UNDERSTANDING COMMON MODE NOISE

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1 Introduction

Understanding the difference between common-mode and differential mode signals is crucial for the correct understanding of how Pulse's magnetic interface modules work. Transformers, common-mode chokes and autotransformer terminations play a key role in the reduction of common-mode interference in our LAN and Telecom interface circuits. Common-mode noise plays an important role in the generation of Radio Frequency Interference (RFI) in communications systems using Unshielded Twisted Pair (UTP) cable, so understanding commonmode noise will lead to a better understanding of Electromagnetic Compatibility (EMC) issues concerning magnetic interfaces. It is the purpose of this document to explain the key characteristics of differential mode and common-mode signals, the principle of operation of common-mode chokes and auto-transformer terminations, and why common-mode noise on UTP cable leads to noise emissions.

2 Differential Mode and Common Mode Signals

In this section we consider a simple two-wire cable, terminated at one end with a load impedance (LOAD). The voltages on each wire relative to ground potential (GND) are denoted V_1 and V_2. The differential-mode signal component is V_{DIFF} and the common-mode signal component is V_{COM}. Parasitic capacitance that exists between the cable and GND are shown as C_P.

2.1 Differential Mode Signals
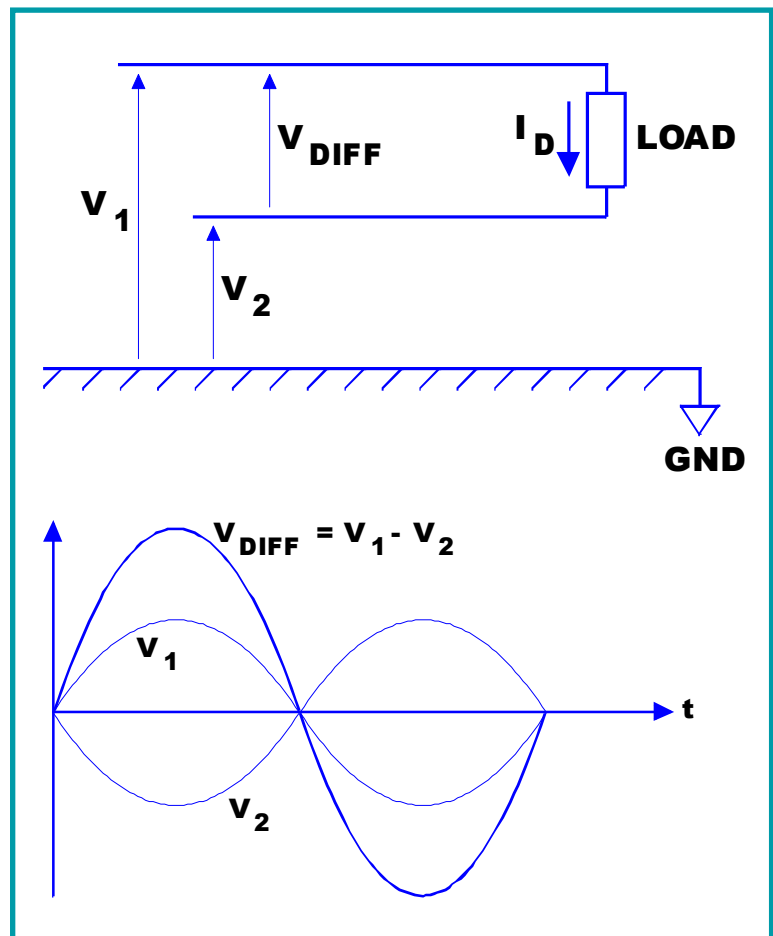
For pure differential mode:

$V_1 = - V_2$ ..... (eqn. 1)

Magnitudes are equal
Phase difference is 180°

$V_{DIFF} = V_1 - V_2$ ..... (eqn. 2)

No current flows to ground because of symmetry of V_1 and V_2 about ground. All differential mode current (I_D) flows through the LOAD.

