



EMC Issues Concerning Magnetic Interfaces

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1 INTRODUCTION

Due to today's vast usage of high-frequency electronic devices, most countries in the world have strict regulations in regards to electro-magnetic interference (EMI) and compatibility. In data communication systems utilizing copper cables as transmission media, EMI is always a concern. All copper-based transmission cables are either single-ended (coaxial, twinaxial, etc.) or balanced (parallel or twisted-pair). Aside from the electro-magnetic noise generated by the system printed circuit board; transformers, common-mode chokes and auto-transformer terminations play a key role in the reduction of electro-magnetic noise emission in LAN and Telecom interface circuits.

In systems using unshielded twisted pair (UTP) cable, common-mode noise plays an important role in the generation of Radio Frequency Interference (RFI), so understanding common-mode noise will lead to a better understanding of Electromagnetic Compatibility (EMC) issues as they relate to magnetic interfaces. This paper is to explain key characteristics of differential-mode and common-mode signals; the principle operation of magnetics, including transformers, common-mode chokes and auto-transformer terminations; and why common-mode noise on Unshielded Twisted Pair (UTP) cable leads to noise emissions. Understanding the difference between common-mode and differential-mode signals will provide a good understanding of how magnetic interface modules work.

2 DIFFERENTIAL-MODE AND COMMON-MODE SIGNALS

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} . The parasitic capacitance that exists between the cable and GND are shown as C_P .

2.1 Differential-mode signals

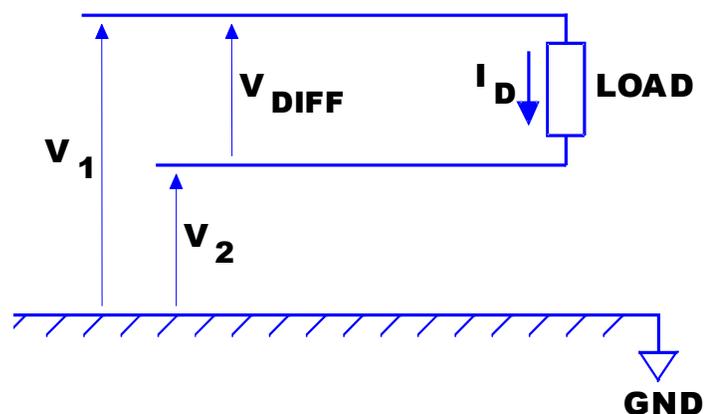
For pure differential-mode:

$$V_1 = -V_2 \quad \dots \text{(equation \#1)}$$

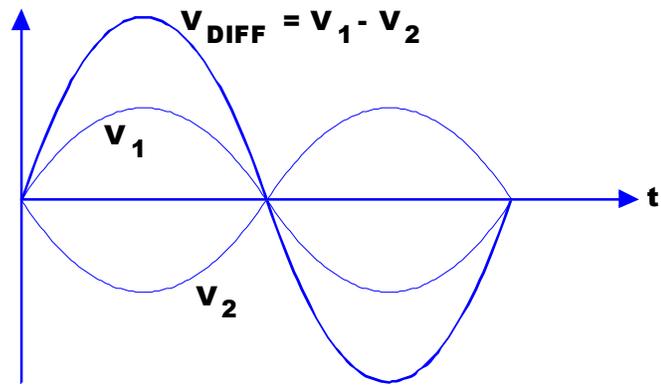
Magnitudes are equal
Phase difference is 180°

$$V_{DIFF} = V_1 - V_2 \quad \dots \text{(equation \#2)}$$

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



In a balanced-cable transmission system, the Differential-mode signal is the “wanted” signal that carries information. All Physical Layer (PHY) transceivers for LAN and Telecom applications working with UTP are differential-mode devices.



The instantaneous AC sum of the two voltages ($V_1 + V_2$) is always zero. Note that only the AC component of this common-mode voltage can radiate and may potentially cause EMI problems.

The common-mode voltage may be at some DC level, but this DC component does not generate radio-frequency noise.

