IEEE P802.11  
Wireless LANs

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| D0.1 Comment Resolution – Clause 22.3.4 | | | | |
| Date: 7 May 2011 | | | | |
| Author(s): | | | | |
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Abstract

This document provides resolutions for CIDs 312, 320, 323, 1223, 324, 872, 326, 873, 889, 1224, 874, 333, 1225, 1350, 876, 1226, 833, 834, 596, 336, 877, 335, 598 and 878.

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| **CommentID** | **Subclause** | **Page** | **Line** | **Comment** | **SuggestedRemedy** | **Response** |
| 312 | 22.3.4.2 | 82 | 46 | "Before Sequence generation" yet not needed until IDFT; also erratic capaitalization | "Before sequence generation:", or better "Beforehand:" or "Required parameters:" Repeat for P83L1, P83L25, P84L6, insert equivalent at P83L54, P84L29, P84L63, P85L44. But arguably this bullet adds little value, and these bullets should just be discarded | Agree in principle |

<Discussion>

I agree that “before XXX” sub-titles are not needed for understanding the paragraph. So, I deleted these phrases for conciseness in expression.

**TGac editor: modify D0.4 P110L13, as follows**

a) Determine the CH\_BANDWIDTH from the TXVECTOR.

**TGac editor: modify D0.4 P110L37, as follows**

a) For a VHT PPDU, set the RATE subfield in the SIGNAL field to 6 Mbps.

**TGac editor: modify D0.4 P111L3--9, as follows**

a) Obtain the CH\_BANDWIDTH, STBC, GROUP\_ID, PARTIAL\_AID (SU only), NUM\_STS, GI\_TYPE, FEC\_CODING, MCS (SU only), BEAMFORMED (SU only), NUM\_USERS from the TXVECTOR. Add the reserved bits and *Ntail* tail bits as shown in section 22.3.9.2.3 (VHT-SIG-A definition). Calculate the CRC and append it. Partition the VHT-SIG-A bits such that the first 24 uncoded bits are modulated by the VHT-SIG-A1 symbol, and the second 24 uncoded bits are modulated by the VHT-SIG-A2 symbol.

**TGac editor: modify D0.4 P112L18--19, as follows**

a) Obtain the MCS (for MU only) and PSDU\_LENGTH from the TX\_VECTOR.

**TGac editor: modify D0.4 P112L58--59, as follows**

a) Insert the CRC calculated for VHT-SIG-B in the SERVICE field as described in 22.3.11.2 (SERVICE field) and append the PSDU to the SERVICE field.

**TGac editor: modify D0.4 P113L45--46, as follows**

a) Insert the CRC calculated for VHT-SIG-B in the SERVICE field as described in 22.3.11.2 (SERVICE field) and append the PSDU to the SERVICE field.

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| 320 | 22.3.4.3 | 83 | 2 | Sentence beginning "Add calculated" tries to dup clause 17 rather than referring to it | Rewrite as "Set the Parity and Tail bits as described in …) | Agree in principle |

<Discussion>

For concise expression, I modified as suggested.

**TGac editor: modify D0.4 P110L38--40, as follows**

Set the Length, the Parity and Tail bits in the SIGNAL field as described in 22.3.9.1.4 (L-SIG definition).

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| **CommentID** | **Subclause** | **Page** | **Line** | **Comment** | **SuggestedRemedy** | **Response** |
| 323 | 22.3.4.4 | 83 | 30 | "Partition the SIG-A … first modulated by the SIG-A1 symbol …" is not correct since the edge bits, once encoded, span both symbols. | Not sure that this partitioning, after the bit field definitions, adds much value. Anyway, change "modulated by" to "assigned to" x2 | Accept |
| 1223 | 22.3.4.4 | 83 | 33 | Under what conditions can sig-a be LDPC encoded? Surely none, given that it itself contains signalling about whether to use ldpc or bcc coding on a per-user basis. | Delete bullet b) | Reject |
| 324 | 22.3.4.4 | 83 | 37 | "rotated by 90deg" - which way? | "rotated by 90 deg counter-clockwise" | Accept |
| 872 | 22.3.4.4 | 83 | 43 | For VHT-SIG-A, the cyclic shift to be applied is per-Tx chain cyclic shift defined in Table 22.3.9.2.1  However, the spec incorrectly states  "CSD: Apply CSD for each transmit chain as described in 22.3.9.2.2." | Change to  "CSD: Apply CSD for each transmit chain as described in 22.3.9.2.1." | Counter |

<Discussion>

As defined in clause 22.3.9.2.3, the VHT-SIG-A symbols shall be BCC encoded at rate 1/2. While the VHT-SIG-A contains the information on coding type, its coding type will be valid for the SERVICE field and Data field.

