Impedance & Audio Interfaces

PNW Chapter of the AES
March 2017

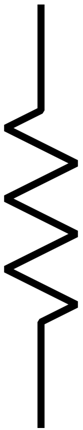
Electrical Impedance Basics

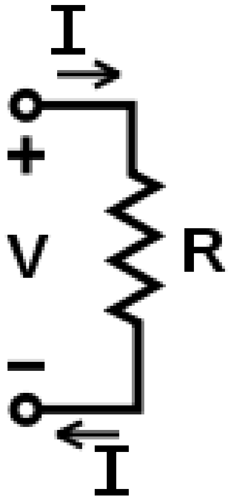
Resistance (Resistor)

Ratio of current (I) and voltage (E or V)

Unit: Ω, Ohm

- Resistors
- Wires
- Circuit board traces





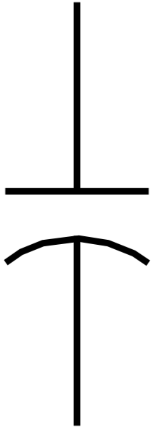
Electrical Impedance Basics

Capacitive Reactance (Capacitor)

Ratio of current (I) and the *change in voltage over time* (dV/dt)

Units: F, Farads

- Capacitors
- Two wires near each other
- PCB Traces near each other
- Any two conductive surfaces



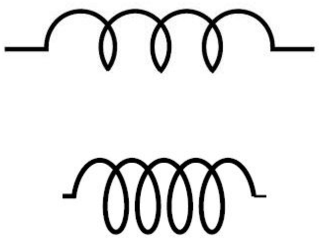
“Resists” instantaneous changes in voltage

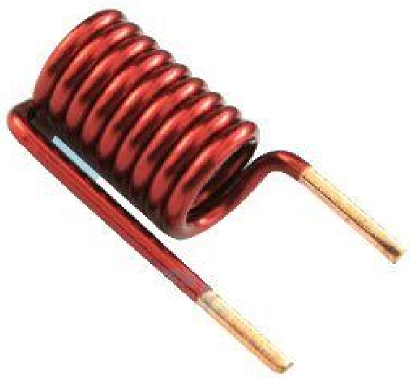
Electrical Impedance Basics

Inductive Reactance (Inductor)

Ratio of voltage (E or V) and the *change in current over time* (dI/dt)

Units: H, Henries





- Inductors
- Wires or coils of wire
- PCB Traces
- Transformers

“Resists” instantaneous changes in current

Audio Interfaces

What’s the point of connecting two things together?

- Information transfer
- Information in what form?
    - Analog audio: frequency, phase and amplitude
    - Digital audio: frequency (data rate)
    - **The higher the frequency, the more cable / wire impedance matters**
- Across what distance?
    - **The longer the distance, the more cable / wire impedance matters**

Audio Interfaces

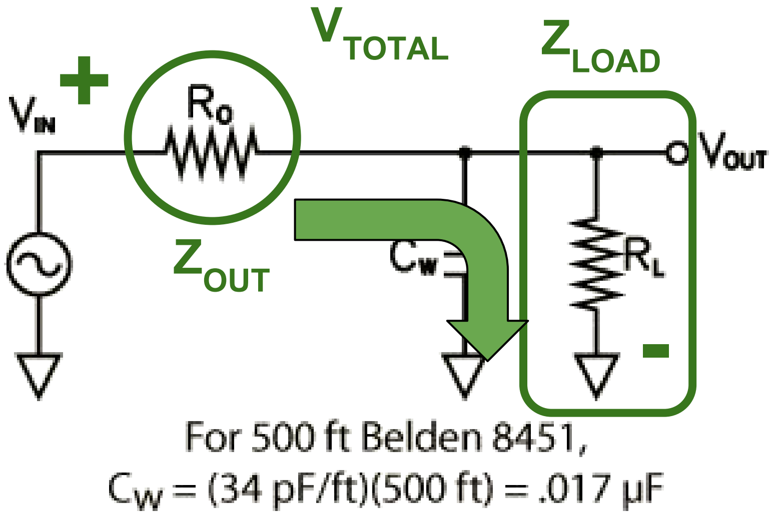
What to do with this information?