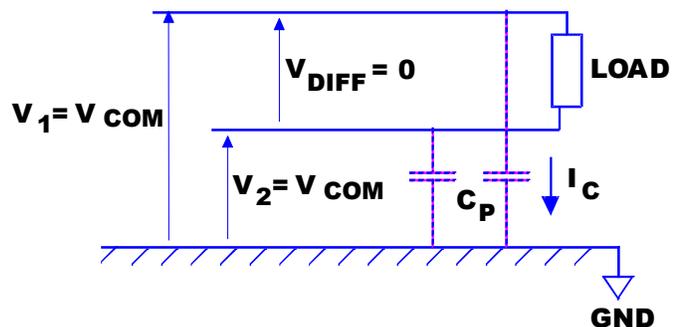
2.2 Common-mode signals

For pure common-mode signals:

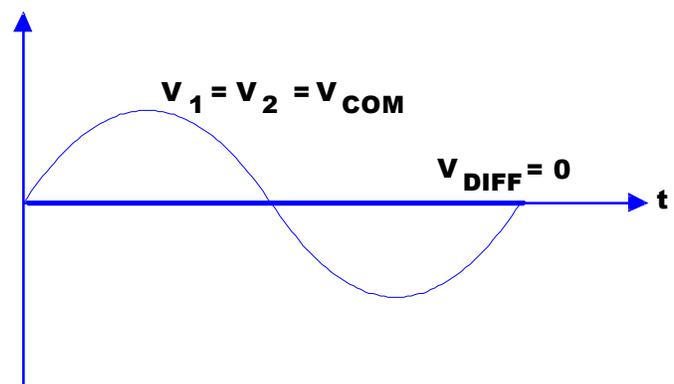
$$V_{COM} = \frac{1}{2} * (V_1 + V_2) \dots\dots \text{(equation \#3)}$$

Magnitudes are equal
Phase difference is 0°

$$V_{DIFF} = V_1 - V_2 = 0 \dots\dots \text{(equation \#4)}$$

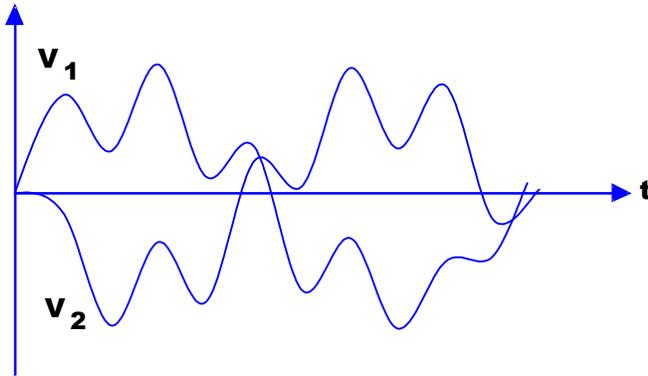


No current flows in the load because there is no potential difference across it. All common-mode current (I_C) flows to GND via the common-mode impedance between the cable and GND. This common-mode impedance is composed mainly of parasitic capacitance of the transformer.



In a cable-based transmission, system the common-mode signal is the “unwanted” signal because it carries no information. Common-mode signals are caused mainly because of the imbalance of the transmitter circuitry, and the imbalance of the transmission channel, including all the magnetics, connector, and cable.

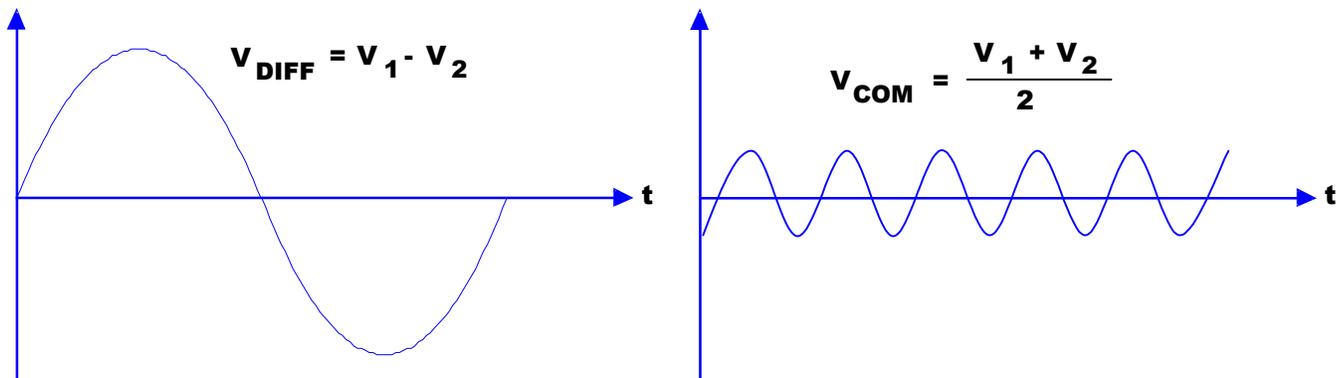
The instantaneous sum of the two voltages V_1 and V_2 is non-zero. The potential of the cable pair varies with respect to ground. This varying potential gives rise to electromagnetic radiation from the cable.