In a cable based transmission system the Differential Mode signal is the "wanted" signal that carries information. All Physical Layer (PHY) transceivers for LAN and Telecom applications are differential mode devices.

The instantaneous sum of the two voltages ($V_1 + V_2$) is always zero.

2.2 Common Mode Signals
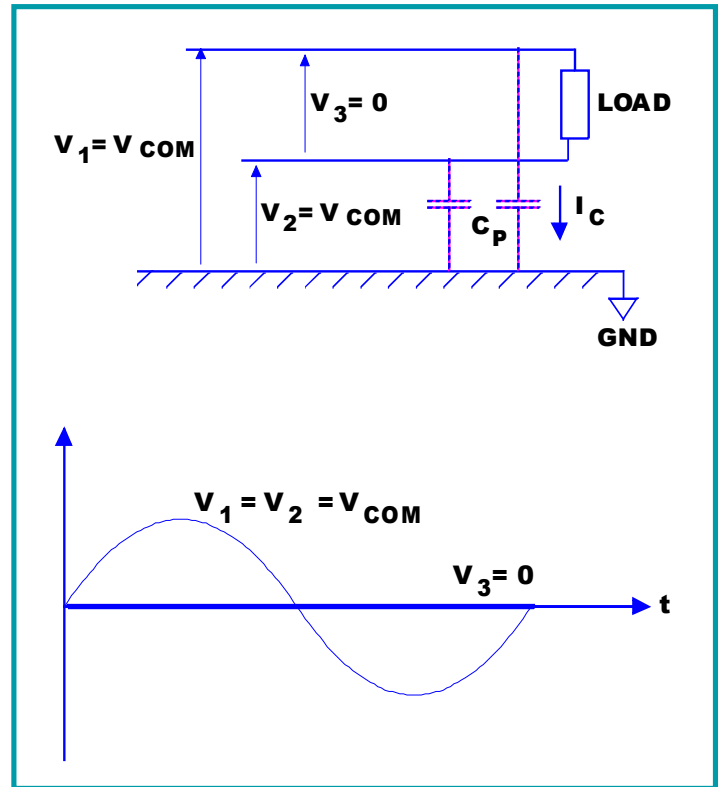
For pure common mode signals:
$V_1 = V_2 = V_{COM}$ ….. (eqn. 3)

Magnitudes are equal
Phase difference is 0°

$V_3 = 0$ ….. (eqn. 4)

No current flows in the load because there is no potential difference across it. All common mode current (I_C) flows to GND via parasitic capacitance between the cable and GND.

In a cable based transmission system the Common Mode signal is the "unwanted" signal because it carries no information. The instantaneous sum of the two voltages V_1 and V_2 is non-zero. The potential of the cable pair varies with respect to ground. This varying potential gives rise to electromagnetic radiation from the cable.

3 Differential Common Mode Signals and EMC in UTP Systmes

Individual wires in a twisted pair cable are wound around each other in a dual helix structure. The spiral form means that induced magnetic fields caused by the current flowing in individual wires is to some extent contained within the confines of the spiral. This containment is not perfect, and a significant magnetic field also exists outside the spiral, but in general, the tighter wound the twisted pair, the better is the flux containment. The direction of flow of current in each wire of a twisted pair determines to what extent the pair will radiate noise. It is the different current flows found in differential and common mode signals that is the crucial difference between the two.

