M1 - AUDIO INTERCONNECTIONS and GROUNDING – DISPPELLING THE MYTHS

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AUDIO INTERCONNECTIONS – DISPELLING THE MYTHS
By Henry W. Ott

Cabling and interconnection is often the “Achilles Heel” of quality audio. Many myths and rules-of-thumb have been perpetuated both in-print and in-practice with respect to proper audio interconnection techniques. Some of these myths have a rationale basis to justify them, many others do not.

This presentation covers the fundamentals of electromagnetic field coupling, cable balancing, grounding and shielding in audio interconnections, based on the laws of physics, not conjecture, hype, or personal opinion.

Further complicating the audio interconnection situation today, is the fact that many audio devices also contain high frequency digital circuits.
OVERVIEW

- We Will Analyze Electromagnetic Coupling To Cables
- We Will Use Circuit Theory, Not Field Theory
  - Electric Field Coupling
  - Magnetic Field Coupling
  - Common Impedance Coupling
  - Shielding
  - Balancing
- We Will Assume That The Cables Are Electrically Short (Less Than One-Quarter of a Wavelength)
- This Will Give Us An Intuitive Understanding Of The Coupling Mechanisms And How To Minimize Noise Coupling
Capacitive Coupling Between Two Conductors.

\[ V_N = \frac{j\omega [C_{12} / (C_{12} + C_{2G})]}{j\omega + 1 / R(C_{12} + C_{2G})} V_1 \]
FREQUENCY RESPONSE OF CAPACITIVE COUPLED NOISE VOLTAGE

\[ \text{Actual } V_N = j\omega R C_{12} V_1 \]

\[ V_N = j\omega R C_{12} V_1 \]

\[ V_N = \frac{C_{12} V_1}{C_{12} + C_{2G}} \]

\[ R \ll \frac{1}{j\omega (C_{12} + C_{2G})} \]

\[ R \gg \frac{1}{j\omega (C_{12} + C_{2G})} \]

\[ V_N = \frac{C_{12} V_1}{C_{12} + C_{2G}} \]
ELECTRIC FIELD (CAPACITIVE) COUPLING

The Best Way to Decrease the Coupling is to:

- Reduce $C_{12}$
- Separation, Orientation, Length & Shielding

$$V_N = j\omega R C_{12} V_1$$

Equivalent Circuit
SHIELDED CABLE - IDEAL CASE

Capacitive Coupling With Shield Placed Around Receiver Conductor.

\[ V_{\text{shield}} = \left( \frac{C_{1S}}{C_{1S} + C_{SG}} \right) V_1 \]

\[ V_N = V_{\text{Shield}} \]
Note:

The Shield on a Shielded Cable is Unshielded!
SHIELDED CABLE - PRACTICAL CASE

Physical Representation

Equivalent Circuit

Simplified Equivalent Circuit

For Grounded Shield

\[ V_N = j\omega R C_{12} V_1 \]
Most Cabling Problems Are Due to Improper Terminations.
The Voltage $V_N$ Induced in a Loop of Area $A$ in a Uniform Magnetic Field is (Faraday’s Law):

\[ V_N = j \omega B A \cos \theta \]

\[ V_N = j \omega \Phi_{12} \]

\[ V_N = j \omega M_{12} I_1 \]
COMPARING ELECTRIC AND MAGNETIC FIELD COUPLING

Electric Field Coupling:

\[ V_N = j\omega RC_{12} V_1 \]

Magnetic Field Coupling:

\[ V_N = j\omega M_{12} I_1 \]
MAGNETIC FIELD (INDUCTIVE) COUPLING

\[ V_N = j\omega B A \cos \theta = j\omega M_{12} I_1 \]

Decreasing The Area Is The Key To Controlling Magnetic Coupling

1) Place Conductors Close Together

2) Use Twisted Pair

3) Use A Shielded Cable ??
CABLE SHIELDING FOR MAGNETIC FIELD SUPPRESSION

\[ V_{n1} = j \omega B A \cos \theta \]

or

\[ j \omega M_{12} I_1 \]

\[ V_{n2} = j \omega M_{s2} I_s \]
MAGNETIC COUPLING BETWEEN A SHIELD AND ITS CENTER CONDUCTOR

All the magnetic flux due to the shield current is outside the tube, none is inside. Therefore....

\[ M = L_s \]

\[ V_N = \frac{j\omega}{j\omega + \frac{R_s}{L_s}} V_s \]

\[ \omega_c = \frac{R_s}{L_s} = \text{Shield Cutoff Freq.} \]
## MEASURED VALUES OF SHIELD CUTOFF FREQUENCY

