EMTF PT LUT address formation

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This documents provides details on PT LUT address formation logic implemented in EMTF in 2017.

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## “Mode” parameter calculation

The standard “mode” (track composition) parameter is calculated for each track as shown below:

|  |  |  |  |
| --- | --- | --- | --- |
| **Bit 3** | **Bit 2** | **Bit 1** | **Bit 0** |
| =1 if ME1 is present | =1 if ME2 is present | =1 if ME3 is present | =1 if ME4 is present |

This “mode” word is not used explicitly in the LUT address itself, but is used to decide the address type.

The 3-bit “mode2” word is used in the PT LUT address to identify specific two-station tracks. The 2-bit “mode3” word is used for most three-station tracks. Mode 7 (station 2-3-4) is omitted intentionally. They are defined as follows (decimal representation):

|  |  |
| --- | --- |
| **Mode** | **Mode2** |
| 3 | 2 |
| 5 | 3 |
| 6 | 4 |
| 9 | 5 |
| 10 | 6 |
| 12 | 7 |

|  |  |
| --- | --- |
| **Mode** | **Mode3** |
| 11 | 1 |
| 13 | 2 |
| 14 | 3 |

## Compressed track theta calculation

In all tracks with two or three stations, the track theta value is compressed into a 5-bit word. Furthermore, it is split into two distinct ranges, depending on whether the track contains an LCT or RPC hit (both referred to as “LCT” in this document) from station 1, ring 2 or 3:

5b\_theta = (min( max(theta, 1), 104)-1)/4;5b\_theta += (ring1 == 2 || ring1 == 3) ? 6 : 0;

In four-station tracks, the original track theta is combined with CLCT information from all four stations to create an 8-bit 8b\_theta\_rpc\_clct1 word, which is described in Appendix A.

## RPC hit identifier

In three-station tracks, the most important combinations of stations with RPC hits are identified using a 2-bit word. ”A” represents the station closest to the IP, ”B” represents the second-closest, and ”C” the furthest. The 2b\_rpc word is obtained using the logic below, with values in decimal format:

if (clctA == 0) 2b\_rpc = 0;else if (clctC == 0) 2b\_rpc = 1;else if (clctB == 0) 2b\_rpc = 2;else 2b\_rpc = 3;

## Endcap and delta phi A-B sign convention

As in the firmware, endcap has a value of 0 for the positive endcap (ME+), and 1 for the negative.

In this code, ”A” represents the station closest to the IP, ”B” represents the second-closest station. The sign of the deltat phi phi between stations ”A” and ”B” is computed as shown below: sphAB = (phA <= phB);

## Compressed CLCT calculation

In two-station tracks, the original 4-bit CLCT pattern from an LCT is compressed into a 3-bit word using the following LUTs:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Initial CLCT** | **3-bit compressed CLCT (“3b\_clct”)** | | | |
| **Endcap == 0** | | **Endcap == 1** | |
| **sphAB == 0** | **sphAB == 1** | **sphAB == 0** | **sphAB == 1** |
| 0 (RPC) | 0 | 0 | 0 | 0 |
| 1 | 1 | 7 | 7 | 1 |
| 2 | 7 | 1 | 1 | 7 |
| 3 | 1 | 7 | 7 | 1 |
| 4 | 7 | 1 | 1 | 7 |
| 5 | 1 | 7 | 7 | 1 |
| 6 | 6 | 2 | 2 | 6 |
| 7 | 2 | 6 | 6 | 2 |
| 8 | 5 | 3 | 3 | 5 |
| 9 | 3 | 5 | 5 | 3 |
| 10 | 4 | 4 | 4 | 4 |
| >= 11 | 4 | 4 | 4 | 4 |

