Specifications for the Upgraded XFT System for High Luminosity Running in Run 2.

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1 Introduction

This document outlines a set of specifications for the upgraded XFT system. The XFT[1][2] is being upgraded to respond to the expected increase in the instantaneous luminosity of the Tevatron. Reconstructing tracks in the Central Outer Tracker is sensitive to multiple interactions. The Accelerator Division anticipates the instantaneous luminosity to increase to between 2 and 4 $\times 10^{32}$ $cm^{-1}s^{-1}$. With the commitment to remain at 396 ns bunch spacing, the mean number of interactions per crossing will increase to approximately 10–12. The existing XFT system was not designed for such a large occupancy of tracks.

The present XFT works off of coarse COT timing information using a mezzanine card residing on each *axial* TDC used for digitizing timing signals from the COT. This mezzanine card performs the timing measurement for the XFT, classifying hits as *prompt* (near the sense wire) or *delayed* (far from the sense wire). Information for each wire on each axial layer is then sent to the XFT Finder boards. The Finders link sets of hits within each axial superlayer into track segments. The track segments are then sent to the XFT Linker boards, where the segments are linked to tracks. The granularity of the XFT is defined by the hardware to be 1.25^o. This means that the XFT can find up to one track for every 1.25^o of azimuth, or 288 tracks overall. The tracks are characterized by their transverse momentum (P_T) and ϕ position at the midpoint of the 3rd outermost axial layer (layer 5). As one can see, XFT tracks are 2D (rϕ) tracks only.

As the luminosity of the Tevatron increases, the number of interactions per crossing will grow. In addition to hard scattering events, additional interactions provide a higher multiplicity of low

momentum charged particles. These *curlers* loop in the magnetic field, leaving ionization in the COT, but are of sufficiently low energy that they cannot be reconstructed. The effect of additional occupancy on the XFT is twofold:

- Fake track segments can be identified and merged to produce fake tracks. The fake segments arise from real ionizing radiation, but they do not arise from high momentum tracks, which is why they are referred to as fake.
- Found tracks may include incorrect hit information from the additional occupancy. This degrades the resolution on the found tracks. With poorer resolution, matching tracks to electromagnetic clusters (to identify electrons) or muon stubs (for muon identification) becomes less efficient and admits more fakes.

A project has been started to replace portions of the XFT system with upgraded electronics and pattern recognition algorithms in order to maintain the current performance of the existing device. The upgrade takes advantage of the full 396ns between crossings (the current XFT system was designed to operate in a 132ns beam crossing mode) to pass more information through the system. In addition, the advances in FPGA designs over the last five years has increase the speed and capacity of the chips. Making use of the additional information and the new generation of FPGAs we can develop and implement more sophisticated algorithms that can maintain good track identification with a reasonable fake rate, even in the more challenging environment.

Figure 1 is a sketch of the full XFT system after the upgrade described in this note. The upgraded XFT will retain almost all of the current system. One class of boards (the Linker Output Modules) will be replaced, and new stereo capability will be added. This document will provide an overview of the complete XFT Upgrade. Other documents will describe in detail the specifications for the replacement of the Linker Output Module (the SLAM[3] boards) and the Stereo XFT System[4].

2 Layer Naming Convention

When the XFT was first designed, only the 4 axial layers were used. Superlayers are typically abbreviated as SL, and are often referred to as just "layers". The axial layers are numbered 1 through 4, and are referred to as SL1, SL2, SL3, and SL4.

In the upgrade, we will add information from the 3 outermost stereo layers. From past historical use, these layers are referred to as SL3, SL5, and SL7. Rather than rename the axial layers (to their more appropriate SL2, SL4, SL6, and SL8), we will use simply prepend the layer name with either "axial" or "stereo": for example, axial SL4 or stereo SL7. A summery of information for each superlayer can be found in Table 2.

3 Retained Components

The Upgraded XFT adds stereo capability to the present 2D XFT. This will be accomplished with minimal changes to the present system. To make this clear, we list below which parts will be retained, which will be changes, and which components need to be added.

