellent EMC Seminars

- **Taught by Henry Ott**
  - **October 15-17, 2008**
  - **Doubletree Inn at San Francisco Airport**
  - **Details at http://www.hottconsultants.com**

References

- **Henry Ott, *Noise Reduction Techniques in Electronic Systems,* Wiley Interscience, 1988**
- **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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- ***Radio Frequency Susceptibility of Capacitor Microphones,*** **Brown/Josephson** (AES Preprint 5720)
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- ***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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