<table>
<thead>
<tr>
<th>CABLE</th>
<th>IMPEDANCE (Ω)</th>
<th>CUTOFF FREQUENCY (kHz)</th>
<th>FIVE TIMES CUTOFF FREQUENCY (kHz)</th>
<th>REMARKS</th>
</tr>
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<tbody>
<tr>
<td>COAXIAL CABLE</td>
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<td></td>
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<tr>
<td>RG-6A</td>
<td>75</td>
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<td>RG-59C</td>
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<td>RG-58C</td>
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<td>SHIELDED TWISTED PAIR</td>
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<tr>
<td>754E</td>
<td>125</td>
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<tr>
<td>24 Ga.</td>
<td>--</td>
<td>2.2</td>
<td>11.0</td>
<td>ALUMINUM FOIL</td>
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<tr>
<td>22 Ga.</td>
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<td>7.0</td>
<td>35.0</td>
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<td>SHIELDED SINGLE</td>
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<tr>
<td>24Ga.</td>
<td>--</td>
<td>4.0</td>
<td>20.0</td>
<td></td>
</tr>
</tbody>
</table>

* One Pair Out Of An 11 Pair Cable (Belden 8775)

For a coaxial shield:

- \( M_{s2} = L_s \)
- \( M_{1s} = M_{12} \)

Total voltage induced into conductor 2 is:

\[ V_N = V_2 - V_c \]
MAGNETIC COUPLING, OPEN-WIRE TO SHIELDED CABLE

\[ V_N = j \omega M_{12} I_1 \]

\[ V_N = M_{12} I_1 \left( \frac{R_s}{L_s} \right) \]

\[ \omega = \frac{R_s}{L_s} \]

\[ V_N = j\omega M_{12} I_1 \left[ \frac{R_s / L_s}{j\omega + R_s / L_s} \right] \]
EFFECT OF SHIELD CURRENT ON INPUT NOISE VOLTAGE

Physical Representation

Equivalent Circuit

\[ V_{\text{in}} = -j \omega M I_s + j \omega L_s I_s + R_s I_s \]

Since \( M = L_s \),

\[ V_{\text{in}} = R_s I_s \]
The Effect Described on the Previous Slide is Called Common Impedance Coupling.

In the Audio World it is Often Referred to as Shield Current Induced Noise (SCIN)*

It Results From the Shield Having to Carry Two Currents:
- The Signal Current
- The Induced Noise Current

Common Impedance Coupling Can be Eliminated or Reduced by Using a Cable That Has Three Conductors
- Triaxial Cable (Two Shields Insulated From Each Other)
- Twinaxial Cable (Two Balanced Signal Conductors Within a Single Shield)

* Brown & Whitlock, 2003
WHAT CAUSES SHIELD CURRENTS

- Differences in Ground Potential
- Magnetic Field Induction
- Radio Frequency Pickup
WHAT CAN WE DO TO REDUCE SCIN

- **In All Cases**
  - Use a Shield With Low Resistance (Cu Braid Not Al Foil)
  - Use Balanced Interconnections

- **In The Case of Low Frequency Shield Currents (< 500 kHz)**
  - Reduce Ground Potential Difference By Adding a Heavy Gauge Parallel Earth Conductor (PEC)
  - Ground Only One End of the Shield (This However May Cause High Frequency Emissions & Susceptibility)
  - Use Hybrid Shield Grounding

- **In The Case of High Frequency Shield Currents (> 500 kHz)**
  - Add Ferrite Core (C-M Choke) to The Cable
  - At Frequencies Above About 10 MHz an Unbalanced Coaxial Cable, Because of Skin Effect, Contains Three Isolated Conductors:
    - The Center Conductor
    - The Inner Surface of the Shield Conductor
    - The Outer Surface of the Shield Conductor
    - Therefore, Common Impedance Coupling Does Not Occur
EXAMPLE OF A HYBRID GROUND

Cable Shield is Hybrid Grounded
XLR CONNECTOR

Hybrid Cable Shield Termination

Spring Fingers For 360º Backshell Contact
REQUIREMENTS FOR A PROPER SHIELD TERMINATION

- Shield Must be Connected to the Proper Potential
- A Low Impedance Connection
- A 360° Contact to the Shield
METHODS OF BREAKING GROUND LOOPS

- Transformer
- Optical Coupling
- Common-Mode Choke
- Balanced Circuit
WHERE NOT TO BREAK A GROUND LOOP

- Why Does Some Equipment Have a Grounded Three Wire Plug?
- For Safety!
- Do Not Break a Ground Loop by Lifting a Ground From Equipment With a Three Wire Plug
- Doing So is Unsafe!
- Rather Break the Ground Loop in the Signal Interconnection as Was Shown on the Previous Slide
- An Excellent Reference for Troubleshooting Ground Loop Problems in Unbalanced Audio Systems is the *Jensen System Troubleshooting Guide*, by Bill Whitlock (www.jensentransformers.com/apps_wp.html)
BALANCING

● Balancing Is Often an Overlooked Noise Reduction Technique.