About a reference section to the CSD for VHT-SIG-A, the CSD table for the legacy part is also applied to VHT-SIG-A, while its section number is not 22.3.9.2.1, which is mentioned in CID #872.

**TGac editor: modify D0.4 P110L62—P111L30, as follows**

**22.3.4.4 Construction of VHT-SIG-A**

The VHT-SIG-A field consists of two symbols, VHT-SIG-A1 and VHT-SIG-A2, as defined in 22.3.2 (VHT PPDU format).

a) Obtain the CH\_BANDWIDTH, STBC, GROUP\_ID, PARTIAL\_AID (SU only), NUM\_STS, GI\_TYPE, FEC\_CODING, MCS (SU only), BEAMFORMED (SU only), NUM\_USERS from the TXVECTOR. Add the reserved bits and tail bits as shown in section 22.3.9.2.3 (VHT-SIG-A definition). Calculate the CRC and append it. Partition the VHT-SIG-A bits such that the first 24 uncoded bits are assigned to the VHT-SIG-A1 symbol, and the second 24 uncoded bits are assigned to the VHT-SIG-A2 symbol.

b) FEC Encoder: Encode the data by a convolution encoder at the rate of R=1/2 as described in 17.3.5.6 (Convolutional encoder).

c) BCC Interleaver: Interleave as described in 17.3.5.7 (Data interleaving).

d) Constellation Mapper: BPSK modulate VHT-SIG-A1 as described in 17.3.5.8 (Subcarrier modulation mapping). Rotate VHT-SIG-A2 by 90° counter-clockwise relative to VHT-SIG-A1.

e) IDFT: Insert pilots for both the symbols. Duplicate VHT-SIG-A1 and VHT-SIG-A2 over each 20 MHz of the CH\_BANDWIDTH. Apply the appropriate phase rotation for each 20 MHz subband. Compute the Inverse Discrete Fourier Transform.

f) CSD: Apply CSD for each transmit chain as described in 22.3.9.1.1 (Cyclic shift definition).

g) Insert GI and apply windowing: Prepend a GI (800ns) and apply windowing as described in 17.3.2.5 (Mathematical conventions in the signal descriptions).

h) Analog and RF: Up-convert the resulting complex baseband waveform associated with each transmit chain to an RF signal according to the center frequency of the desired channel and transmit. Refer to 22.3.7 (Mathematical description of signals) and 22.3.8 (Transmission of PPDU with bandwidth less than the BSS bandwidth) for details.

**TGac editor: modify D0.4 P129L2—5, as follows**

The BPSK constellation for VHT-SIG-A2 subfield is rotated by 90° counter-clockwise relative to VHT-SIG-A1 subfield in order to accommodate differentiation of the VHT format PPDU from a non-HT and HT PPDU.

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| **CommentID** | **Subclause** | **Page** | **Line** | **Comment** | **SuggestedRemedy** | **Response** |
| 326 | 22.3.4.5 | 83 | 60 | VHT-STF should have Q applied | Add a bullet for spatial mapping | Accept in principle |
| 873 | 22.3.4.5 | 83 | 60 | For VHT-STF, the cyclic shift to be applied is per-space time stream cyclic shift. However, the spec states:  "CSD: Apply CSD for each transmit chain as described in 22.3.9.2.2." | Change to  "CSD: Apply CSD for each space time stream as described in 22.3.9.2.2." | Accept in principle |
| 889 | 22.3.4.5 | 83 | 60 | Specify that spatial mapping Q is used, as is specified for VHT-LTF and VHT-SIGB. | add after c): Spatial Mapping: Q matrix is applied as described in 22.3.11.10.1. | Accept in principle |

<Discussion>

Spatial mapping with the matrix *Q* needs to be also applied to VHT-STF. As shown in clause 22.3.11.11.1, *Q* matrix for VHT-STF can be dependent on *k* index (frequency domain). So, spatial mapping is to be done before the IDFT as in the case of VHT-LTF.

