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Audio-frequency shield current induced noise is negligible

(as long as it does not flow in the 0V system)

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Presented at the Tutorial session "Grounding and Shielding" chaired by Tony Waldron, at the Audio Engineering Society's 114th Convention, Amsterdam, March 23rd 2003

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Contents

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Audio benefits from EMC installation techniques

- To meet the EMC directive, a number of large pro-audio systems have followed IEC 61000-5-2
  - with cable shields connected to chassis at both ends
    - allowing 'ground loop' currents to flow in the shields
- These systems have been excellent for EMC
  - but have also been found to have improved audio performance over precious systems (S/N, bandwidth)
- This short presentation helps to explain why the audio performance is so good

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The origin of common mode (CM) noise in a system

- Systems have a number of items of equipment located in different places
  - so experiencing different ground (earth) potentials from each other
  - and interconnected by balanced shielded cables
- The balanced interconnect is intended to reject the "system CM noise"
    - the noise voltage that exists between the grounds of two items of interconnected equipment
  - but nothing is perfect

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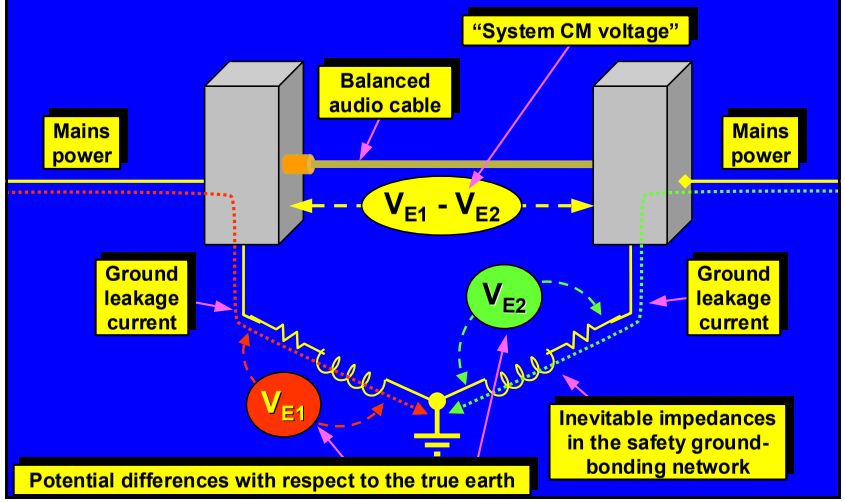
System CM noise
(example of a single-point grounded system)



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How should we connect the shield of the balanced cable?

- We can choose to connect each cable's shield to the equipment at one end only, or at both ends
- Experience shows that good EMC performance and low levels of RF demodulation
  - and compliance with the EMC Directive (EN 55103-1 / -2)
  - is most easily achieved at lowest cost by direct (DC) shield bonding at *both ends*
    - as recommended by IEC 61000-5-2
  - but how does this affect the amount of system CM noise that gets into the signal?

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The system noise voltage couples from the shield to the signal conductors by...

- Stray capacitance, which causes a common-mode (CM) noise voltage
  - and the *imbalance* between the stray capacitances causes differential-mode (DM) noise voltage
- Stray mutual inductance
  - i.e. a 1:1:1 transformer (above some frequency)
  - causes a CM noise voltage (180° to capacitance noise)
  - and the *imbalance* between the stray mutual inductances causes a DM noise voltage

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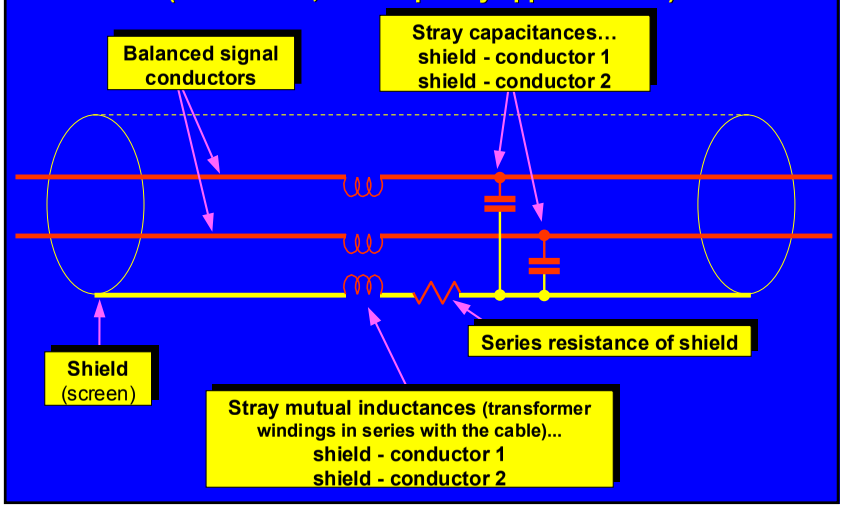
Cable noise coupling
(a first order, low-frequency approximation)