● The Purpose of Balancing is to Make the Noise Pickup in Both Conductors Equal, In Which Case it Can be Made to Cancel Out in the Load.

● Balancing Can Be Used in Addition to Other Techniques for Additional Noise Suppression; or It Can Be Used As the Primary Means of Noise Suppression.

● Balancing Is Normally Used in Interconnection or Cabling Systems to Reduce Noise Pick-up or to Minimize Radiation.
Balance is defined in terms of the impedance of the two signal conductors with respect to a reference, which is usually ground. If these impedances are equal and non-zero, the system is balanced. If the impedances are unequal the system is unbalanced. A signal conductor with a grounded return conductor is, therefore, an unbalanced (sometimes referred to as a single ended) system.
A BALANCED CIRCUIT

For Balance: \( R_{s1} = R_{s2} \)
\( C_{s1} = C_{s2} \)

For Balance: \( R_{in1} = R_{in2} \)
\( C_{in1} = C_{in2} \)

Note: \( V_{s1} \) Does Not Have to Equal \( V_{s2} \)
\( V_{s1} \) or \( V_{s2} \) May Even be Zero
THE TELEPHONE CONNECTION

An excellent example of the effectiveness of using a balanced system to reduce noise is the telephone system, where signal levels are typically tens to hundredths of millivolts. Telephone cables often run for many miles parallel to high voltage (4,000 to 14,000 volts) AC power lines and you do not hear any 60 Hertz hum in the telephone. This is because the telephone system is balanced. On the rare occasions where you do hear hum in the telephone, it is because something has caused an unbalance to occur in the lines and it will go away once the balance is restored.
CMRR DUE TO AN UNBALANCED SOURCE RESISTANCE

\[ CMRR = \frac{(R_{in} + R_s + \Delta R)(R_{in} + R_s)}{R_{in} \Delta R} \]

If \( R_{in} \gg R_s + \Delta R \) Then

\[ CMRR = \frac{R_{in}}{\Delta R} \]

Example:
\( R_{in} = 10 \, k\Omega \)
\( \Delta R = 10 \, \Omega \)
CMRR = 1,000 or 60 dB
TWISTED PAIR WIRING

- Twisted Pair Wiring, Even When Unshielded, is Very Effective in Reducing Magnetic Field Coupling
- Two Necessary Conditions
  - Signal Must Flow Equally & in Opposite Directions in the Two Conductors
  - The Pitch of the Twist Must be Less Than 1/20 Wavelength (One Twist per Inch Will be Effective Up to 500 MHz)
- The Above is True Whether the Terminations are Balanced or Not
- If the Terminations are Balanced, Twisted Pair Wiring Will Also be Effective in Reducing Electric Field Coupling
- Do Not Confuse Twisted Pair Wiring With Balancing, They Are Two Different Things, Although Often Used Together
Twisted Pairs or Shielded Twisted Pairs Are Usually Used in Balanced Circuits, Since a Twisted Pair is Inherently a Balanced Configuration. A Coaxial Cable is Inherently an Unbalances Structure But Can Still Be Used In a Balanced System if Properly Configured as Shown Above.
CABLE SHIELD TERMINATIONS TO A SHIELDED ENCLOSURE

Think of Cable Shields as an Extension of the Shielded Enclosure, and Therefore, They Should be Connected DIRECTLY to The Enclosure With a 360° Termination.
CABLE SHIELD TERMINATION METHODS

- Very Poor
- Poor
- Better (Long Pigtail)
- Good (Short Pigtail)
- Best (360° Shield Connection)
IMBALANCE IN A BALANCED SYSTEM

- In An Ideal Balanced System, No Noise Will Couple Into the Circuit.
- In the Real World, However, Small Unbalance Will Limit the Noise Suppression Possible. These Include:
  - Load Imbalance
  - Source Imbalance
  - Cable Imbalance
- Cable Imbalance
  - Resistive Unbalance (Usually Negligible)
  - Capacitive Unbalance (Typically 3 to 5%)
  - Inductive Unbalance
    - Improper Shield Termination (Non 360° Contact)
    - Common in Foil Shielded Cables Due to the Drain Wire Current
    - Virtually Nonexistent in Braid Shielded Cables @ High Frequencies (> 100 kHz), if Properly Terminated
SLIDES FOR PRESENTATION AVAILABLE AT:

BIBLIOGRAPHY

BIBLIOGRAPHY (CONT.)