**TGac editor: modify D0.4 P111L32—50, as follows**

**22.3.4.5 Construction of VHT-STF**

Construct the VHT-STF field as described in 22.3.9.2.4 (VHT-STF definition).

a) Sequence generation: Generate the VHT-STF in the frequency-domain over the bandwidth indicated by CH\_BANDWIDTH as described in 22.3.9.2.4 (VHT-STF definition).

b) Phase rotation: Apply appropriate phase rotation for each 20MHz sub-band.

c) CSD: Apply CSD for each space time stream as described in 22.3.9.2.2 (Cyclic shift definition).

d) Spatial mapping: Apply the *Q* matrix as described in 22.3.11.11.1 (Transmission in VHT format).

e) IDFT: Compute the Inverse Discrete Fourier Transform.

f) Insert GI and apply windowing: Prepend a GI (800ns) and apply windowing as described in 17.3.2.5 (Mathematical conventions in the signal descriptions).

g) Analog and RF: Up-convert the resulting complex baseband waveform associated with each transmit chain to an RF signal according to the center frequency of the desired channel and transmit. Refer to 22.3.7 (Mathematical description of signals) and 22.3.8 (Transmission of PPDU with bandwidth less than the BSS bandwidth) for details.

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| 1224 | 22.3.4.6 | 84 | 7 | This could usefully describe how to determine the number of symbols of VHT-LTF | Add such a description | Reject |
| 874 | 22.3.4.6 | 84 | 14 | For VHT-LTF, the cyclic shift to be applied is per-space time stream cyclic shift. However, the spec states:  "CSD: Apply CSD for each transmit chain as described in 22.3.9.2.2." | Change to  "CSD: Apply CSD for each space time stream as described in 22.3.9.2.2." | Accept in principle |

<Discussion>

How to determine the number of symbols of VHT-LTFs is described in detail with a table (Table 22-10) in clause 22.3.9.2.5, which is already mentioned as a reference here. So, additional description seems not needed in this overview section.

**TGac editor: modify D0.4 P111L52—P112L12, as follows**

**22.3.4.6 Construction of VHT-LTF**

The VHT-LTF fields allow the receiver to estimate the MIMO channel. The transmitter provides training for exactly the space time streams used for transmission of the PSDU.

a) Sequence generation: Generate the VHT-LTF sequence in the frequency-domain over the bandwidth indicated by CH\_BANDWIDTH as described in 22.3.9.2.5 (VHT-LTF definition).

b) Pilot insertion: Insert pilots and apply appropriate phase rotation for each 20 MHz sub-band.

c) VHT-LTF matrix mapping: Apply the *P* matrix to the VHT-LTF sequence and apply the *R* matrix to the pilot tones as described in 22.3.9.2.5 (VHT-LTF definition).

d) CSD: Apply CSD for each space time stream as described in 22.3.9.2.2 (Cyclic shift definition).

e) Spatial mapping: Apply the *Q* matrix as described in 22.3.11.11.1 (Transmission in VHT format).

f) IDFT: Compute the Inverse Discrete Fourier Transform.

g) Insert GI and apply windowing: Prepend a GI (800ns) and apply windowing as described in 17.3.2.5 (Mathematical conventions in the signal descriptions).

h) Analog and RF: Up-convert the resulting complex baseband waveform associated with each transmit chain to an RF signal according to the center frequency of the desired channel and transmit. Refer to 22.3.7 (Mathematical description of signals) and 22.3.8 (Transmission of PPDU with bandwidth less than the BSS bandwidth) for details.