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Implications for signal/noise (S/N) ratios

- The CM voltage on both of the signal conductors
  - is processed by the amplifier's CMRR and its gain, resulting in a DM noise
- The imbalance (DM) voltage between the signal conductors
  - is processed by amplifier gain as if it is wanted signal
- Here are some examples for a cable type "F"
  - showing the relative effects of each of the above noise contributions….

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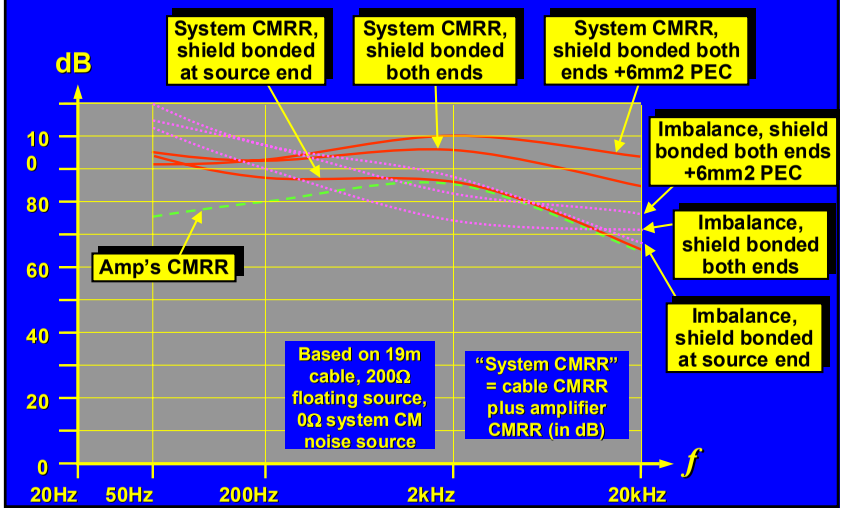
Good quality mixing desk amplifier, with 19 metres of 'cable F' (braid, no drain wire)



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19m of 'cable F' with a *good* mixing desk amplifier

- Single-ended shield bonding at source
  - gives better system CM noise than would be expected from the amp's CMRR spec, below 2kHz
- Bonding shield at both ends makes system CM noise worse by up to 15dB above 300Hz
  - achieving >70dB overall, over the frequency range
- Both-ends-bonded plus 6mm^2 PEC makes system CM noise worse by up to 4dB above 1kHz
  - achieving >75dB overall, over the frequency range

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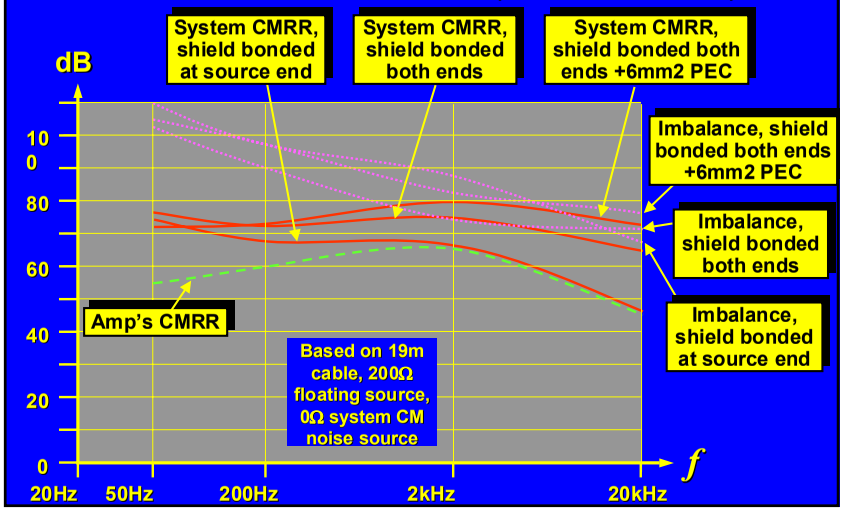
Average mixing desk input amplifier, with 19m of 'cable F' (braid, no drain wire)