SuperLayer	Name	Radius	Cells	Pixels/Cell	Slopes/Pixel
1	stereo SL1	46.0	168	xx	xx
2	axial SL1	58.5	196	12	0
3	stereo SL3	70.0	240	12	0
4	axial SL2	82.1	288	12	0
5	stereo SL5	94.0	336	6	2
6	axial SL3	105.6	384	6	2
7	stereo SL7	119.0	432	6	2
8	axial SL4	129.1	480	6	2

Table 1: Information for each of the Superlayers. Stereo Layer 1 is not expected to be used in the XFT upgrade.

3.1 XTC Cards:

These cards identify hits on each axial wire as either prompt and/or delayed. This information is then sent to the axial TDC Transition Cards. There are a total of 168 XTC Cards (one for each axial TDC).

3.2 Axial TDC Transition Cards:

These capture the data from the XTC card and drive hit data on the ansley cable to the first floor counting room. There are a total of 168 axial TDC Transition Cards (one for each axial TDC).

3.3 Ansley Cables:

These cables carry hit data from the detector front-end crates to the first floor counting room. Each Ansley cable sends data for 4 adjacent cells from the axial TDCs. The data from a given collision is multiplexed and sent up the cable using a 22nsec clock. All of the data from one collision is transmitted within 132nsec. There are a total of 336 4-cell groupings of axial cells. Since there are 3 Finder crates and 4 axial layers, cells lying on the 6 boundaries require 24 additional Ansley cables for a total of 360 cables.

3.4 Axial Finder Transition Boards:

These 48 boards reside in the back of the Finder crates. Ansley cables plug into these boards which route the signal through the backplane to the Finder boards.

3.5 Axial Finder Crate Backplane:

The 3 Finder crates have a specialized backplane for the sharing of hits between neighboring boards.

3.6 Axial Finder Boards:

These boards reside in the front of the Finder crates. They receive data from Ansley cables plugged into the Finder Transition Boards in the slot they occupy, as well as neighbor information from Ansleys plugged in on either side of this slot.

There are 24 axial SL2-4 cards each covering a 15° ϕ slice.

- Each card receives a total of 8 Ansley cables, carrying XTC hit data for cells within that ϕ slice. Hit data needed from neighbor cells comes from Ansley cables plugged into neighboring slots, and routed to that card via the backplane.
- Each card has 5 identical finder chips for axial SL4 and 3 identical Finder chips for axial SL2.
- Each of these cards send outs found segment information to two different Linker cards via 2 cables, using the National Semiconductor Channel Link.

There are 24 axial SL1-3 cards each covering a 15° ϕ slice.

- Each card receives a total of 6 Ansley cables, carrying XTC hit data for cells within that ϕ slice. Hit data needed from neighbor cells comes from Ansley cables plugged into neighboring slots, and routed to that card via the backplane.
- Each card has 4 identical finder chips for axial SL3 and 2 identical Finders chips for axial SL1.
- Each of these cards send outs found segment information to two different Linker cards via 2 cables, using the National Semiconductor Channel Link.

The minimum number of allowed misses for segment finding can be adjusted by downloading a modified algorithm to the Finder chips. The number of allowed misses can be 1, 2, or 3 (out of a maximum of 12 wire hits per layer).

3.7 Axial Finder-Linker Cables:

These cables route Finder segment information from the Finder to the Linker. Each axial Finder card sends data out on two cables (to 2 linkers neighboring in ϕ), while each Linker card receives a total of 4 cables (2 from 2 separate SL2-4 cards, 2 from 2 separate SL1-3 cards).

3.8 Linker Module:

These boards in the Linker crates are responsible for finding all tracks in a 15° ϕ slice. There are 24 Linker cards each covering 15° ϕ slice.

- Each card receives a total of 4 Channel Link cables, carrying found segment data for all cells needed to finder Linker tracks within that ϕ slice.
- Each card has 12 identical Linker chips covering a 1.25^o ϕ slice. Each chip can report at most 1 found track.
- If a track traversing all 4 axial layers is not found in a given chip, then that chip will report a track found traversing the 3 innermost axial layers.