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| 333 | 22.3.4.7 | 84 | 24 | No description of SIGB in a MU PPDU | Add | Accept in principle |
| 1225 | 22.3.4.7 | 84 | 27 | "is constructed as follows", but this takes place per user | "is constructed per user as follows" | Accept |
| 1350 | 22.3.4.7 | 84 | 28 | PSDU\_LENGTH is Rxvector. Should use LENGTH here. There might be some other places in the spec that mixes LENGTH and PSDU\_LENGTH. | Change to LENGTH. Fix other similar issues if there is any. | Accept |
| 876 | 22.3.4.7 | 84 | 45 | For VHT-SIG-B, the cyclic shift to be applied is per-space time stream cyclic shift. However, the spec states:  "CSD: Apply CSD for each transmit chain as described in 22.3.9.2.2." | Change to  "CSD: Apply CSD for each space time stream as described in 22.3.9.2.2." | Accept |
| 1226 | 22.3.4.7 | 84 | 47 | Data and sig-b may have different #SS, so how does the same Q matrix apply to them both. | Indicate how Q matrix is applied when #SS of this users data is > 1. | Reject |
| 833 | 22.3.4.7 | 84 | 42-44 | This is inconsistent with equation 22-35. The data is multiplied by a Row Vector of P based on Mu and m (STS). | This needs to be resolve as to the correct way. The assumption is that Equation 22-35. | Reject |
| 834 | 22.3.4.7 | 84 | 42-44 | This is inconsistent with equation 22-35. The pilot in equation 22-35 is NOT multiplied by the P or R Matrix. | This needs to be resolve as to the correct way. The assumption is that Equation 22-35. | Accept in principle |

<Discussion>

As suggested by CID #1350, VHT-SIG-B uses the LENGTH in the TX\_VECTOR rather than the PSDU\_LENGTH in the RX\_VECTOR. For your information, there is one more comment similar to this, CID #1349 in clause 22.3.11 by Hongyuan Zhang. But, CID #1349 was resolved by other approach which was suggested in CID #420 by Brian Hart.

About CID #1226, although the Data field and VHT-SIG-B may have different number of spatial streams due to the optional use of STBC functionality from the Service field on, there is no change in terms of number of space time streams, which the VHT-SIG-A field informs beforehand as well as STBC option. As shown in Equation (22-22), (22-31), (22-36) and (22-76), the same spatial mappting matrix *Q* is applied to all the fields from VHT-STF on (VHT-STF, VHT-LTF, VHT-SIG-B, SERVICE field and Data field) with the same range upto *NSTS,u* -1 per each user.

About CID #833, TGac actually decided to use the first ‘column’ of P as mapping for VHT-SIG-B such that the first VHT-LTF could be used for channel estimation for VHT-SIG-B. This is correctly reflected in Equation (22-35) by [*PVHTLTF*]{(*Mu+m*),1}. For your information, the matrix *R* mapping used for pilot tones in the VHT-LTFs field, is constructed from the first ‘row’ of *PVHTLTF*.

As CID #834 pointed out, the previous text may give some ambiguity on whether 1st column of *P* matrix calculation is applied to the pilot tones as well. To clarify this, I added some phrase at the end of the sentence such as: “Multiply with 1st column of [*P*]*u*: Insert pilots and apply 1st column of *P* matrix to the data tones.”

**TGac editor: modify D0.4 P112L14—50, as follows**

**22.3.4.7 Construction of VHT-SIG-B**

The VHT-SIG-B field is constructed per user as follows:

a) Obtain the MCS (for MU only) and LENGTH from the TX\_VECTOR.

b) VHT-SIG-B bits: For a VHT PPDU, set the MCS (for MU only) and VHT-SIG-B Length field as described in 22.3.9.2.6 (VHT-SIG-B definition). Add the reserved bits (for SU only) and bits tail. For an NDP, set VHT-SIG-B to the fixed bit pattern for the bandwidth used as described in 22.3.9.2.6 (VHT-SIG-B definition).

c) VHT-SIG-B Bit Repetition: Repeat the VHT-SIG-B bits over the bandwidth indicated by CH\_BANDWIDTH.

d) BCC Encoder: Encode the VHT-SIG-B field using BCC at rate R=1/2 as described in 17.3.5.6 (Convolutional encoder).

e) BCC Interleaver: Interleave as described in 22.3.11.8 (BCC interleaver).

f) Constellation Mapper: Map to a BPSK constellation.

g) Multiply with 1st column of [*P*]*u* : Insert pilots and apply 1st column of *P* matrix to the data tones. The total number of data and pilot subcarriers is the same as in the Data field.

h) CSD: Apply CSD for each space time stream as described in 22.3.9.1.1 (Cyclic shift definition).

i) Spatial Mapping: Apply the *Q* matrix as described in 22.3.11.11.1 (Transmission in VHT format).

j) IDFT: Apply the appropriate phase rotations for each 20 MHz sub-band and compute the Inverse Discrete Fourier Transform.

k) Insert GI and apply windowing: Prepend a GI (800ns) and apply windowing as described in 17.3.2.5 (Mathematical conventions in the signal descriptions).

l) Analog and RF: Up-convert the resulting complex baseband waveform associated with each transmit chain to an RF signal according to the center frequency of the desired channel and transmit. Refer to 22.3.7 (Mathematical description of signals) and 22.3.8 (Transmission of PPDU with bandwidth less than the BSS bandwidth) for details.