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19m of 'cable F' with an *average* mixing desk amplifier

- Single-ended shield bonding at source
  - gives better system CM noise than would be expected from the amp's CMRR spec, below 2kHz
- Bonding shield at both ends makes system CM noise better by up to 19dB, above 50Hz
  - achieving >65dB overall, over the frequency range
- Both-ends-bonded + 6mm² PEC makes system CM noise better by up to 28dB above 100Hz
  - achieving >70dB overall, over the frequency range

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But the system's voltage noise source does *not* have a 0Ω impedance

(as the previous graphs assumed)

- So bonding shields at both ends will *reduce the source noise voltage*
  - as will using using PECs
- Reducing both capacitive and inductive coupled cable noise (CM and DM)
- In a large system there can be >100 cables
  - and bonding all their shields at both ends has a *very* beneficial effect indeed on system CM noise rejection

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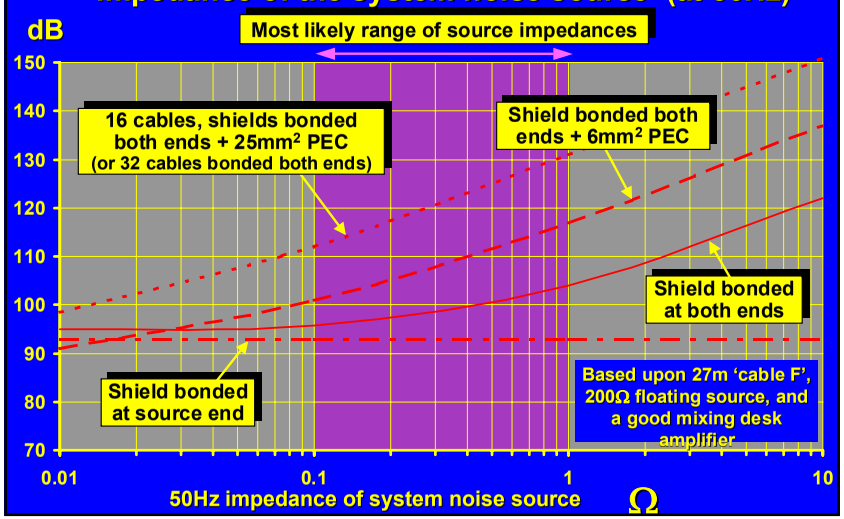
Example of the influence of the finite impedance of the system noise source (at 50Hz)



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Always connect the shield to the chassis, frame or enclosure shield

- It used to be common to connect shields to circuit 0V
  - now well-known to be very bad practice
  - because of 'common-impedance coupling'
- If the circuit's 0V reference is pure clean water…
  - then the shields are sewers
  - and their currents should never flow in the 0V

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Why we don't let shield currents flow in the 0V any more

- Example: a 0.1" wide 0V trace just 1" long (in a 1oz copper printed circuit board)
  - has an impedance of 4.8mΩ at 50Hz
- Just 25mV of 'system CM noise' at 50Hz creates a shield current of 100mA (in 19 metres of 'cable F')
- If this 100mA shield noise current was allowed to flow in the 1" long 0V trace…
  - it would create 480µV of 'common impedance noise' in the circuit's 0V reference system

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For a singer or violinist using a typical 200Ω dynamic microphone…

- 480µV of noise in the 0V could result in a S/N ratio of 20dB
  - worse, where a number of signals share the noisy 0V
- Whereas S/N due to shield-coupled noise alone
  - would be 56dB for an average mixing desk amplifier, and 76dB for a good one (single cable, 0Ω noise source)
  - both much lower than the acoustic background noise for a microphone signal
    - for 16 cable shields in parallel: >66dB and >86dB likely

