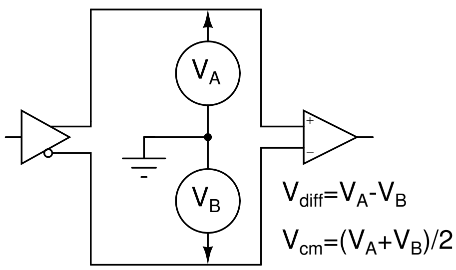
Differential Signalling

This chapter covers differential signalling.
After this chapter you should be able to: compute common-mode and differential voltages.

Differential Signalling

The average of the voltages on two conductors, with each voltage referenced to ground, is called the *common-mode* voltage. The voltage difference between these two conductors is the *differential* voltage.



A differential transmitter encodes data as the differential voltage – the voltage difference between its two outputs. For example, $V_A = +5$ V and $V_B = 0$ V for a logical '1' and $V_A = 0$ V and $V_B = +5$ V for a logical '0'.

Exercise 1: What are the differential and common-mode voltages for this example?

A differential receiver measures the differential voltage by subtracting the two voltages. Note that the differential voltage can be negative even though neither of the two voltages is negative relative to ground.

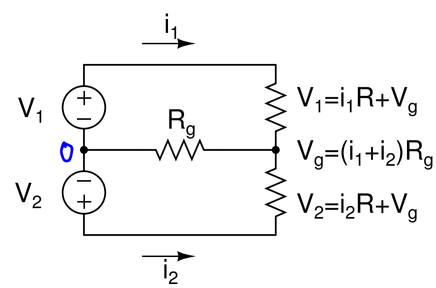
Data transmitted using the differential voltage (or current) is called *differential signalling*[1]. Differential signalling is commonly used at higher speeds and longer distances where the use of a shared ("common") ground path can add significant amounts of noise as described below.

Noise From Shared Grounds

Some communication channels such as RS-232 transmit over one conductor and use a return path (a "ground" connection) that is shared with other circuits. These other circuits could be other communication links or could be used for power distribution.

A problem with a common ground is that there will be a voltage shift in the apparent "ground" voltage level equal to the sum of the return currents multiplied by the resistance of the return path. This results in an offset voltage at the receiver that is proportional to the product of the sum of the currents on the return path and and the resistance of the return path. This voltage will be superimposed on the signal. Therefore the common-ground approach is only practical when this offset voltage is small relative to the signal levels.

For example, in the figure below the current on one circuit (i_1) affects the "ground" voltage (V_g) and thus the voltage seen on the second circuit (V_2):



These effects can be particularly severe when the shared ground circuit is used as the return path for a power supply.

Differential signalling, such as used with POTS[2], RS-485, or twisted-pair Ethernet, avoids this problem because the receiver only measures the voltage difference between the two conductors. Since offsets in the ground voltage affect the voltage on both conductors equally, this common-mode voltage does not affect the differential voltage.

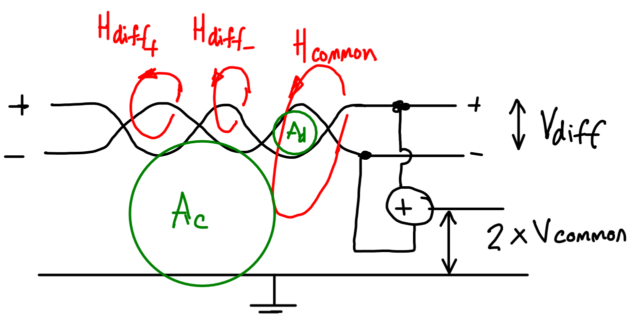
Of course, the drawback is that each communication link requires two conductors instead of one.

[1]Not to be confused with differential line codes which encode data as the difference between successive symbols.

[2]Plain Old Telephone Service – "landlines".

Inductively-Coupled Noise

The following diagram shows a twisted-pair transmission line[3] and a ground return path. The differential and common-mode voltages are shown. Also shown are the two magnetic field loops ($H_{\text{diff}\pm}$ and H_{common} which could cause differential and common-mode noise to be induced on the conductors (imagine the magnetic field direction perpendicular to the page):



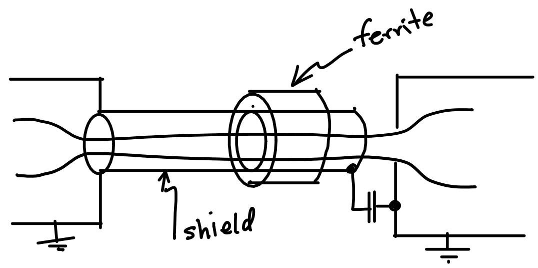
The two conductors of the twisted pair are next to each other and the area between the wires (A_d) is much smaller than the area between the wires and ground (A_c). This will result in a smaller voltage being induced on the differential signal. In addition, the voltages induced on the twisted pair by the magnetic field (the parts of the field $H_{\text{diff}+}$ and $H_{\text{diff}-}$) will cancel out due to the twisting.

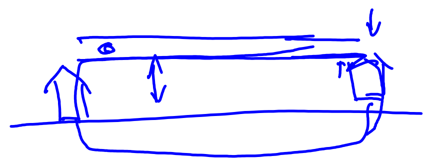
Thus the use of differential signalling over twisted pair reduces inductively-coupled noise both compared to common-mode signalling and compared to differential signalling without twisted pair.

Shielding and Grounding

Some differential communication cables also use a shield[4]) to limit radiation from the signals carried by the cable. To avoid radiation or inducing noise on other circuits, it's desirable to limit currents flowing along the shield.

The diagram below shows some approaches that can be used to limit current flow along the shield. In some cases the shield can be left disconnected at one end. It can also be connected through a capacitor to block low-frequency currents (if the main concern is low-frequencies, typical from 50/60 Hz line voltage) or placing a ferrite cylinder around the shield (if the concern is RF radiation).





[3]A twisted-pair transmission line consists of two conductors twisted around each other.

[4]Although the construction is similar to co-axial cables, the differential signals do not use TEM propagation.