# HT PHY Specification

*Enhanced Wireless Consortium publication*

***V1.01***
***October 7th, 2005***

## Contents

# 1 Introduction

This document specifies the interoperability specification of a device. It specifies the signals that may be transmitted by the device and received by the device's receivers. The device is compliant with the 802.11a/b/g/j standards. This document will describe the extension needed for high throughput transmission.

# 2 PHY Interface

The PHY interfaces to the MAC through the TX vector and the RX vector. The TX vector gives the PHY the TX parameters. Using the RX vector, the PHY informs the MAC of the received packet parameters. The specification of this interface is outside the scope of this document.

# 3 PLCP frame format

The PLCP (PHY Layer Convergence Protocol) frame shall have one of the following three formats:

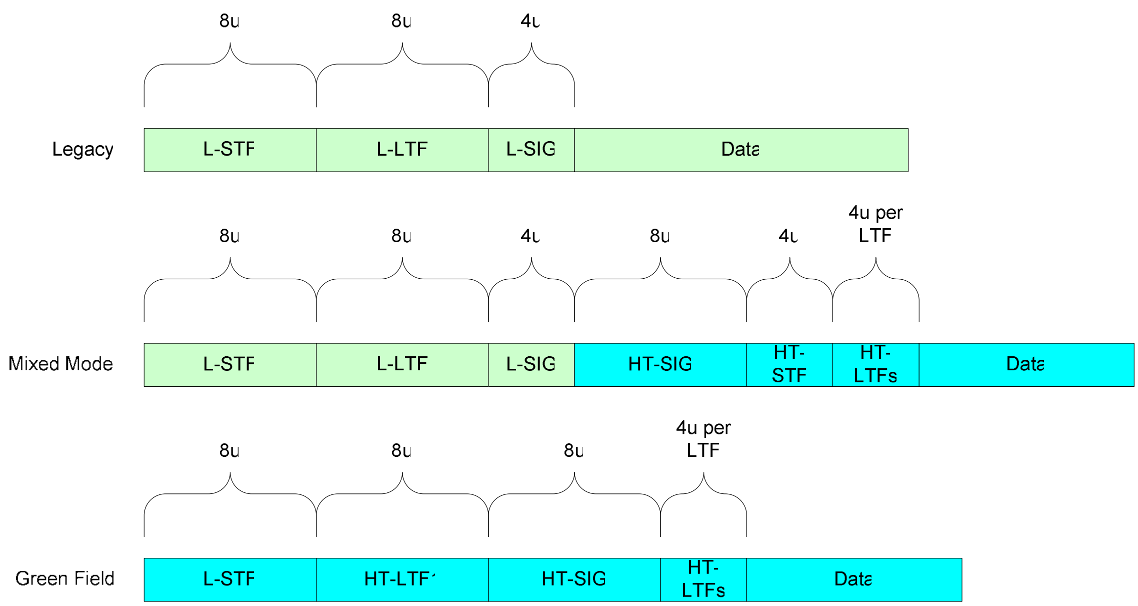


**Figure 1- PLCP frame format**

The elements of the PCLP frame are:

L-STF: Legacy Short Training Field

L-LTF: Legacy Long Training Field

L-SIG: Legacy Signal Field

HT-SIG: High Throughput Signal Field

HT-STF: High Throughput Short Training Field

HT-LTF1: First High Throughput Long Training Field

HT-LTF's: Additional High Throughput Long Training Fields

Data – The data field includes the PSDU (PHY Sub-layer Data Unit)

The HT-SIG, HT-STF and HT-LTF's exist only in HT frames. In legacy and legacy duplicate format only the L-STF, L-LTF, L-SIG and Data fields exist.

## *3.1 Operating Mode*

The PHY will operate in one of 3 modes –

- **Legacy Mode** – in this mode packets are transmitted in the legacy 802.11a/g format.
- **Mixed Mode –** in this mode packets are transmitted with a preamble compatible with the legacy 802.11a/g – the legacy Short Training Field (STF), the legacy Long Training Field (LTF) and the legacy signal field are transmitted so they can be decoded by legacy 802.11a/g devices. The rest of the packet has a new format**.** In this mode the receiver shall be able to decode both the Mixed Mode packets and legacy packets.
- **Green Field –** in this mode high throughput packets are transmitted without a legacy compatible part. This mode is optional. In this mode the receiver shall be able to decode both Green Field mode packets and legacy format packets.