2.3 Mixed signals

In real life, signals on balanced cable pairs contain both differential- and common-mode components. However, the effects of each component can still be analyzed independently.

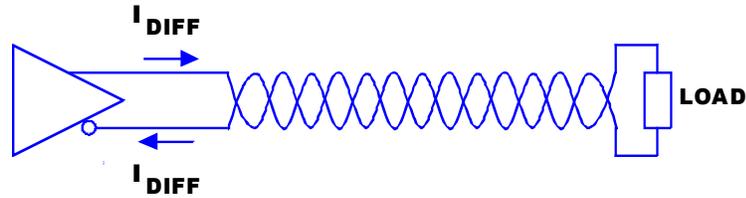
As we will see below, only common-mode signals will emit radio-frequency (RF) noise, causing systems to potentially fail EMI tests, for which most modern countries have regulations.



3 DIFFERENTIAL AND COMMON-MODE SIGNALS AND EMC IN UTP SYSTEMS.

Unshielded twisted pair (UTP) cable consists of two insulated conductors twisted around each other in a dual helix structure. The well-controlled dielectric constant of the insulation jacket and fixed number of twists per unit length provide known and relatively constant impedance over the working frequencies. The spiral form also ensures that the two conductors are kept close together, and the result is that for differential signals, the induced electro-magnetic waves caused by the two conductors will cancel out each other since the currents are always flowing in the opposite directions.

3.1 Differential-mode signals and EMC



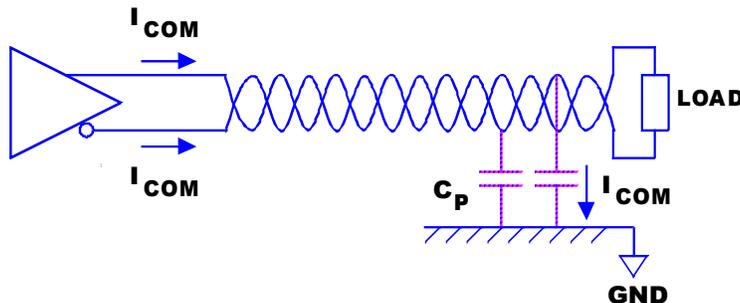
For pure differential-mode signals, the currents in each of the wires in a pair travel in opposite directions. If the pair is uniformly wound, these opposing currents produce equal and opposite polarized electro-magnetic fields that cancel each other out.

Even with the signal source sending perfectly balanced differential signal, if the two signal paths are not the same, the generated electro-magnetic fields will not be exactly equal and opposite and so will not exactly cancel. This asymmetry may also contribute significantly to RFI radiation. This process is called “differential to common-mode conversion”. The test parameter used to measure the balance of the cables or components is differential-to-common-mode rejection ratio (DCMR), commonly expressed in decibels (dB), which is the ratio of the differential-signal to common-mode signal.

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 in both wires in the same direction, and returns to GND via parasitic capacitance C_P . In this case, the currents generate magnetic fields of equal magnitude



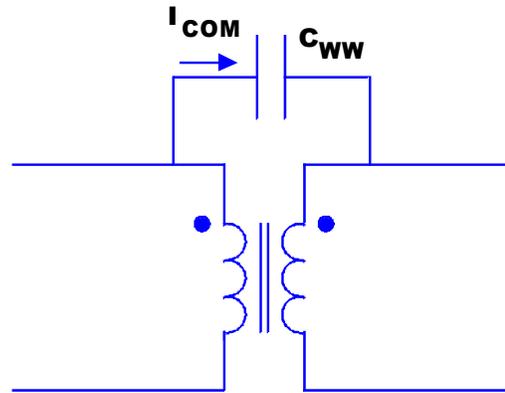
and polarity, which do not cancel each other out. Therefore, the net generated electro-magnetic field extends outside the spiral wound pair, and the whole cable acts just like a long antenna.