A 2-bit compression is used in tracks with three or four stations:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Initial CLCT** | **2-bit compressed CLCT (“2b\_clct”)** | | | |
| **Endcap == 0** | | **Endcap == 1** | |
| **sphAB == 0** | **sphAB == 1** | **sphAB == 0** | **sphAB == 1** |
| 0 (RPC) | 0 | 0 | 0 | 0 |
| 1 | 0 | 3 | 3 | 0 |
| 2 | 3 | 0 | 0 | 3 |
| 3 | 0 | 3 | 3 | 0 |
| 4 | 3 | 0 | 0 | 3 |
| 5 | 0 | 3 | 3 | 0 |
| 6 | 3 | 0 | 0 | 3 |
| 7 | 0 | 3 | 3 | 0 |
| 8 | 2 | 1 | 1 | 2 |
| 9 | 1 | 2 | 2 | 1 |
| 10 | 1 | 1 | 1 | 1 |
| >= 11 | 1 | 1 | 1 | 1 |

## Compressed delta theta calculation

Initial 7-bit delta theta values are calculated as shown below:

dth = (thX <= thY) ? thY - thX : thX - thY;sth = (thX <= thY);

In this code, thX is always taken from the station closer to the IP, thY from the farther station. Note that the sign calculation convention is the same as phi. This is the reverse of the 2016 convention.

The compressed 3-bit delta theta, and a 2-bit delta theta for four-station tracks, are calculated from the initial 7-bit delta theta value and its 1-bit sign using the LUTs below:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Initial dth** | **3-bit dTheta (“3b\_dTh”)** | | **2-bit dTheta (“2b\_dTh”)** | |
|  | **sth == 0** | **sth == 1** | **sth == 0** | **sth == 1** |
| 0 | 4 | 4 | 2 | 2 |
| 1 | 3 | 5 | 2 | 2 |
| 2 | 2 | 6 | 1 | 1 |
| 3 | 1 | 7 | 0 | 3 |
| >= 4 | 0 | 7 | 0 | 3 |

## Compressed delta phi calculation

The initial 13-bit delta phi and sign are calculated as shown below:

dph = (phX <= phY) ? phY - phX : phX - phY;sph = (phX <= phY);

In this code, phX is always taken from the station closer to the IP, phY from the farther station.

Initial 13-bit absolute values of phi differences are first trimmed to 9 bits. If the initial value was more than 511, it is set to 511, otherwise the original value is retained. The 9-bit values are then used as indexes for the compression LUTs. There are three different compression LUTs that return 4, 5, or 7-bit compressed delta phi values. The contents of the compression LUTs can be found in Appendix C. **TODO**

## Combined delta phi signs

There are multiple delta phi parameters available for three- and four-station tracks. To save PT LUT address bits, the sphBC and sphCD quantities are computed with respect to sphAB as follows:

sphBC = ((phB <= phC) == sphAB);sphCD = ((phC <= phD) == sphAB);

## Address for two-station tracks

To form the PT LUT address for two-station tracks, parameters of the two LCTs are taken as shown in the table below. LCT “A” is always from the station closer to the IP, “B” is from the other available station.

|  |  |  |
| --- | --- | --- |
| **Bits** | **Symbol** | **Description** |
| 29:26 | 0000 | Identifier for two-station tracks |
| 25:23 | mode2 | Two-station track composition |
| 22:18 | 5b\_theta | Compressed 5-bit track theta |
| 17:15 | 3b\_clctB | Compressed 3-bit CLCT from station B |
| 14:12 | 3b\_clctA | Compressed 3-bit CLCT from station A |
| 11 | frB | Front-rear bit from station B |
| 10 | frA | Front-rear bit from station A |
| 9:7 | 3b\_dThAB | Compressed 3-bit delta theta A-B |
| 6:0 | 7b\_dPhAB | Compressed 7-bit delta phi A-B |

## Address for 2-3-4 tracks

|  |  |  |
| --- | --- | --- |
| **Bits** | **Symbol** | **Description** |
| 29:26 | 0001 | Unique identifier for mode 7 |
| 25:21 | 5b\_theta | Compressed 5-bit track theta |
| 20:19 | 2b\_rpc | Compressed 2-bit RPC hit identifier |
| 18:17 | 2b\_clct2 | Compressed 2-bit CLCT from station 2 |
| 16 | fr2 | Front-rear bit from station 2 |
| 15:13 | 3b\_dTh24 | Compressed 3-bit delta theta 2-4 |
| 12 | sph34 | Delta phi 3-4 sign, relative to the 2-3 sign |
| 11:7 | 5b\_dPh34 | Compressed 5-bit delta phi 3-4 |
| 6:0 | 7b\_dPh23 | Compressed 7-bit delta phi 2-3 |

