High Speed Electrical Transmission

Swapnil Namekar[1], Ashutosh Mishra[2]
[1]*Assistant Professor, Department of Electrical Engineering, Bharati Vidhyapeeth Deemed To Be University, College of Engineering, Pune, India*
[2]*Student, Department of Electrical Engineering, Bharati Vidhyapeeth Deemed To Be University, College of Engineering, Pune, India*

***Abstract*- This paper presents a model for computing High Energy Physics (HEP) experiments have unique requirements for data communication. High data speeds, combined with extreme restrictions on materials allowed, leads to custom transmission lines. Based on this model, the electric field intensity under power line is calculated and the distribution is analyzed in different condition such as different distant between phase line, different phase order for double circuit, and different arrangement of line in single circuit or double circuit. This paper will present transmission line design theory, simulation and testing methods. Transmission line designs options like flexes and rigid PCBs as well as cables will be studied. Finite Element Analysis (FEA) software packages simulate energy dissipation and quality of transmitted signals. Methods to improve quality, like three different types of equalization are described.**

INTRODUCTION

This paper will focus on the design, simulation, characterization and test of flex transmission lines, whose results can be extrapolated to PCB transmission line designs and wire cables. Vertexing and tracking sub detectors for High Energy Physics (HEP) experiments delivery high data rates, requiring multi-gigabits transmission links. Commercial solutions for handling these high date rates are neither optical transmission nor thick wire cables. However due to high radiation environments and low radiation length requirements in HEP experiments, electrical transmission with low mass custom designs are needed. Therefore, as the amount of material is a very important constraint, its minimization is a design challenge to overcome for transmission line design for HEP purposes. Optical data transmission is possible in HEP experiments when space and radiation limits allow, which preclude use in the ATLAS silicon pixel detector. Examples of transmission lines that are currently being used for both LHCb [1, 2] and ATLAS [3] upgrades will be presented and analyzed.

Transmission line distortions

A differential transmission line can be defined as a pair of electrical conductors carrying an electrical signal from one place to another, see chapter7of ref. [4]. The two conductors have an inductance and capacitance per unit length, which can be calculated from their size, shape and the dielectric constant of the insulating material. Considering these factors there are four main types of losses that govern the propagation of waves through transmission lines. Radiative losses occur when the transmission line acts as an antenna due to the small separation distance between the conductors in comparison to the signal wavelength. This results in energy loss radiation. The radiative losses increase linearly with signal frequency and can be controlled by appropriate conductor shielding. The second type are resistive and dielectric losses, the energy of the transmitted wave is dissipated due to the conduction resistance in the conductors and to molecular excitation of the dielectric material used as isolating material. Resistive losses can be controlled by using low resistivity conductors with low surface roughness and low loss dielectrics. Cross-talk, the third type of losses, takes place when a transmission line collects energy via radiation from neighboring conductors. This effect can be minimized by using guard traces, which are traces installed parallel to an existing high-speed signal line to isolate it. Reflections can be prevented by controlling the geometry and the dielectric of the transmission line to achieve matching of the transmission line and load impedances.

Transmission line design

For the optimized transmission line design all the distortions described in the section above must be minimized so that the quality of the signal at the receiver allows data recovery within the error rate specification.

PC Band cable layout and routing basics

For a differential line designing flex or rigid PCB there are some basic rules to follow in order to achieve optimum data transmission [5]. The first design rule is to use tightly coupled differential lines, which helps maintain balance within the differential pair and ensures that stray inductance is coupled equally on each conductor within the pair. Furthermore, tightly coupled differential pairs diminish EMI susceptibility (radiative losses). Secondly it is also critical to match the trace lengths of a given differential pair. Any propagation delay difference (skew) between signals of a differential pair will result in mode conversion between differential and common mode. These two mode shave different propagation constants that will result in signal distortion at the far end. High-speed signals should be routed over a solid GND reference plane and not across a plane split or a void in the reference plane unless absolutely necessary. Routing across a plane split or a void forces return high-frequency current to flow around the split or void. This can result in the following conditions: excess radiated emissions from an unbalanced current flow, delays in signal propagation due to increased series inductance, interference with adjacent signals and degraded signal integrity (that is, more jitter and reduced signal amplitude). A via presents a short section of change in geometry to a trace and can appear as a capacitive and/or an inductive discontinuity.