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the end

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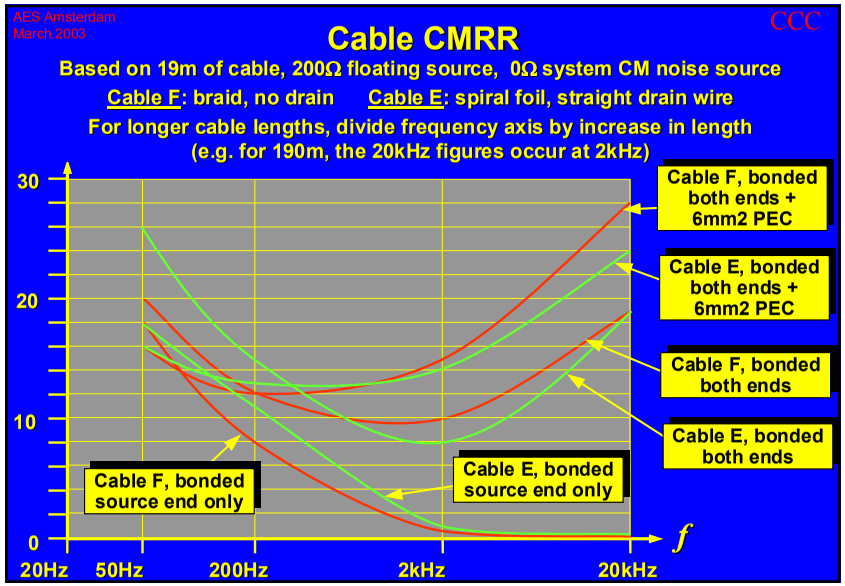
Some additional useful material follows…..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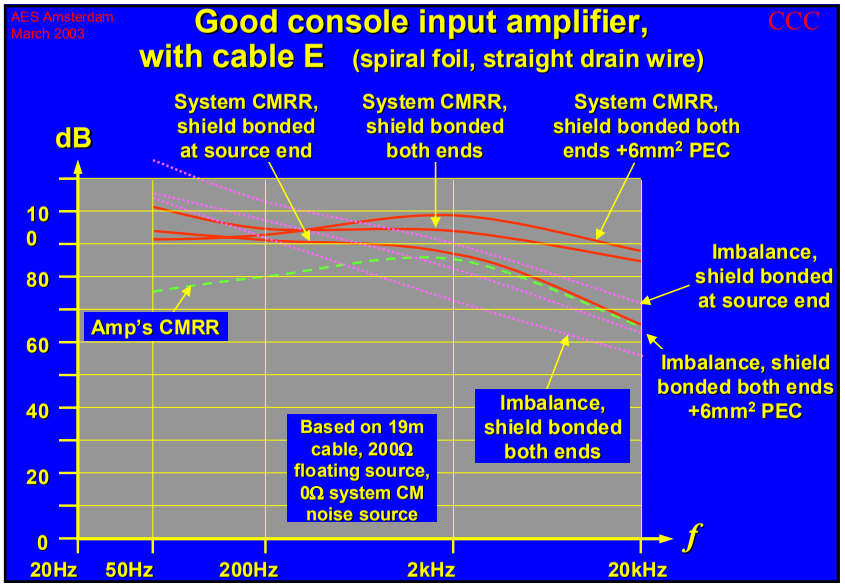
Cable CMRR
Based on 19m of cable, 200Ω floating source, 0Ω system CM noise source
Cable F: braid, no drain Cable E: spiral foil, straight drain wire
For longer cable lengths, divide frequency axis by increase in length
(e.g. for 190m, the 20kHz figures occur at 2kHz)
30
20
10
0
20Hz
50Hz
200Hz
2kHz
20kHz
f
Cable F, bonded both ends + 6mm2 PEC
Cable E, bonded both ends + 6mm2 PEC
Cable F, bonded both ends
Cable E, bonded both ends
Cable F, bonded source end only
Cable E, bonded source end only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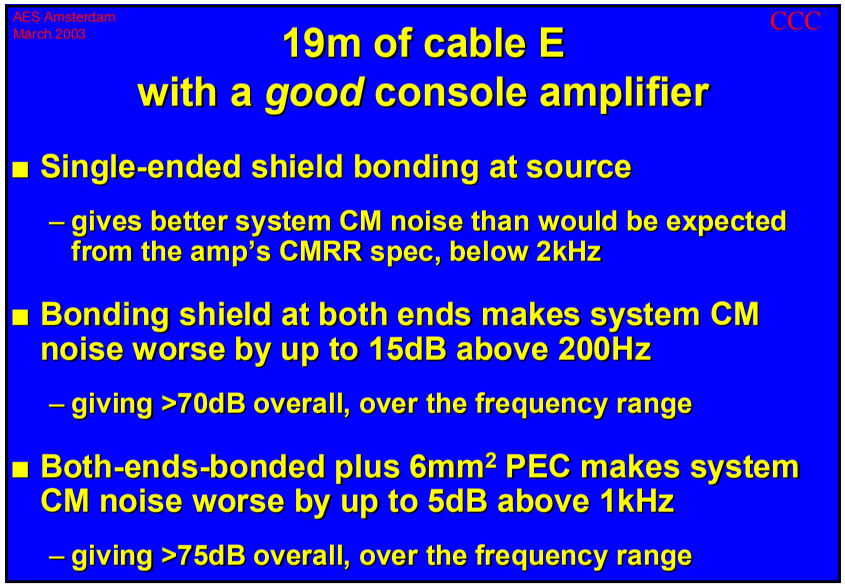
Good console input amplifier,
with cable E (spiral foil, straight drain wire)
dB
System CMRR, shield bonded at source end
System CMRR, shield bonded both ends
System CMRR, shield bonded both ends +6mm² PEC
10
0
80
60
40
20
0
Amp's CMRR
Imbalance, shield bonded at source end
Imbalance, shield bonded both ends +6mm² PEC
Imbalance, shield bonded both ends
Based on 19m cable, 200Ω floating source, 0Ω system CM noise source
20Hz
50Hz
200Hz
2kHz
20kHz
f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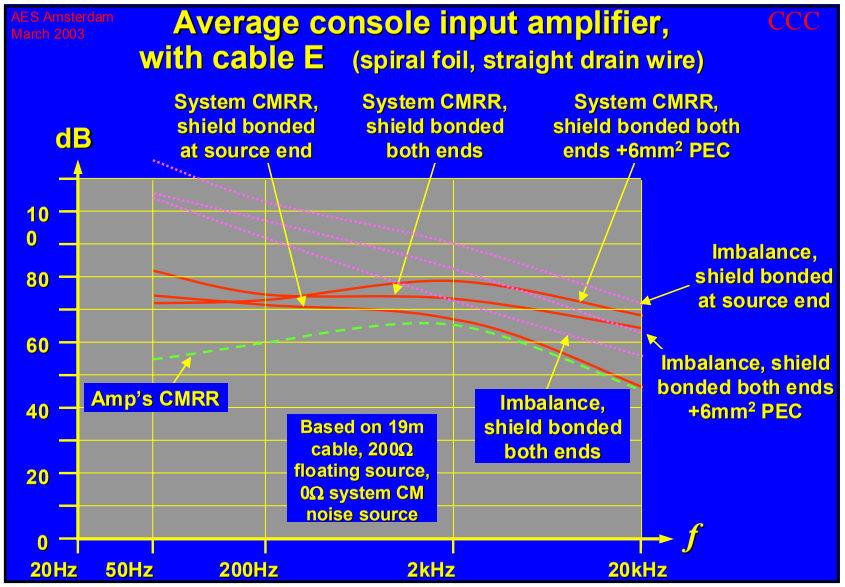
19m of cable E