## Address for three-station tracks (except 2-3-4)

To form PT LUT address for three-station tracks, parameters of the three LCTs are taken as shown in the table below. LCT “A” is always from station 1, “B” is from the station second-closest to the IP, and “C” is from the station furthest from the IP.

|  |  |  |
| --- | --- | --- |
| **Bits** | **Symbol** | **Description** |
| 29 | 0 | Identifier for two- and three-station tracks |
| 28:27 | mode3 | Three-station track composition |
| 26:22 | 5b\_theta | Compressed 5-bit track theta |
| 21:20 | 2b\_rpc | Compressed 2-bit RPC hit identifier |
| 19:18 | 2b\_clctA | Compressed 2-bit CLCT from station A |
| 17 | frB | Front-rear bit from station B |
| 16 | frA | Front-rear bit from station A |
| 15:13 | 3b\_dThAC | Compressed 3-bit delta theta A-C |
| 12 | sphBC | Delta phi B-C sign, relative to the A-B sign |
| 11:7 | 5b\_dPhBC | Compressed 5-bit delta phi B-C |
| 6:0 | 7b\_dPhAB | Compressed 7-bit delta phi A-B |

## Address for 1-2-3-4 tracks

|  |  |  |
| --- | --- | --- |
| **Bits** | **Symbol** | **Description** |
| 29 | 1 | Unique identifier for mode 15 |
| 28:21 | 8b\_theta\_rpc\_clct1 | 8-bit compressed track theta + RPC hit identifier + CLCT from station 1 |
| 20 | fr1 | Front-rear bit from station 1 |
| 19:18 | 2b\_dTh14 | Compressed 2-bit delta theta |
| 17 | sph34 | Delta phi 3-4 sign, relative to the 1-2 sign |
| 16 | sph23 | Delta phi 2-3 sign, relative to the 1-2 sign |
| 15:12 | 4b\_dPh34 | Compressed 4-bit delta phi 3-4 |
| 11:7 | 5b\_dPh23 | Compressed 5-bit delta phi 2-3 |
| 6:0 | 7b\_dPh12 | Compressed 7-bit delta phi 1-2 |

## Appendix A – Mode 15 compression for track theta + RPC hits + station 1 CLCT

In four-station tracks, there are four variables used in the pT assignment whose values are interrelated:

1. Ring number of station 1 LCT – may be 1 or 2
2. Track theta value – separate those passing through station 1, ring 1 and station 1, ring 2 or 3
3. Stations with RPC hits – up to 2 stations (in almost all cases), but only for high theta values
4. CLCT value in station 1 – not relevant if there is an RPC hit in station 1

These variables are all combined into an 8-bit 8b\_theta\_rpc\_clct1 word, which is constructed using compressed versions of the track theta, RPC hit identifiers, and the station 1 CLCT value.

The 3-bit compressed track theta word m15\_theta is computed as follows:

if (ring1 == 2 || ring1 == 3) m15\_theta = (min( max(theta, 46), 87) – 46) / 7;else m15\_theta = (min( max(theta, 5), 52) - 5) / 6;

The compressed CLCT input is the standard 2-bit 2b\_clct1 word defined in the main body of the text.

The 5-bit RPC hit identifier m15\_r2\_rpc for ring1 == 2/3 tracks is computed as shown below:

int nRPC = (clct1 == 0) + (clct2 == 0) + (clct3 == 0) + (clct4 == 0)