The operation of PHY in the frequency domain is divided to the following modes:

- **LM –** Legacy Mode – equivalent to 802.11a/g
- **HT-Mode –** In HT mode the device operates in either 40MHz bandwidth or 20MHz bandwidth and with one to four spatial streams. This mode includes the HT-duplicate mode.
- **Duplicate Legacy Mode –** in this mode the device operates in a 40MHz channel composed of two adjacent 20MHz channel. The packets to be sent are in the legacy 11a format in each of the 20MHz channels. To reduce the PAPR the upper channel (higher frequency) is rotated by 90º.
- **40 MHz Upper Mode –** used to transmit a legacy or HT packet in the upper 20MHz channel of a 40MHz channel.
- **40 MHz Lower Mode –** used to transmit a legacy or HT packet in the lower 20MHz channel of a 40MHz channel

LM is mandatory and HT-Mode for 1 and 2 spatial streams are also mandatory.

### 3.2 Modulation and Coding Scheme (MCS)

The Modulation and Coding Schemes indexed 0 through 32 for the HT modes are described in the following table:

**Table 1 - Modulation and Coding Schemes**

| Bits 0-6 in HT-SIG1 (MCS index) | Number of spatial streams | Modulation | Coding rate | $N_{ES}$ | | $N_{SD}$ | | $N_{CBPS}$ | | GI = 800ns | | GI = 400ns | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 20 | 40 | 20 | 40 | 20MHz | 40MHz | Rate in 20MHz | Rate in 40MHz | Rate in 20MHz | Rate in 40MHz |
| 0 | 1 | BPSK | ½ | 1 | 1 | 52 | 108 | 52 | 108 | 6.5 | 13.5 | 7 2/9 | 15 |
| 1 | 1 | QPSK | ½ | 1 | 1 | 52 | 108 | 104 | 216 | 13 | 27 | 14 4/9 | 30 |
| 2 | 1 | QPSK | ¾ | 1 | 1 | 52 | 108 | 104 | 216 | 19.5 | 40.5 | 21 2/3 | 45 |
| 3 | 1 | 16-QAM | ½ | 1 | 1 | 52 | 108 | 208 | 432 | 26 | 54 | 28 8/9 | 60 |
| 4 | 1 | 16-QAM | ¾ | 1 | 1 | 52 | 108 | 208 | 432 | 39 | 81 | 43 1/3 | 90 |
| 5 | 1 | 64-QAM | ⅔ | 1 | 1 | 52 | 108 | 312 | 648 | 52 | 108 | 57 7/9 | 120 |
| 6 | 1 | 64-QAM | ¾ | 1 | 1 | 52 | 108 | 312 | 648 | 58.5 | 121.5 | 65 | 135 |
| 7 | 1 | 64-QAM | 5/6 | 1 | 1 | 52 | 108 | 312 | 648 | 65 | 135 | 72 2/9 | 150 |
| 8 | 2 | BPSK | ½ | 1 | 1 | 52 | 108 | 104 | 216 | 13 | 27 | 14 4/9 | 30 |
| 9 | 2 | QPSK | ½ | 1 | 1 | 52 | 108 | 208 | 432 | 26 | 54 | 28 8/9 | 60 |
| 10 | 2 | QPSK | ¾ | 1 | 1 | 52 | 108 | 208 | 432 | 39 | 81 | 43 1/3 | 90 |