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.

Practical transformers, however, will have a small, but non-zero capacitance linking primary to secondary windings. The capacitance is a result of the physical spacing and the dielectric between the windings. The size of this interwinding capacitance can be reduced by increasing the separation between the windings, if this is possible, and by using a low permittivity material to fill the space between the windings. In addition, the use of high-permeability materials for transformer cores will help reduce the amount of wires used, and therefore, will also reduce the capacitance.



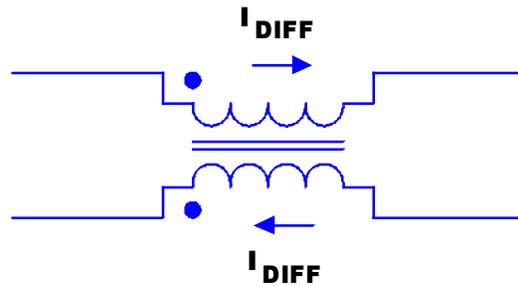
For common-mode current, C_{ww} offers a path across the transformer, the impedance of which is dependent on the magnitude of the capacitance, the signal frequency, and the common-mode impedance on the receiving end of the cable.

5 COMMON-MODE CHOKE - PRINCIPLE OF OPERATION

In this section we consider an ideal two-winding, single core, common-mode choke. We neglect the effects of parasitic components (DCR, C_{ww} , C_p , L_L , etc.) that are always present to a greater or lesser extent in a choke. This is a reasonable assumption, because in practical common-mode choke designs, these parasitic components present very little change to the final circuit analysis in regards to their effect on both differential-mode and common-mode performance of the system.

5.1 Effect of differential-mode signal on an ideal choke

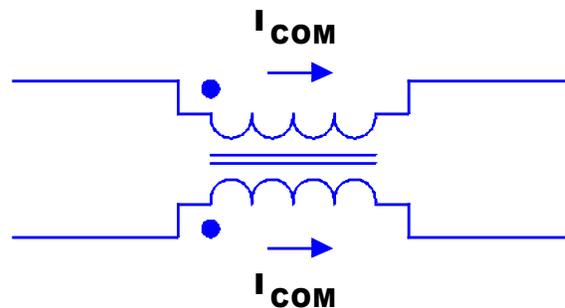
The differential-mode current, flowing in opposite directions through the choke windings, creates equal and opposite magnetic flux fields which cancel each other out. This results in the choke



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

On the other hand, 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

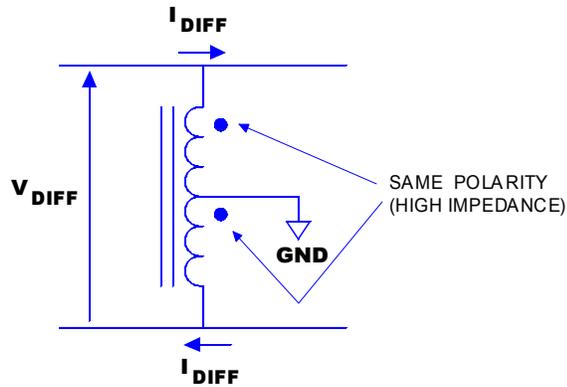


choke presenting a high impedance to the common-mode signal, which passes through the choke heavily attenuated. The actual attenuation (or common-mode rejection) depends on the relative magnitudes of the choke impedance, which is mainly dependent on the permeability of the core material at the frequency, and the common-mode load impedance.

6 CENTER TAPPED AUTO-TRANSFORMER - PRINCIPLE OF OPERATION

An auto-transformer is so called because it consists of only one winding, and energy transfer through the device is affected by direct current transfer. In the following section we consider an ideal auto-transformer termination. We neglect the effects of stray impedance (DCR, C_{ww} , C_p , R_L 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 auto-transformer