- Measure it (microphone level or line level audio)
  - Transfer a measureable voltage
  - Minimizes losses in the interface
- Do some work with it (telephone system or power amplifier)
  - Transfer usable power
  - Drive a loudspeaker
  - Heat a rack room
  - More losses in the interface
- Go the distance
  - Transmission line behaviors

Audio Interfaces: Voltage Transfer

Very common in pro and consumer audio systems

Voltage divider when reactance is minimized



(1) Bohn / Rane

Resistive Voltage Divider:

$R_L > 10 * R_O$

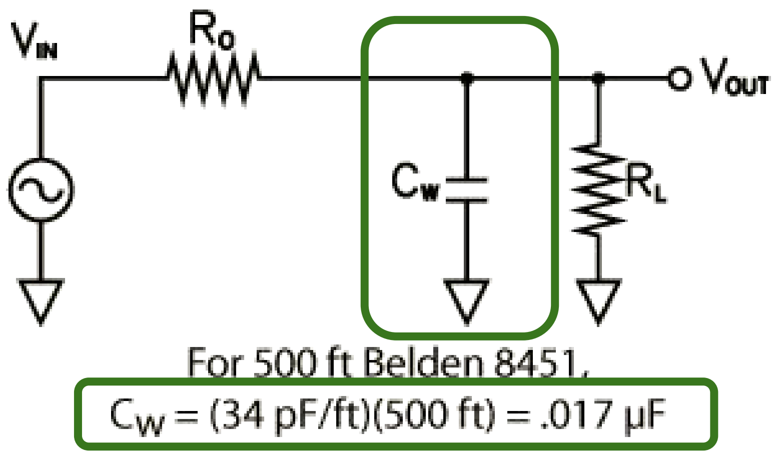
$$V_{OUT} = V_{IN} * (R_L / (R_O + R_L))$$
$$= V_{IN} * (10 / 11)$$

V_{OUT} = 90.9% of V_{IN}

Audio Interfaces: Cable Capacitance

Cable specs typically note the capacitance per unit length in picofarads (pF)

At higher frequencies the cable impedance increases, lowering signal level



(1) Bohn / Rane

RC Low pass filter

$f_C = 1/(2\pi * R_O * C_W)$

R_O = 200 ohms

C_W = 0.017 uF

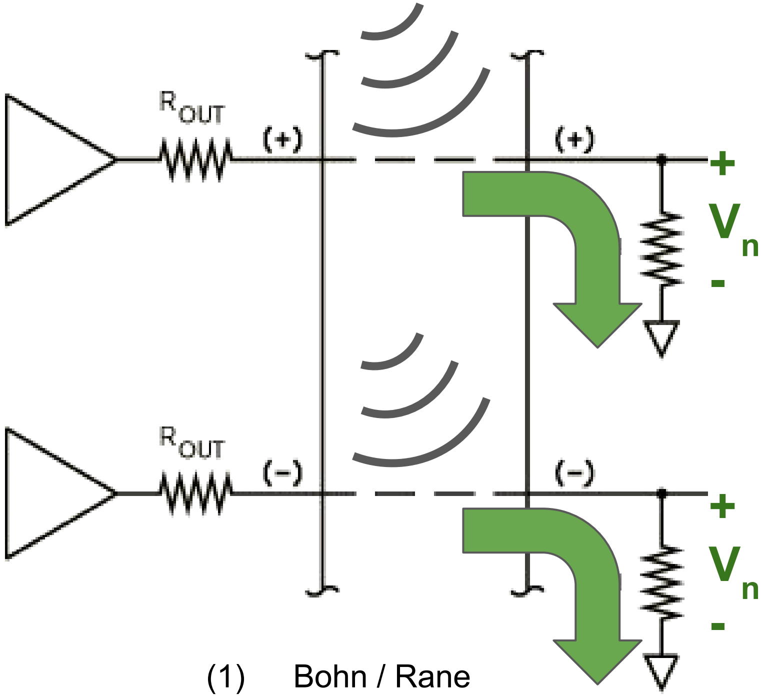
$f_C = 1/(2\pi * 200 * 0.017 * 10^{-6})$

f_C(-3 dB down) = 46.8 kHz

Audio Interfaces: Balanced Impedance

“In a balanced interconnect system both of the signal conductors have an equal, and nonzero, impedance to ground.” (2)

(Henry Ott consultants)