| 11 | 2 | 16-QAM | ½ | 1 | 1 | 52 | 108 | 416 | 864 | 52 | 108 | 57 7/9 | 120 |
| 12 | 2 | 16-QAM | ¾ | 1 | 1 | 52 | 108 | 416 | 864 | 78 | 162 | 86 2/3 | 180 |
| 13 | 2 | 64-QAM | ⅔ | 1 | 1 | 52 | 108 | 624 | 1296 | 104 | 216 | 115 5/9 | 240 |
| 14 | 2 | 64-QAM | ¾ | 1 | 1 | 52 | 108 | 624 | 1296 | 117 | 243 | 130 | 270 |
| 15 | 2 | 64-QAM | 5/6 | 1 | 1 | 52 | 108 | 624 | 1296 | 130 | 270 | 144 4/9 | 300 |
| 16 | 3 | BPSK | ½ | 2 | 2 | 52 | 108 | 156 | 324 | 19.50 | 40.50 | 21.67 | 45.00 |
| 17 | 3 | QPSK | ½ | 2 | 2 | 52 | 108 | 312 | 648 | 39.00 | 81.00 | 43.33 | 90.00 |
| 18 | 3 | QPSK | ¾ | 2 | 2 | 52 | 108 | 312 | 648 | 58.50 | 121.50 | 65.00 | 135.00 |
| 19 | 3 | 16-QAM | ½ | 2 | 2 | 52 | 108 | 624 | 1296 | 78.00 | 162.00 | 86.67 | 180.00 |
| 20 | 3 | 16-QAM | ¾ | 2 | 2 | 52 | 108 | 624 | 1296 | 117.00 | 243.00 | 130.00 | 270.00 |
| 21 | 3 | 64-QAM | ⅔ | 2 | 2 | 52 | 108 | 936 | 1944 | 156.00 | 324.00 | 173.33 | 360.00 |
| 22 | 3 | 64-QAM | ¾ | 2 | 2 | 52 | 108 | 936 | 1944 | 175.50 | 364.50 | 195.00 | 405.00 |
| 23 | 3 | 64-QAM | 5/6 | 2 | 2 | 52 | 108 | 936 | 1944 | 195.00 | 405.00 | 216.67 | 450.00 |
| 24 | 4 | BPSK | ½ | 2 | 2 | 52 | 108 | 208 | 432 | 26.00 | 54.00 | 28.89 | 60.00 |
| 25 | 4 | QPSK | ½ | 2 | 2 | 52 | 108 | 416 | 864 | 52.00 | 108.00 | 57.78 | 120.00 |
| 26 | 4 | QPSK | ¾ | 2 | 2 | 52 | 108 | 416 | 864 | 78.00 | 162.00 | 86.67 | 180.00 |
| 27 | 4 | 16-QAM | ½ | 2 | 2 | 52 | 108 | 832 | 1728 | 104.00 | 216.00 | 115.56 | 240.00 |
| 28 | 4 | 16-QAM | ¾ | 2 | 2 | 52 | 108 | 832 | 1728 | 156.00 | 324.00 | 173.33 | 360.00 |
| 29 | 4 | 64-QAM | ⅔ | 2 | 2 | 52 | 108 | 1248 | 2592 | 208.00 | 432.00 | 231.11 | 480.00 |
| 30 | 4 | 64-QAM | ¾ | 2 | 2 | 52 | 108 | 1248 | 2592 | 234.00 | 486.00 | 260.00 | 540.00 |
| 31 | 4 | 64-QAM | 5/6 | 2 | 2 | 52 | 108 | 1248 | 2592 | 260.00 | 540.00 | 288.89 | 600.00 |
| 32 | 1 | BPSK | ½ | 1 | 1 | | 48 | | 48 | | 6 | | 6.67 |

The parameters in the table are:

- Rate: Rate in Mbps
- $N_{SS}$: Number of Spatial Streams
- $N_{SD}$: Number of Data Subcarriers

- $N_{CBPS}$: Number of Code Bits Per Symbol (total of all spatial streams)
- $N_{ES}$: Number of FEC encoders used

Modulations and Coding scheme indexed 33-127 are reserved.