- Each of these cards sends out found track information to a Linker Output module in a neighboring slot over the backplane using a simple short cable.

- The minimum P_T threshold for track finding can be adjusted by downloading a modified algorithm to the Linker chips. The algorithm is also modified if there is a significant displacement of the beam spot.

3.9 XFT-XTRP Cables:

Since the information sent to the XTRP is not changing, we would retain this cable plant. There is one cable output to XTRP per Linker Output Module (described next). Data is clocked at 33ns over this cable.

4 Modified Components

In order to use stereo XFT information in the Level 1 trigger, the found Stereo segments must be associated with 2D XFT tracks before the tracks are sent to XTRP. A logical place to do this is on the Linker Output Module (LOM). The LOMs in the present system route the the Linker board output to the front of the Linker crate. There is one LOM for every Linker card in the system, for a total of 24 cards. The XFT to XTRP cables attach to the front of these boards.

To attach Stereo segments to XFT tracks, we will develop a replacement for the LOM called the Stereo Linker Association Module (SLAM)[3]. The basic functionality of the LOM will be reproduced on this board, and as with the LOM, there will be a total of 24 boards. The changes which allow the association of stereo information include:

- Optical cables from the stereo SL3, 5, and 7 layers will provide stereo segment information. The format of the data will be similar (12 pixels/cell) to that of axial finder data sent to the Linker module. The data will arrive on 9 optical cables, 3 for each of the stereo Finder Layers. The mapping of cables for a single Stereo Finder Layer to each SLAM is illustrated in Figure 2.

- A single FPGA will be used to implement the association algorithm. This device will need to receive Stereo Finder segment data and perform the association within approximately 132nsec. This additional time comes from dropping 3-Layer tracks from the Linker algorithm (and so only reporting 4-Layer tracks).

- Of the 13 bits/track now sent to the XTRP, 3 bits (isolation, reserved, and short track) can be redefined to correspond to stereo track information.

5 Additional Components

This section details the modules and cables which must be added to the XFT system in order to implement Stereo Segment Finding.

5.1 Stereo XTC Cards:

These cards will define hits in up to 6 different time bins (in contrast to the two bins of prompt and delayed used on the axial XTC cards). If the existing TDCs card are replaced by the TDC board being developed at Chicago, the XFT hit classification would be done in the FPGA on the new board, and no Stereo XTC cards would be needed.

5.2 Stereo TDC Transition Cards:

These capture the data from the stereo XTC card (or new TDC) and drive hit data on optical cables to the first floor counting room. The data transfer must be done within 396nsec.

5.3 Stereo TDC Cables:

These optical cables carry hit data from the detector front-end crates to the first floor counting room. There will be one optical fiber for every 4 COT cells (so effectively one optical fibers carries what one Ansley cable does now).

5.4 Stereo Finder Boards:

These boards reside in the front of the two Stereo Finder crates. They receive all of the data they need to do stereo segment finding in a 30° ϕ slice from optical fibers via front panel connectors. Segment Finding will be done using ALTERA FPGAs as in the axial Finder system. Separate boards will be used for Stereo SL3,5,7; however, the same board design will be used in each case (the FPGAs will be programmed differently).

A total of 36 Stereo Finder cards will be needed, 12 for each of the 3 layers. Each card will cover a 30° ϕ slice. Although the cards will be the same for each layer, then number of cells processed by the cards decreases as the layer number decreases. In the present system, Altera FPGA process 4 neighboring cells for the axial Finder cards. We assume the same for the stereo system.

Stereo SL7 Finder cards will have the following requirements:

- This board will process 36 cells total. The cells are numbered from 0-35 in phi order.
- 9 finder FPGA chips are needed, each producing 12 bits per cell of output.
- The output of all of the finder chips goes to a single device which is responsible for splitting the data into two sets, A and B.
  - Set A will cover cells 0-17.
  - Set B will cover cells 18-35.

Stereo SL5 Finder cards will have the following requirements:

- This board will process 28 cells total. The cells are numbered from 0-27 in phi order.
- 7 finder FPGA chips are needed, each producing 12 bits per cell of output.