(1) Bohn / Rane

Audio Interfaces: Power Transfer

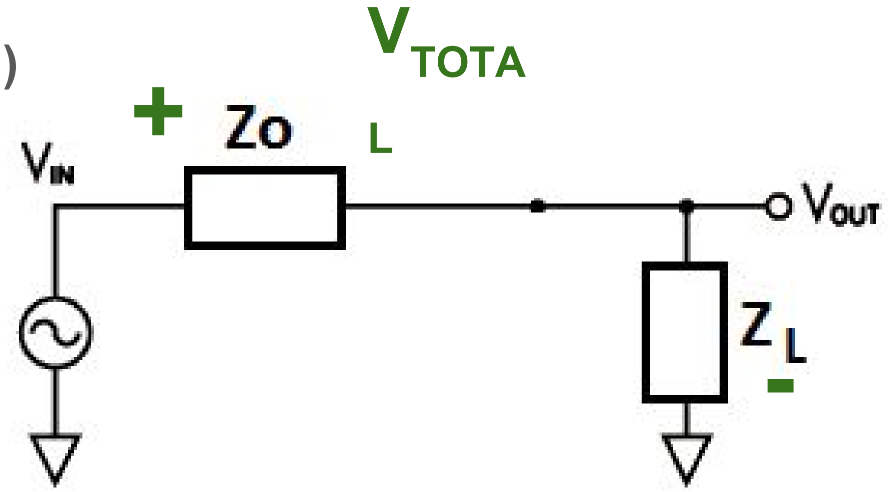
Electrical Power:

P = V * I **(or historically... P = E * I)**

Unit: Watts (Joules per second)

When is power necessary?

- **Do some work**
  - Move air using a loudspeaker
  - Turn a crank



(1) Bohn / Rane

Audio Interfaces: Power Transfer

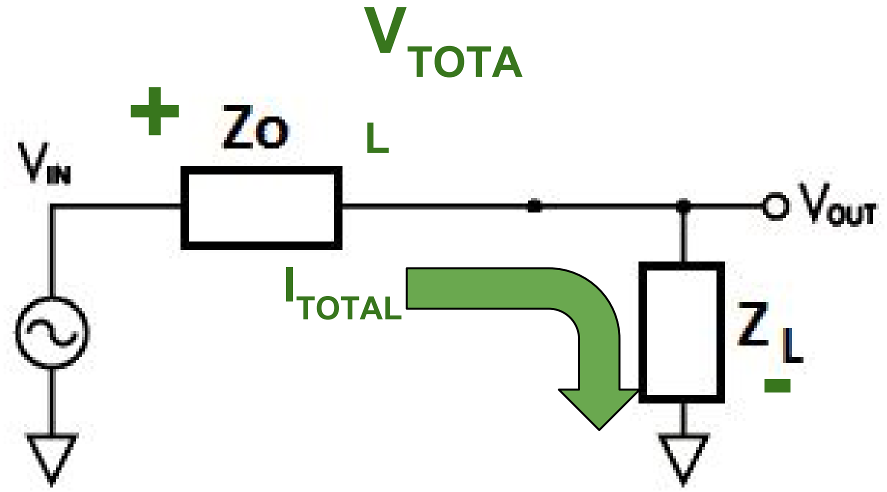
Interface Power:

$$I_{TOTAL} = V_{TOTAL} / (Z_{TOTAL})$$

$$P = I_{TOTAL} * (V_{TOTAL})$$

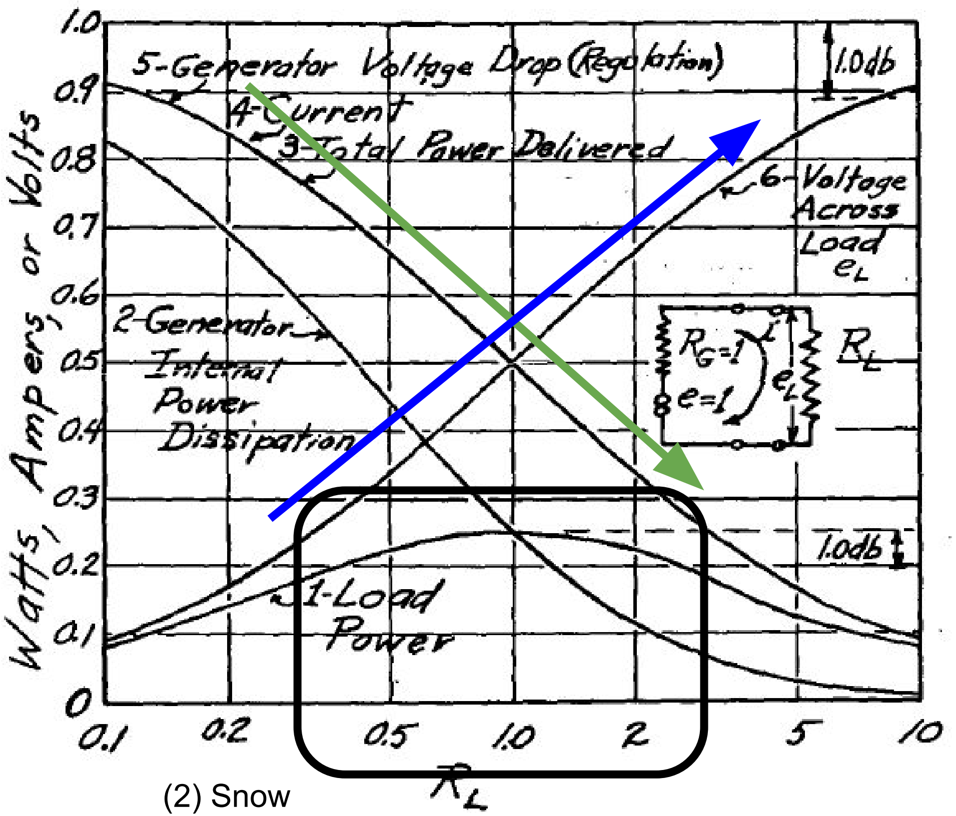
$$P = V_{TOTAL}^{2} / Z_{TOTAL}$$

- For fixed max voltage, interface power is determined by input and output impedance



(1) Bohn / Rane

Power Transfer: Impedance Matching



(2) Snow

Example:

Tube amplifier output transformers

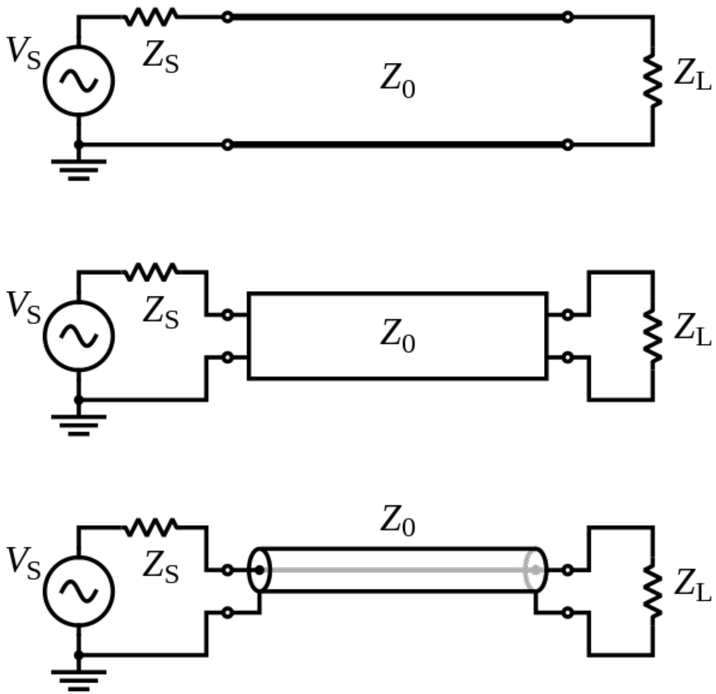
- Z_{OUT} ~ 2 kΩ, Z_L ~ 8 Ω
- Transformer turns ratio matches low-z loudspeaker impedance to high-Z amplifier output impedance

Transmission Lines

- When cable lengths exceed one wavelength of the highest frequency, transmission line behaviors must be addressed
- Source and load termination is recommended when lines approach ¼ wavelength

¼ Wavelengths:

- 20 kHz - 3.75 km
- 6.144 MHz - 12.2 m



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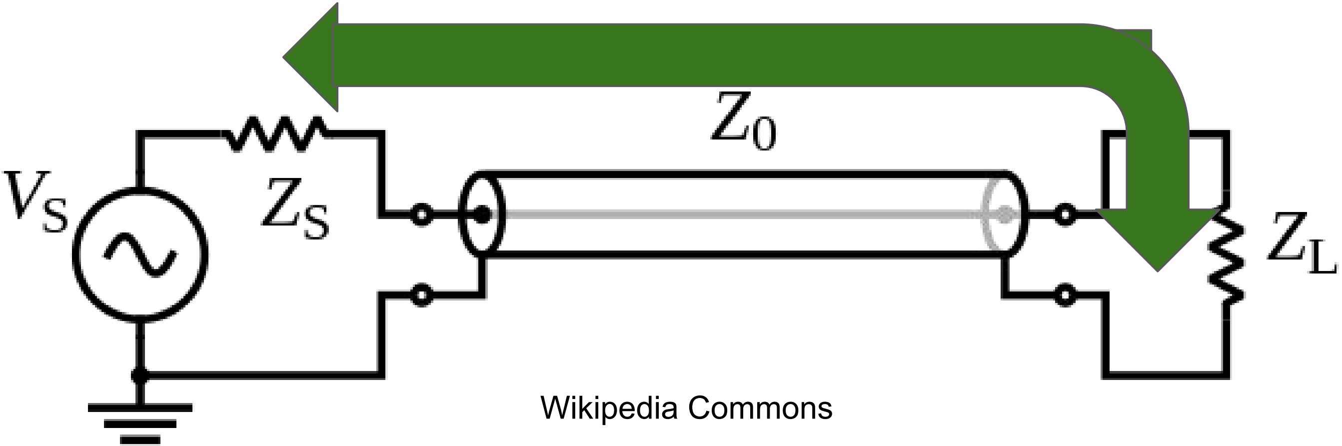
Transmission Lines: Wave Propagation

(6) Fun Science Demos

Transmission Lines: Impedance Matching

$$Z_S = Z_0 = Z_L$$



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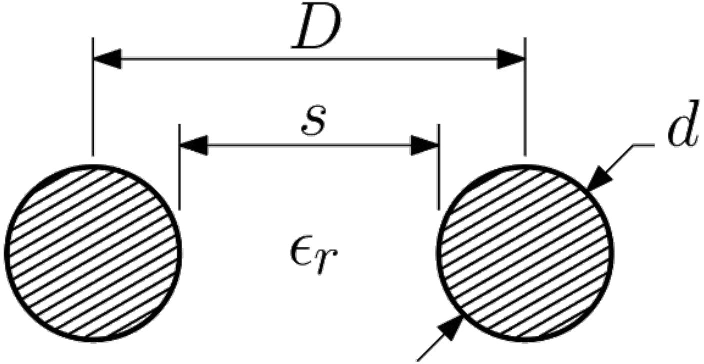
- Without proper termination, reflections with continue until dissipated
- Every out of phase reflection can cause destructive interference

Telephone Transmission Lines

University of California



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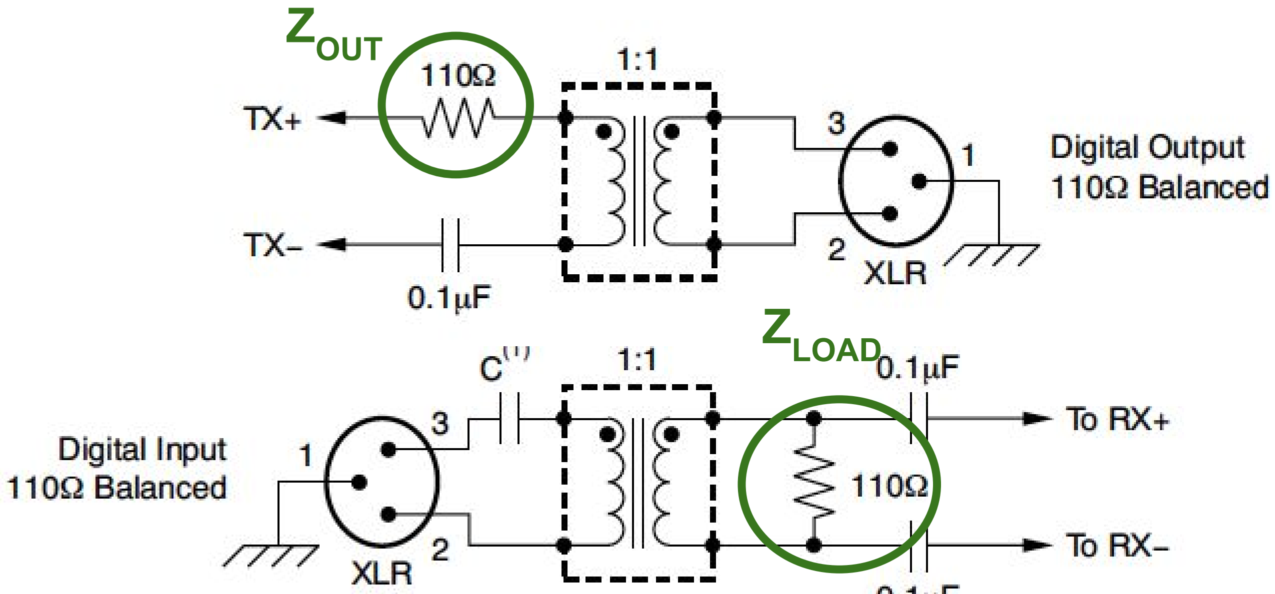
s **= 12 in.**