## *3.3 Transmitter Block Diagram (this section is informative)*

The transmitter will be composed of the following blocks:

- **Scrambler** – scrambles the data to prevent long sequences of zeros or ones – see section 4.2.
- **Encoder Parser** – de-multiplex the scrambled bits among $N_{ES}$ FEC encoders, in a round robin manner.
- **FEC encoders** – encodes the data to enable error correction – it may include a binary convolutional encoder followed by a puncturing device, or an LDPC encoder
- **Stream Parser** – divides the output of the encoders into blocks that will be sent to different interleaver and mapping devices. The sequences of the bits sent to the interleaver shall be denoted **spatial streams**.
- **Interleaver** – interleaves the bits of each spatial stream (changes order of bits) to prevent long sequence of noisy bits from entering the FEC decoder.
- **QAM mapping** – maps the sequence of bit in each spatial stream to constellation points (complex numbers).
- **Spatial Mapping** – maps spatial streams to different transmit chains. This may include one of the following:
  - **Direct mapping** – each sequence of constellation points is sent to a different transmit chain.
  - **Spatial expansion** – each vector of constellation points from all the sequences is multiplied by a matrix to produce the input to the transmit chains.
  - **Space Time Block coding** - TBD
  - **Beam Forming -** TBD
- **Inverse Fast Fourier Transform** – converts a block of constellation points to a time domain block.
- **Cyclic shift insertion** – inserts the cyclic shift into the time domain block. In the case that spatial expansion is applied that increases the number of transmit chain, the cyclic shift may be applied in the frequency domain as part of the spatial spreading.
- **Guard interval insertion** – inserts the guard interval.

- **Optional windowing** – smoothing the edges of each symbol to increase spectral decay

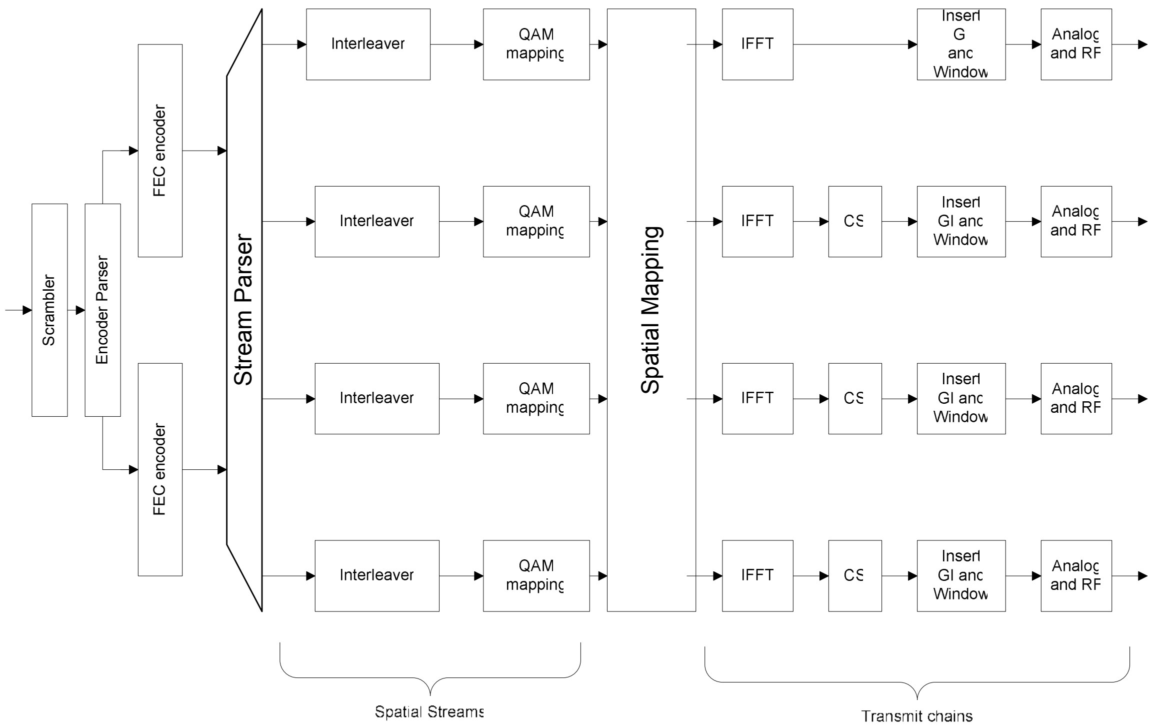


**Figure 2 - Transmitter block diagram**

Figure 2 shows a block diagram of the transmitter. Different implementation may be used as long as they are mathematically equivalent.