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| **CommentID** | **Subclause** | **Page** | **Line** | **Comment** | **SuggestedRemedy** | **Response** |
| 596 | 22.3.4.8.1 | 85 | 3 | INDICATED\_CH\_BANDWIDTH and INDICATED\_DYN\_BANDWIDTH are defined only for NON\_HT packets. Since this section is describing construction of VHT packets, the initial state of the scrambler should not be a function of INDICATED\_CH\_BANDWIDTH or INDICATED\_DYN\_BANDWIDTH. | Change step c) to "c) Scrambler: Scramble the PHY padded data". | Accept |
| 336 | 22.3.4.8.1 | 85 | 4 | INDICATED\_CH\_BANDWIDTH and INDICATED\_DYN\_BANDWIDTH are not used in VHT format packets - make explicit. This is still needed for selected NON-HT-DUP packets though. Basically, make this dependent according to whether these parameters are present in the TXVECTOR or not. Ditto for LDPC section | As in comment | Accept in principle |
| 877 | 22.3.4.8.1 | 85 | 29 | For DATA, the cyclic shift to be applied is per space time stream cyclic shift. However, the spec states:  "CSD: Apply CSD for each transmit chain as described in 22.3.9.2.2." | Change to  "CSD: Apply CSD for each space time stream as described in 22.3.9.2.2." | Accept |

<Discussion>

Because this clause (22.3.4.8.1) is describing construction of VHT packets, CH\_BANDWIDTH\_IN\_NON\_HT and DYN\_BANDWIDTH\_IN\_NON\_HT related things need to be deleted in the scrambling process.

**TGac editor: modify D0.4 P112L54—P113L38, as follows**

**22.3.4.8.1 Using BCC**

The construction of the Data field in a VHT SU packet with BCC encoding proceeds as follows:

a) Insert the CRC calculated for VHT-SIG-B in the SERVICE field as described in 22.3.11.2 (SERVICE field) and append the PSDU to the SERVICE field.

b) PHY Padding: Append the PHY pad bits and tail bits to the PSDU.

c) Scrambler: Scramble the PHY padded data.

d) Encoder Parser: Divide the scrambled bits between the encoders by sending bits to different encoders in a round robin manner. The number of encoders is determined by rate-dependent parameters described in 22.5 (Parameters for VHT MCSs).

e) BCC Encoder: BCC encode as described in 22.3.11.5.1 (Binary convolutional coding).

f) Stream Parser: Rearrange the output of the BCC encoders into blocks as described in 22.3.11.6 (Stream parser).

g) Segment Parser (if needed): For a contiguous 160 MHz or non-contiguous 80+80 MHz transmission, divide the output bits of each stream parser into two frequency segments as described in 22.3.11.7 (Segment parser). For a contiguous 160 MHz transmission, map each segment to the upper and the lower part of one IDFT. For a non-contiguous 80+80 MHz transmission, map each segment to the separate IDFT. This block is bypassed in case of 20 MHz, 40 MHz and 80 MHz VHT PPDU transmissions.

h) BCC Interleaver: Interleave as described in 22.3.11.8 (BCC interleaver).

i) Constellation Mapper: Map to BPSK, QPSK, 16-QAM, 64-QAM or 256-QAM constellation points as described in 22.3.11.9 (Constellation mapping).

j) STBC: Apply STBC as described in 22.3.11.9.3 (Space-time block coding).

k) CSD: Insert pilots and apply CSD for each space time stream as described in 22.3.9.2.2 (Cyclic shift definition).

l) Spatial Mapping: Apply the *Q* matrix as described in 22.3.11.11.1 (Transmission in VHT format).

m) IDFT: Apply the appropriate phase rotations for each 20 MHz sub-band and compute the Inverse Discrete Fourier Transform.

n) Insert GI and apply windowing: Prepend a GI (400 ns or 800 ns) and apply windowing as described in 17.3.2.5 (Mathematical conventions in the signal descriptions).

o) Analog and RF: Up-convert the resulting complex baseband waveform associated with each transmit chain to an RF signal according to the center frequency of the desired channel and transmit. Refer to 22.3.7 (Mathematical description of signals) and 22.3.8 (Transmission of PPDU with bandwidth less than the BSS bandwidth) for details.