if (nRPC >= 2 && clct1 == 0 && clct2 == 0) m15\_r2\_rpc = 0;else if (nRPC >= 2 && clct1 == 0 && clct3 == 0) m15\_r2\_rpc = 1;else if (nRPC >= 2 && clct1 == 0 && clct4 == 0) m15\_r2\_rpc = 2;else if (nRPC == 1 && clct1 == 0 ) m15\_r2\_rpc = 3;else if (nRPC >= 2 && clct4 == 0 && clct2 == 0) m15\_r2\_rpc = 4;else if (nRPC >= 2 && clct4 == 0 && clct3 == 0) m15\_r2\_rpc = 8;else if (nRPC >= 2 && clct2 == 0 && clct3 == 0) m15\_r2\_rpc = 12;else if (nRPC == 1 && clct4 == 0 ) m15\_r2\_rpc = 16;else if (nRPC == 1 && clct2 == 0 ) m15\_r2\_rpc = 20;else if (nRPC == 1 && clct3 == 0 ) m15\_r2\_rpc = 24;else m15\_r2\_rpc = 28;

The combined 5-bit RPC + CLCT identifier to be used in tracks with a station 1, ring 2/3 LCT is then: m15\_r2\_rpc\_clct1 = m15\_r2\_rpc + 2b\_clct1

The 2-bit RPC hit identifier m15\_r1\_rpc for ring1 == 1 tracks is computed as shown below:

if (m15\_theta >= 4 && clct4 == 0) m15\_r1\_rpc = 0;else if (m15\_theta >= 4 && clct3 == 0) m15\_r1\_rpc = 1; else if (m15\_theta >= 4 ) m15\_r1\_rpc = 2; else m15\_r1\_rpc = 3;

The combined 4-bit RPC + CLCT identifier to be used in tracks with a station 1, ring 1 LCT is then: m15\_r1\_rpc\_clct1 = m15\_r1\_rpc\*4 + 2b\_clct1

The final 8-bit 8b\_theta\_rpc\_clct1 word (abbreviated 8b\_th) is then constructed as follows:

if (ring1 == 2 || ring1 == 3) 8b\_th = (m15\_theta )\*32 + m15\_r2\_rpc\_clct1 + 64;else 8b\_th = (m15\_theta % 4)\*16 + m15\_r1\_rpc\_clct1;

For the firmware, I suspect it will be simplest to perform this transformation using a small LUT. This could take as input the full-precision theta (7 bits), a boolean from each station indicating clctX == 0, and the 2-bit 2b\_clct1 word, making it a 13-bit to 8-bit conversion LUT.

## Appendix B - Schematic of 2017 PT LUT address bits

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **PT LUT address bits** | **29** | **28** | **27** | **26** | **25** | **24** | **23** | **22** | **21** | **20** | **19** | **18** | **17** | **16** | **15** | **14** | **13** | **12** | **11** | **10** | **9** | **8** | **7** | **6** | **4** | **4** | **3** | **2** | **1** | **0** |
| **Two-station tracks** | 0 | 0 | 0 | 0 | mode2 | | | 5b\_theta | | | | | 3b\_clctB | | | 3b\_clctA | | | frB/A | | 3b\_dThAB | | | 7b\_dPhAB | | | | | | |
| **Station 2-3-4 tracks** | 0 | 0 | 0 | 1 | 5b\_theta | | | | | 2b\_rpc | | clct2 | | fr | 3b\_dTh24 | | | s | 5b\_dPh34 | | | | | 7b\_dPh23 | | | | | | |
| **Three-station tracks** | 0 | mod3 | | 5b\_theta | | | | | 2b\_rpc | | clctA | | frB/A | | 3b\_dThAC | | | s | 5b\_dPhBC | | | | | 7b\_dPhAB | | | | | | |
| **Four-station tracks** | 1 | 8b\_theta\_rpc\_clct1 | | | | | | | | fr | dTh14 | | s34-23 | | 4b\_dPh34 | | | | 5b\_dPh23 | | | | | 7b\_dPh12 | | | | | | |

\*\*\* Some names truncated for space. **Two-station:** [frB/A] = [frB][frA]. **Station 2-3-4:** [fr] = [fr2], [s] = [sph34]. **Three-station:** [mod3] = [mode3], [frB/A] = [frB][frA], [s] = [sphBC]. **Four-station:** [fr] = [fr1], [s34-23] = [sph34][sph23], [dTh14] = [2b\_dTh14].