## *3.4 Mathematical description of signals*

For the description of the convention on mathematical description of signals see section 17.3.2.4 of [1]

In the case of a legacy mode and HT mode transmission over 20MHz channel, the channel is divided into 64 sub-carriers. In the legacy mode, signal is transmitted on sub-carriers -26 - -1 and 1-26, with 0 being the center (DC) carrier. In the HT modes signal is transmitted on sub-carriers -28– -1 and 1–28.

In the case of a HT transmission on 40MHz, two adjacent 20MHz channels will be used. The channel is divided into 128 sub-carriers. Signal is transmitted on sub-carriers -58– -2 and 2–58.

In the case of the legacy duplicate mode over 40MHz, the same data are transmitted over two adjacent 20MHz channels. In the case of duplicate mode the 40MHz channel is divided into 128 sub-carriers and the data are transmitted on carriers -58– -6 and 6–58.

**Table 2 - Timing related constants**

| Parameter | Value in legacy 20MHz channel | Value in HT 20MHz channel | Value in 40MHz channel | |
|---|---|---|---|---|
| **$N_{SD}$: Number of data subcarriers** | 48 | 52 | 108 | 48[1] |
| **$N_{SP}$: Number of pilot subcarriers** | 4 | 4 | 6 | 8[1] |
| **$N_{ST}$: Total Number of subcarriers** | 52 | 56 | 114 | |
| **$N_{SR}$: Number of subcarriers occupying half of the overall BW** | 26 | 28 | 58 | |
| **$\Delta_F$ : subcarrier frequency spacing** | 312.5kHz (20MHz/64) | 312.5kHz | 312.5kHz (40MHz/128) | |
| **$T_{FFT}$: IFFT/FFT period** | 3.2μsec | 3.2μsec | 3.2μsec | |
| **$T_{GI}$: Guard Interval length** | 0.8μsec= $T_{FFT}/4$ | 0.8μsec | 0.8μsec | |
| **$T_{GI2}$: Double GI** | 1.6μsec | 1.6μsec | 1.6μsec | |
| **$T_{GIS}$: Short Guard Interval length** | 0.4μsec= $T_{FFT}/8$ | 0.4μsec | 0.4μsec | |
| **$T_{L-STF}$: Legacy Short training sequence length** | 8μsec=10× $T_{FFT}/4$ | 8μsec | 8μsec | |
| **$T_{L-LTF}$: Legacy Long training sequence length** | 8μsec=2× $T_{FFT}+T_{GI2}$ | 8μsec | 8μsec | |
| **$T_{SYM}$: Symbol Interval** | 4μsec= $T_{FFT}+T_{GI}$ | 4μsec | 4μsec | |
| **$T_{SYMS}$: Short GI Symbol Interval** | 3.6μsec= $T_{FFT}+T_{GIS}$ | 3.6μsec | 3.6μsec | |
| **$T_{L-SIG}$** | 4μsec= $T_{SYM}$ | 4μsec | 4μsec | |

[1] This value used for HT duplicate mode

| Parameter | Value in legacy 20MHz channel | Value in HT 20MHz channel | Value in 40MHz channel |
|---|---|---|---|
| **$T_{HT\text{-}SIG}$** | NA | 8μsec= $2T_{SYM}$ | 8μsec |
| **$T_{HT\text{-}STF}$: HT STF time** | NA | 4μsec | 4μsec |
| **$T_{HT\text{-}LTF1}$: HT first long training field length** | NA | 4μsec in mixed mode, 8usec in green field | 4μsec in mixed mode, 8usec in green field |
| **$T_{HT\text{-}LTFs}$: HT second, third and fourth long training field length** | NA | 4μsec | 4μsec |

**Table 3 - frequently used parameters**

| Symbol | Explanation |
|---|---|
| $N_{CBPS}$ | Number of coded bits per symbol |
| $N_{CBPSS}$ | Number of coded bits per symbol per spatial stream |
| $N_{DBPS}$ | Number of data bits per symbol |
| $N_{BPSC}$ | Number of coded bits per single carrier |
| $N_{SS}$ | Number of spatial streams |
| $N_{TX}$ | Number of transmit chains. |
| $N_{ES}$ | Number of FEC encoders |
| $N_{LTF}$ | Number of HT long training fields |

The transmitted signal will be described in a complex base band signal notation. The actual transmitted signal is related to the complex signal by the following relation:

$$r_{RF}(t) \quad = \quad \mathrm{Re}\left\{ r(t)\exp\left(j2\pi f_c t\right)\right\} \qquad (1)$$

where

$\mathrm{Re}\{\cdot\}$ represents the real part of a complex variable;

$f_c$ denotes the center frequency of the carrier.