- The output of all of the finder chips goes to a single device which is responsible for splitting the data into two sets, A and B.
  - Set A will cover cells 0-13.
  - Set B will cover cells 14-27.

Stereo SL3 Finder cards will have the following requirements:

- This board will process 20 cells total. The cells are numbered from 0-19 in phi order.
- 5 finder FPGA chips are needed, producing 12 bits per cell of output.
- The output of all of the finder chips goes to a single device which is responsible for splitting the data into two sets, A and B.
  - Set A will cover cells 0-9.
  - Set B will cover cells 10-19.

The Stereo Finders output their results to both Level 1 (the SLAM board) and Level 2 (the Pulsar). The output to the SLAM board will be serialized and sent over 6 optical cables per Stereo Finder board: 3 copies of set A and 3 copies of set B.

The data will be serialized using the TLK1501 SEEDERS device. The data into the TALK1501 will be clocked at 16.5 nsec. Since events occur every 396 nsec, this means there are (396/16.5)=24 buckets that we have to transmit the data. The TLK can nominally transmit 16 bits/16.5 nsec, but we need only 12 for pixel data. The remaining 4 bits can transmit other data (marker bits, beam zero, etc) if desired. There are a total of 18 words which will be transmitted per 396nsec. The remaining 6 words (out of 24 available) can be used for synchronization for the optical link.

5.5 Stereo Finder-SLAM Cables:

These optical cables route Stereo Finder segment information from the Finder to the SLAM boards. The description of the data transferred on these cables can be found in the Stereo Finder and SLAM board specifications.

5.6 Stereo Finder-L2 Cables:

These optical cables route Stereo Finder segment information from the Finder to the L2 Pulsar boards. The description of the data transferred on these cables can be found in the Stereo Finder and Stereo XFT L2[5] specifications.

References

[1] E. Thomson et al., *Online Track Processor for the CDF Upgrade*, IEEE Transactions on Nuclear Science, Vol. 49, No. 3, June 2002.

[2] R. Blair et al., *The CDF II Detector Technical Design Report*, Fermilab-Pub-96/390-E (1996).

[3] S. Holm *et al.*, *The XFT SLAM Board Specification* CDF Note 7073.

[4] S. Holm *et al.*, *Stereo XFT Finder Specification* CDF Note XXXX.

[5] S. Holm *et al.*, *Stereo XFT L2 Specification* CDF Note XXXX.