with a *good* console amplifier
■ Single-ended shield bonding at source
– gives better system CM noise than would be expected from the amp's CMRR spec, below 2kHz
■ Bonding shield at both ends makes system CM noise worse by up to 15dB above 200Hz
– giving >70dB overall, over the frequency range
■ Both-ends-bonded plus 6mm² PEC makes system CM noise worse by up to 5dB above 1kHz
– giving >75dB overall, over the frequency range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Average console input amplifier,
with cable E (spiral foil, straight drain wire)
dB
System CMRR, shield bonded at source end
System CMRR, shield bonded both ends
System CMRR, shield bonded both ends +6mm² PEC
10
0
80
60
40
20
0
Amp's CMRR
Imbalance, shield bonded at source end
Imbalance, shield bonded both ends +6mm² PEC
Imbalance, shield bonded both ends
Based on 19m cable, 200Ω floating source, 0Ω system CM noise source
20Hz
50Hz
200Hz
2kHz
20kHz
f

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19m of cable E with an average console amplifier

- Single-ended shield bonding at source
  - gives better system CM noise than would be expected from the amp's CMRR spec, below 2kHz
- Bonding shield at both ends makes system CM noise better by up to 10dB, above 200Hz
  - giving >55dB overall, over the frequency range
- Both-ends-bonded + 6mm^2 PEC makes system CM noise better by up to 18dB above 50Hz
  - giving >62dB overall, over the frequency range