The transmitted baseband signal consists of several subframes. The timing boundaries for the various subframes are shown in Figure 3.

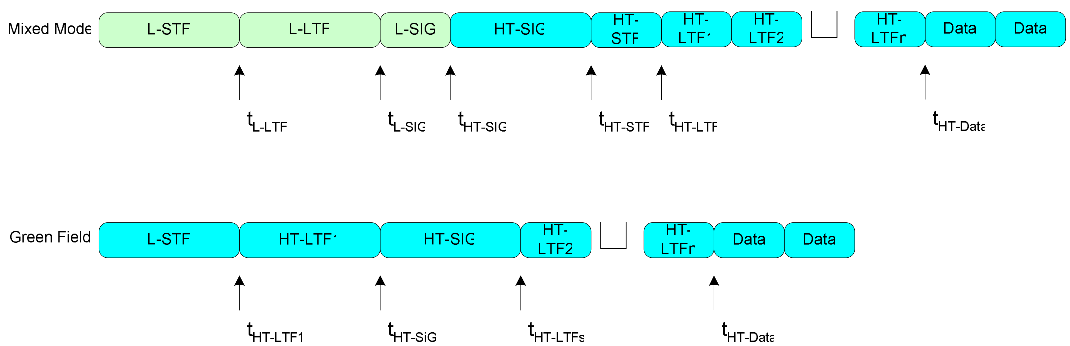


**Figure 3: Timing boundaries for PPDU Fields**

The time offsets $t_{Field}$ determines the starting time of the corresponding subframe.

The signal transmitted on spatial stream $i_{SS}$ if the packet is in Mixed Mode is

$$\begin{aligned} r_{PPDU}^{(i_{SS})}(t) \;=\; & r_{L-STF}^{(i_{SS})}(t) + r_{L-LTF}^{(i_{SS})}\left(t - t_{L-LTF}\right) \\ & + r_{L-SIG}^{(i_{SS})}\left(t - t_{L-SIG}\right) \\ & + r_{HT-SIG}^{(i_{SS})}\left(t - t_{HT-SIG}\right) \\ & + r_{HT-STF}^{(i_{SS})}\left(t - t_{HT-STF}\right) \\ & + \sum_{i_{LTF}=1}^{N_{LTF}} r_{HT-LTF}^{(i_{SS},i_{LTF})}\left(t - t_{HT-LTF} - \left(i_{LTF}-1\right)T_{HT-LTFs}\right) \\ & + r_{HT\ DATA}^{(i_{SS})}\left(t - t_{HT\ DATA}\right) \end{aligned} \quad (2)$$

where

$$t_{L-LTF} = T_{L-STF}, \quad (3)$$

$$t_{L-SIG} = t_{L-LTF} + T_{L-LTF}, \quad (4)$$

$$t_{HT-SIG} = t_{L-SIG} + T_{L-SIG}, \quad (5)$$

$$t_{HT-STF} = t_{HT-SIG} + T_{HT-SIG},$$

$$t_{HT-LTF} = t_{HT-STF} + T_{HT-STF} \tag{6}$$

and

$$t_{HT-Data} = t_{HT-LTF} + N_{LTF} \cdot T_{HT-LTFs}. \tag{7}$$

In the case of Green Field mode the transmitted signal on spatial stream $i_{SS}$ is:

$$\begin{aligned} r_{PPDU}^{(i_{SS})}(t) = {} & r_{L-STF}^{(i_{SS})}(t) + r_{HT-LTF1}^{(i_{SS})}\left(t - t_{HT-LTF1}\right) \\ & + r_{HT-SIG}^{(i_{SS})}\left(t - t_{HT-SIG}\right) \\ & + \sum_{i_{LTF}=2}^{N_{LTF}} r_{HT-LTF}^{(i_{SS}, i_{LTF})}\left(t - t_{HT-LTFs} - \left(i_{LTF} - 2\right) T_{HT-LTFs}\right) \\ & + r_{HT\ DATA}^{(i_{SS})}\left(t - t_{HT\ DATA}\right) \end{aligned}$$