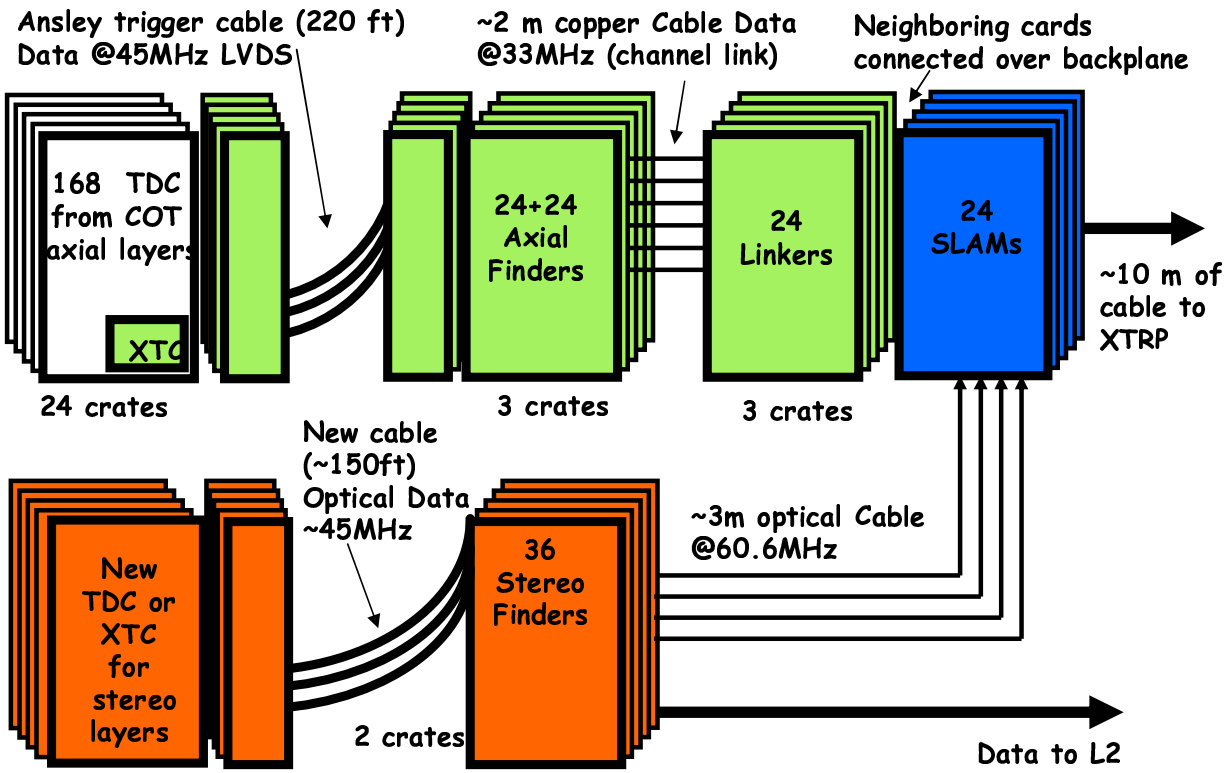
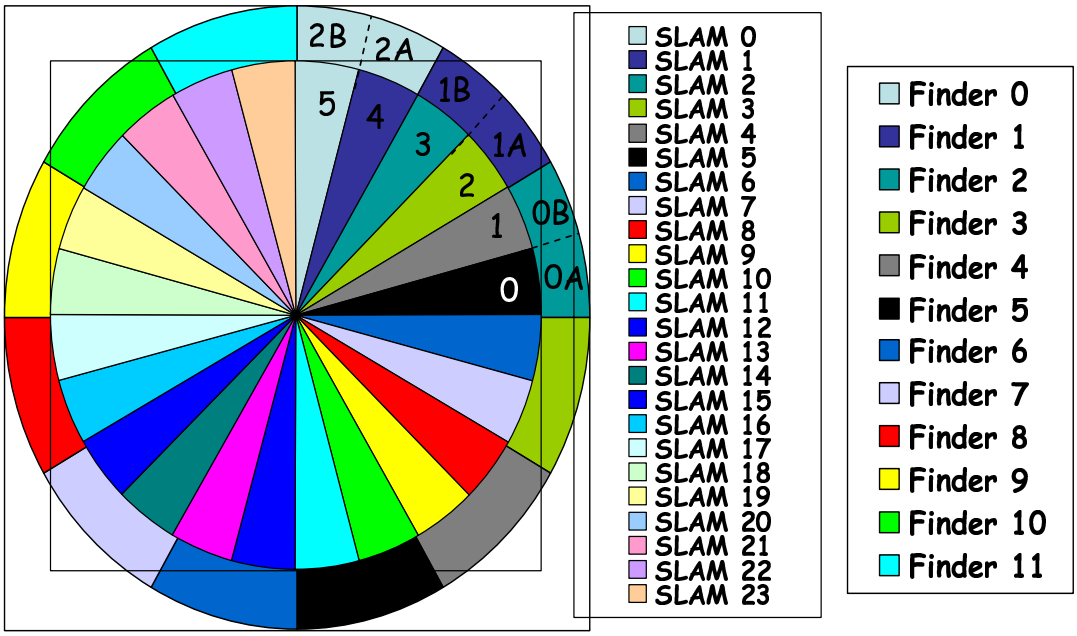


Figure 1: Sketch of the XFT system, including retained (green), modified (blue) and new (orange) components.



Example: SLAM 1 receives 3 cables: Finder cables 0A, 0B, 1A.
Finder 1 sends out 6 cables: 2 to SLAMs 2 & 3, 1 each to SLAMs 1 & 4

Figure 2: A sketch showing the ϕ arrangement of the SLAM boards (inner circle) and one of the Stereo Finder Layers (outer circle). Each slice represents a single board in both systems.