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| 335 | 22.3.4.8.2 | 85 | 45 | LDPC sequence omits reference to SIG-B inserted in service field | Insert | Accept in principle |
| 598 | 22.3.4.8.2 | 85 | 50 | INDICATED\_CH\_BANDWIDTH and INDICATED\_DYN\_BANDWIDTH are defined only for NON\_HT packets. Since this section is describing construction of VHT packets, the initial state of the scrambler should not be a function of INDICATED\_CH\_BANDWIDTH or INDICATED\_DYN\_BANDWIDTH. | Change step c) to "c) Scrambler: Scramble the PHY padded data". | Accept |
| 878 | 22.3.4.8.2 | 86 | 6 | For DATA, the cyclic shift to be applied is per space time stream cyclic shift. However, the spec states:  "CSD: Apply CSD for each transmit chain as described in 22.3.9.2.2." | Change to  "CSD: Apply CSD for each space time stream as described in 22.3.9.2.2." | Accept |

<Discussion>

Because this clause (22.3.4.8.2) is also describing construction of VHT packets, CH\_BANDWIDTH\_IN\_NON\_HT and DYN\_BANDWIDTH\_IN\_NON\_HT related things need to be deleted in the scrambling process.

As described in clause 22.3.11.6, LDPC encoding uses the LENGTH in the TX\_VECTOR during the process. So, I added some phase as suggested by CID #335.

**TGac editor: modify D0.4 P113L40—P114L20, as follows**

**22.3.4.8.2 Using LDPC**

The construction of the Data field in a VHT SU packet with LDPC encoding proceeds as follows:

a) Insert the CRC calculated for VHT-SIG-B in the SERVICE field as described in 22.3.11.2 (SERVICE field) and append the PSDU to the SERVICE field.

b) PHY Padding: Append the PHY pad bits to the PSDU. There are no tail bits.

c) Scrambler: Scramble the PHY padded data.

d) LDPC Encoder: The scrambled bits are encoded using the LDPC code with the LENGTH in the TX\_VECTOR as described in 22.3.11.5.2 (LDPC coding).

e) Stream Parser: The output of the LDPC encoder is rearranged into blocks as described in 22.3.11.6 (Stream parser).

f) Segment Parser (if needed): For a contiguous 160 MHz or non-contiguous 80+80 MHz transmission, divide the output bits of each stream parser into two frequency segments as described in 22.3.11.7 (Segment parser). For a contiguous 160 MHz transmission, map each segment to the upper and the lower part of one IDFT, respectively. For a non-contiguous 80+80 MHz transmission, map each segment to the separate IDFT. This block is bypassed in case of 20 MHz, 40 MHz and 80 MHz VHT PPDU transmissions.

g) Constellation Mapper: Map to BPSK, QPSK, 16-QAM, 64-QAM or 256-QAM constellation points as described in 22.3.11.9 (Constellation mapping).

h) LDPC Tone Mapper: The LDPC tone mapping shall be performed on all LDPC coded streams as described in 22.3.11.8.2.

i) STBC: Apply STBC as described in 22.3.11.9.3 (Space-time block coding).

j) CSD: Apply CSD for each space time stream as described in 22.3.9.2.2 (Cyclic shift definition).

k) Spatial Mapping: Apply the *Q* matrix as described in 22.3.11.11.1 (Transmission in VHT format).

l) IDFT: Apply the appropriate phase rotations for each 20 MHz sub-band and compute the Inverse Discrete Fourier Transform.

m) Insert GI and apply windowing: Prepend a GI (400 ns or 800 ns) and apply windowing as described in 17.3.2.5 (Mathematical conventions in the signal descriptions).

n) Analog and RF: Up-convert the resulting complex baseband waveform associated with each transmit chain to an RF signal according to the center frequency of the desired channel and transmit. Refer to 22.3.7 (Mathematical description of signals) and 22.3.8 (Transmission of PPDU with bandwidth less than the BSS bandwidth) for details.