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# Lessons Learned in High Frequency Data Transmissions Design

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HEP experiments requirements lead to highly integrated systems with many electrical, mechanical and thermal constraints. A complex performance optimisation is required. High speed data transmission lines are designed, while simultaneously minimising radiation length. Methods to improve the signal integrity of point to point links and multi-drop configurations are described. FEA calculations are essential to the optimisation which allow data rates of 640 Mbps for point to point links over a length of up to 1.4m, as well as 160 Mbps for multi-drop configuration. The designs were validated using laboratory measurements of S-parameters and direct BER tests.

## Summary

High speed transmission is required for data and trigger propagation in HEP experiments. The ATLAS ITk strips require point to point data transmission at 640 Mbps and multi-drop transmission at 160 Mbps over distances of up to 1.4m. Many constraints such as radiation length, thermal conductivity, grounding etc. require custom solutions. The optimal solution for the ATLAS ITk strips involves highly integrated systems based on carbon fibre structures. Complex optimisation of signal integrity, radiation length, electrical and thermal performance is required. As carbon fibre is electrically conductive it must be integrated into the grounding scheme. However it is a poor conductor, and should not be used in transmission lines.

The dominant loss mechanism for our application is resistive loss. The theory is reviewed to explain the slow turn-on and how this leads to dispersion. Ways of combating this effect using data encoding and pre-emphasis are described. The advantages of microstrip and stripline configurations are reviewed from the perspective of minimising material. Multi-drop lines are attractive for distribution of clock and trigger with minimal material. These lines suffer from reflections from each load. FEA calculations are used to predict the magnitude of the losses. Several methods to minimise these losses are discussed.

Laboratory measurements of S-parameters for 1.4 m long ITk strip bus tapes have been performed for point to point links and multi-drop lines. They are compared to FEA of the transmission lines. The measured S-parameters are then used to predict "eye diagrams". Good eye-opening was achieved for the longest lines and improvements with data encoding and pre-emphasis were studied. The multi-drop lines showed large reflections at high frequency, as expected from the FEA calculations. The reflections result in signal loss and ringing which generates Inter Symbol Interference. However the computed eye diagrams still showed reasonable eye opening at 160 Mbps, even with 28 capacitive loads along the line. Ideas on how to improve the signal integrity are discussed including series inductors, back termination and reducing rise times.

Test tapes were produced with identical transmission lines to those on the proposed ITk strip bus tapes. More direct measurements of the maximum data rates that could be achieved with these test tapes have been performed using a BERT system. These tests confirmed that low Bit Error Ratio (BER) could be achieved for the long lines at data rates in excess of 640 Mbps. It was demonstrated that a large increase in data rates could be achieved with the use of 8b10b encoding as expected from transmission line theory. The system was also used with representative loads to measure BER for multi-drop configuration, demonstrating viability of multi-drop configuration working at 160 Mbps

This work is relevant to the topics of integrated systems, links and trigger. FEA calculations have helped achieve the required data rates by optimizing the trade off between minimal material and sufficient electrical performance. The performance was validated with laboratory measurements of S-parameters and BER.

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