$\mathbf{E_r}$ **= 1.0054 (air)**

d **= 0.1620 in. (6 AWG)**

$\mathbf{Z_0}$ **= 598.2**

AES/EBU Transmission Lines



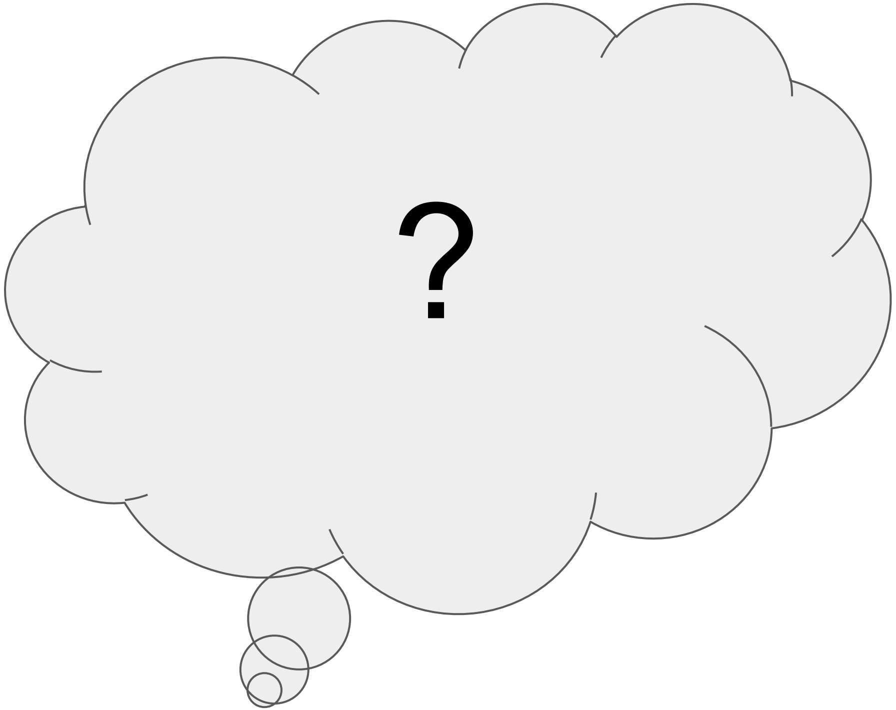
(5) Texas Instruments

- AES/EBU inputs and outputs are designed for a 110-ohm transmission line, so use 110-ohm cable!

Review

- Voltage Transfer (Impedance Bridging)
  - Analog audio interfaces
  - Zin should be ~10x Zout impedance
  - Keep reactance low, review cable capacitance for long cable runs
- Power Transfer (Impedance matching)
  - Matched Zin and Zout impedance maximizes power transfer
  - Typically necessary when the output is not low impedance
- Transmission Lines (Impedance Matching)
  - Matching Zin and Zout to the line impedance (Z0) minimizes reflections
  - Minimizing reflections maintains signal integrity

Questions



References

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3. Ott, Henry. "Balanced vs. Unbalanced Audio Interconnections." *hottconsultants.com*. 2 July 2008. Web. 18 March 2017.
4. Whitlock, Bill and Rod Elliot. "Design of High-Performance Balanced Audio Interfaces" http://sound.whsites.net/articles/balanced-2.htm#s2. 2010. Web. March 12 2017.
5. Texas Instruments. "DIX4192 Integrated Digital Audio Interface Receiver and Transmitter." DIX4192 datasheet. February 2006 [Revised September 2010].
6. FunScienceDemos. "Sound Light Travel in Waves" Youtube. Fun Science Demos. 14 March 2015.