These discontinuities result in reflections and some degradation of a signal as it travels through the reflection. Finally using guard/ground traces between each differential pairs will reduce the crosstalk between them. The signal quality at the receiver can deteriorate due to the skin effect and dielectric losses. The skin effect increases resistive losses as it reduces the effective cross-section of the conductor for high-speed signal transmission. The skin depth is given by the following equation

Where δ is the skin-depth in meters, f is the frequency in Hz, μ0 is the permeability of free space (4π × 10−7N/A2) and σ is the conductivity in S/m (for annealed copper 5.80 × 107 S/m). Dielectric losses are due to the varying electric field from the signal causing small realignment of weakly bonded molecules in the dielectrics around the signal conductors, which lead to heating of the material. It is proportional to the signal frequency. The oscillating field drives charge in the bond back and forth between two alternative configurations. In real dielectrics this current dissipates energy, just as a current in aresistordoes, giving it a small phase shift, δ and this phase shift is known as loss tangent.

CHARACTERIZATION TECHNIQUES

Any point to point transmission line can be evaluated with a port topology, see chapter12 of ref. [4]. A simple transmission line, as the device under test (DUT) is described by a 4-port topology, as shown in figure1.

Furthermore, the DUT impedance should match the impedance of the VNA ports so there are no additional impedance mismatches. Eventually, a DUT can be characterized with the Bit Error Rate (BER), number of errors in there covered data per unit time. Never the less as it is necessary to have all the devices include in the communication chain and for the examples presented this was not the case these tests will not be included.

EXAMPLE SO TRANSMISSION LINE DESIGNS AND CHARACTERIZATION

In this section, some transmission line designs are presented.

1 ATLAS ITK pixel end cap ring tape- The first prototype of the ATLAS ITk pixel end cap ring tape is basically a curved bus tape that carries data to the “End of Stave” (EOS) where it is collected by a GBTx [6]. Nevertheless the design can be used to learn practices that need to be avoided whilst designing for high speed transmission. The designed geometry, trace width, spacing and material choices do not result in the desired 100ohms impedance.

2 LHCb tape- The LHCb Velo upgrade data transmission tape was designed with the following criteria: 56 cm long, data transmission rate of 5.12

Gbps with differential signaling and mechanical flexibility.

3 ATLAS cables-The ATLAS Ring Tape wasn't suitable for high speed data transmission so instead it was decided to design a cable that will transmit data at speeds between 2.5 and 5 Gbps directly from the module to the electrical to optical conversion circuitry outside of the high radiation area of the ATLAS inner tracker.

CONCLUSIONS

In summary, it can be said that transmission lines for high-speed applications require a very careful design. The main parameters to consider while designing a transmission line are:

- Material choice→ In order to avoid skin effect and dielectric losses as well as matching the impedance.
- Geometry of the design→ PCBs (strip line, micro strip etc.) or cable. Recovering performance→ Equalization techniques.

In order to be able to fully characterize at transmission line in the measurements should be included the whole chain: transmitter plus channel (tapes and cables) and receiver.

ACKNOWLEDGEMENT

We would like to express our special thanks of great fullness to Dr. D.S Bankar Head of Department of Electrical Engineering for their able guidance and support for completing my research paper. I would also like to thank the faculty members of the Department of Electrical Engineering would helped us with extended support

REFERENCES

[1] LHCb collaboration, LHCb VELO upgrade technical design report, CERN-LHCC-2013-021(2013).
[2] LHCb collaboration, Framework TDR for the LHCb upgrade, CERN-LHCC-2012-007(2012).
[3] ATLAS collaboration, Letter of intent for the Phase-II upgrade for the ATLAS experiment, CERN-LHCC-2012-022(2012).
[4] A.Bala murugan, S.Ram Kumar, 2016. Fuzzy Gain Scheduled PI Controller for Resonant Power converter fed Hybrid Electric vehicle With BLDC Motor drive, Tamilnadu, India.
[5] Zhen-Yu Zhao. 1993. Masayoshi Tomizuka and Satoru Osaka Fuzzy Gain Scheduling of PID controllers. IEEE transactions on systems, man and cybernetics.
[6] Online PCB calculator.
[7] A.K.Singh and K.Kumar, Modelling and Simulation of PID Controller Type PMBLDC Motor, Proceedings of National Seminar on Infrastructure Development Retrospect and prospects, Vol. I, pp. 137-146.
[8] Math Works, 2001, Introduction to MATLAB, the Math Works, Inc.