3.1 Differential Mode Signals and EMC

For pure differential mode signals, the currents in each of the wires in a pair travel in opposite directions. If the pair is uniformly wound these opposing currents produce equal and opposite polarized magnetic fields that cancel each other out.
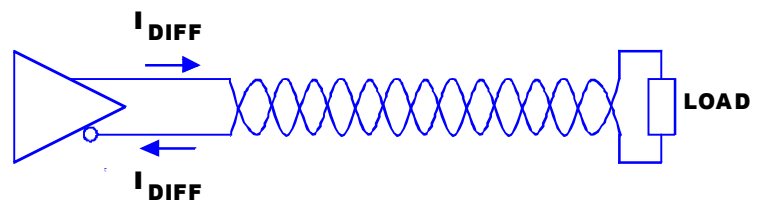
(If the two wires in a given pair are not identically wound, the generated magnetic fields will not be exactly equal and opposite and so will not exactly cancel. This asymmetry gives rise to RFI radiation. This process is called "Differential to Common-mode conversion")

Differential mode signals do not directly generate RFI in UTP cable systems.

3.2 Common Mode Signals and EMC

Common mode current I_{COM} flows both in both wires in the same direction, and returns to GND via parasitic capacitance C_P. In this case, the currents generate magnetic fields with equal magnitude and polarity, which do not cancel each other out. The common mode current is able to generate an electromagnetic field outside the spiral wound pair, which acts just like an antenna.
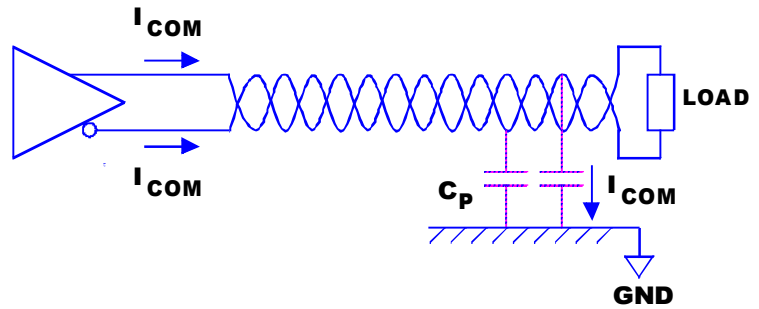
Common mode signals directly generate RFI in UTP cable systems.

4   How A Transformer Conducts Common Mode Noise

An ideal transformer is a notional perfect circuit element that transfers electrical energy between primary and secondary windings by the action of perfect magnetic coupling. The ideal transformer will only transfer alternating, differential mode current. Common mode current will not be transferred because it results in a zero potential difference across the transformer windings and therefore does not generate any magnetic field in the transformer windings.

Any real transformer will have a small, but non-zero capacitance linking primary to secondary windings. The capacitance is a result of the physical spacing.
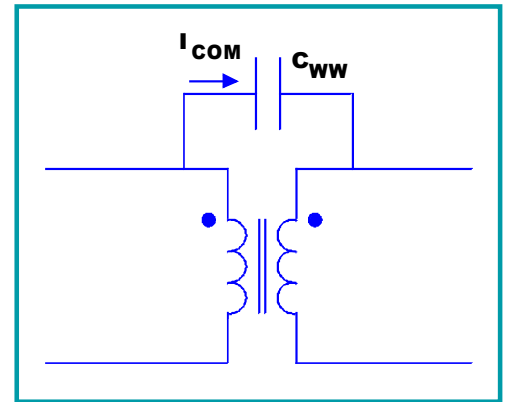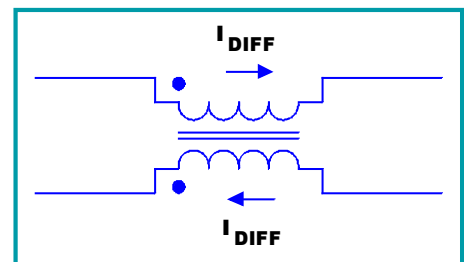
For common-mode current, Cww offers a path across the transformer, the impedance of which is dependent on the magnitude of the capacitance and the signal frequency.

5   Common Mode Choke - Principle of Operation

In the following section we consider an ideal two winding, single core, common mode choke. We neglect the effects of stray impedance (DCR, Cww, Cp, RL etc.) that are always present to a greater or lesser extent in a real choke. This assumption is reasonable, because in a well-designed choke, the stray impedance will always be negligible compared to the circuit source and load impedance.