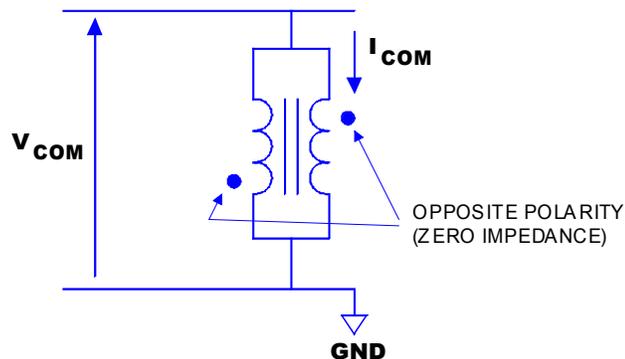
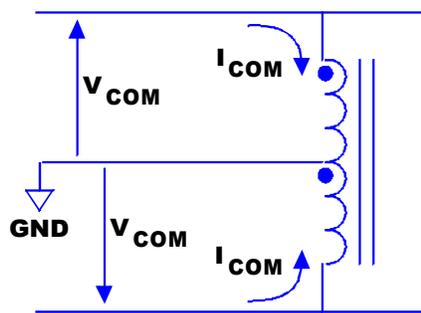


A differential-mode signal sees the two halves of the center-tapped auto-transformer with the windings in series, forming a single large parallel inductance.

This inductance presents a high value parallel impedance to the differential-mode signal, and if properly designed (so that the resultant reactance of the inductor is large as compared to the impedance of the cable), will not significantly attenuate the signal.

6.2 Effect of common-mode signal on an ideal auto-transformer

A common-mode signal sees the two halves of the center-tapped auto-transformer with the windings in anti-phase. This means that current in the device causes equal and opposite phase

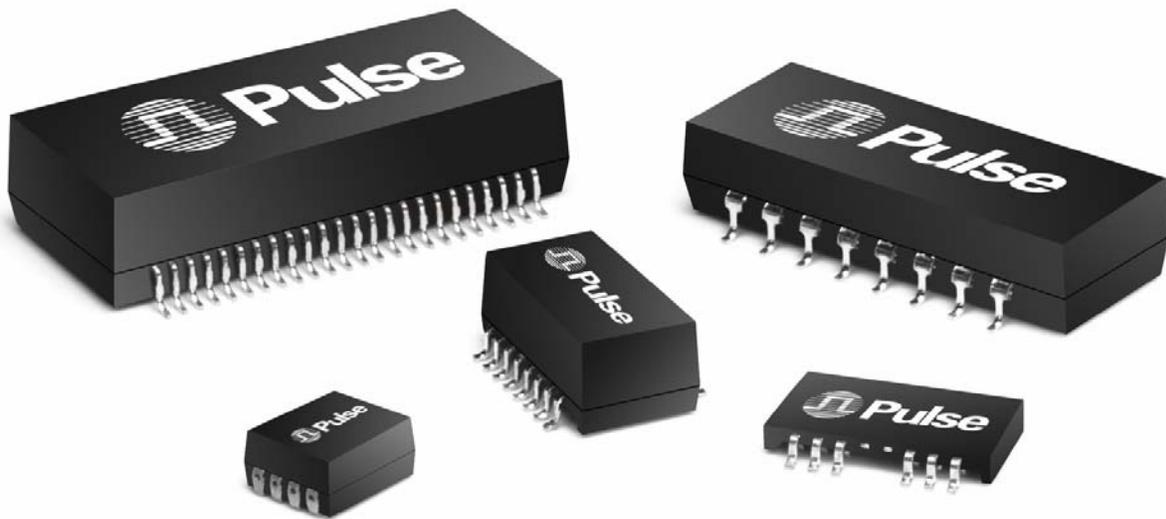


magnetic fields to be generated which cancel each other out. The effect is that the device presents zero impedance to common-mode signals, shorting them directly to ground potential.

7 SUMMARY:

In designing data communications systems with unshielded twisted pair (UTP) cables, common-mode signals must be controlled to ensure compliance with regulatory requirements for electro-

magnetic interference (EMI). Understanding how the two signal types (common-mode and differential-mode) and the magnetic building blocks such as transformers, common-mode chokes, etc. affect EMI performance, should allow the designers to select the proper components to use to effectively design a quiet system.



(Image 1)

Modules, like the ones above, provide electrical circuit isolation that meets applicable IEE and AMSI standards, while maintaining signal integrity needed for the most demanding applications. 100Base-T and ATM Modules provide “tuned” common mode noise attenuations best matched to the transceiver being considered.

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