5.1 Effect of Differential Mode Signal on an ideal Choke

The differential mode current, flowing in opposite directions through the choke windings, creates equal and opposite magnetic fields which cancel each other out. This results in the choke presenting zero impedance to the differential mode signal, which passes through the choke unattenuated.

5.2 Effect of Common Mode Signal on an Ideal Choke

The common mode current, flowing in the same direction through each of the choke windings, creates equal and in-phase magnetic fields which add together. This results in the choke presenting a high impedance to the common mode signal, which passes through the choke heavily attenuated. The actual attenuation (or common mode rejection) depends on the relative magnitudes of the choke impedance and the load impedance.

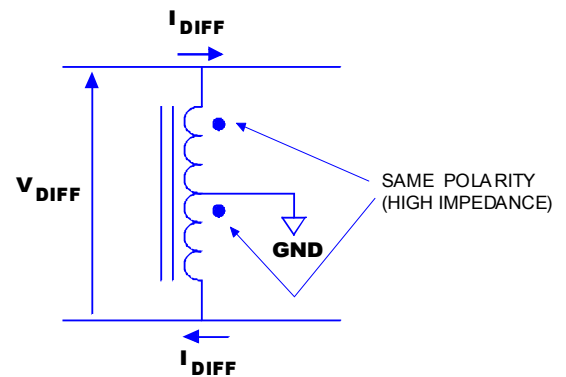## 6 Center Tapped Autotransformer - Principle of Operation

An autotransformer is so called because it consists of only one winding, and energy transfer through the device is effected by direct current transfer. In the following section we consider an ideal autotransformer termination. We neglect the effects of stray impedance (DCR, Cww, Cp, RL etc.) that are always present to a greater or lesser extent in a real device. This assumption is reasonable, because in a well-designed termination, the stray impedance will always be negligibly small compared to the circuit source and load impedance.

6.1 Effect of Differential Mode Signal on an Ideal Autotranformer

A differential mode signal sees the two halves of the center-tapped autotransformer with the windings in phase.
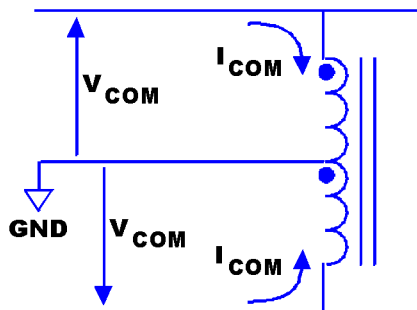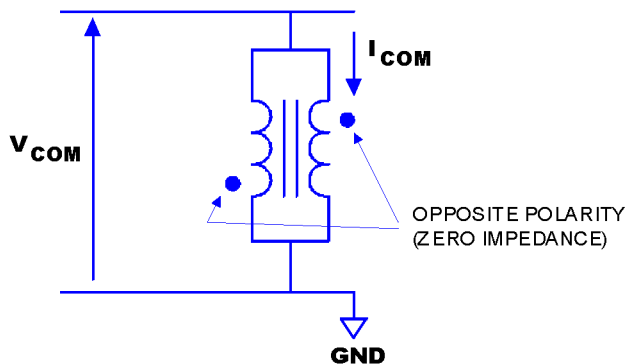
This means that current in the device causes a magnetic field to be formed and the device presents a high impedance.

The device acts as a high value parallel impedance, and does not significantly attenuate the differential mode signal.

6.2 Effect of Common Mode Signal on an Ideal Autotransformer

A common mode signal sees the two halves of the center-tapped autotransformer with the windings in anti-phase. This means that current in the device causes equal and opposite phase magnetic fields to be generated which cancel each other out. The effect is that the device presents zero impedance to common mode signals, shorting them directly to ground potential.

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