where

$$t_{HT-LTF1} = T_{L-STF}, \tag{8}$$

$$t_{HT-SIG} = t_{HT-LTF1} + T_{HT-LTF1}, \tag{9}$$

$$t_{HT-LTFs} = t_{HT-SIG} + T_{HT-SIG} \tag{10}$$

and

$$t_{HT-Data} = t_{HT-LTFs} + (N_{LTF} - 1) g T_{HT-LTFs}, \tag{11}$$

Each baseband waveform $r_{Field}^{(i)}(t)$ is defined via the discrete Fourier transform as

$$r_{Field}^{(i)}(t) = \frac{1}{\sqrt{N_{Field}^{Tone}}} w_{T_{Field}}(t) \sum_k X_k^{(i)} \exp\left( j 2\pi k \Delta_F t \right) \tag{12}$$

This general representation holds for all fields, which are L-STF, L-LTF, L-SIG, HT-SIG, HT-STF, HT-LTF and HT-Data. The definition of $w_{T_{Field}}(t)$ is given in section 17.3.2.4 of [1]. The frequency domain symbols $X_k^{(i_{Tx})}$ define the field, as shall be specified in the following subsections. We adopt the convention that:

$$\sum_{i_{Tx}=0}^{N_{Tx}-1} E\left[ | X_k^{(i_{Tx})} |^2 \right] = 1 \quad (13)$$

With this convention, the $1/\sqrt{N_{Field}^{Tone}}$ scale factor in (12) ensures that the total power of the time domain signal as summed over all transmit chains is 1. The following table summarizes the various values of $N_{Field}^{Tone}$ :

| Field | $N_{Field}^{Tone}$ | |
|---|---|---|
| | 20 MHz | 40 MHz |
| **L-STF** | 12 | 24 |
| **L-LTF** | 52 | 104 |
| **L-SIG** | 52 | 104 |
| **HT-SIG** | 52/56* | 104/114* |
| **HT-STF** | 12 | 24 |
| **HT-LTF** | 56 | 114 |
| **HT-Data** | 56 | 114 |
| **HT-Data- 40 MHz Dup. Format** | - | 104 |

**Table 4 - number of tones in each field**

*56 and 114 are for green field mode, 52 and 104 are for mixed mode.

The numbers in the table refer only to the value of $N_{Field}^{Tone}$ as it appears in equation (12) and in subsequent specification of various fields. It may be different from the actual number of tones being transmitted.

### 3.4.1 Spatial Mapping – (This section is Informative)

This document separates spatial streams and transmit chains. A spatial stream is defined as the bit stream out of the stream parser, passing through the interleaver and constellation mapper.

Any signal defined in this document for $N_{SS}$ spatial streams may be transmitted using more transmit chains[2] using spatial expansion. If the signal is defined as in equation (12) for $N_{SS}$ spatial stream, it is possible to transmit it using $N_{TX} \geq N_{SS}$ transmit chain if for all the fields

[2] We avoid using the term antenna since the number of antennas may exceed the number of transmit chains.

$$r_{Field}^{(l_{Tx})}(t) = \frac{1}{\sqrt{N_{Field}^{Tone}}} w_{T_{Field}}(t) \sum_{k} \sum_{i_{SS}=0}^{N_{SS}-1} Q_{l_{TX} i_{SS}}^{(k)} X_k^{(i_{SS})} \exp\left( j 2\pi k \Delta_F t \right) \quad (14)$$

where $Q_{l_{Tx}, i_{SS}}^{(k)}$ are elements from a matrix $\mathbf{Q}^{(k)}$ with $N_{Tx}$ rows and $N_{SS}$ columns. The columns of the matrix $\mathbf{Q}^{(k)}$ shall be orthogonal. In Mixed mode operation, the transmitter may use different $\mathbf{Q}$ matrices before and after $t_{HT-STF}$.

In the rest of the document, the number of streams $N_{SS}$ refers to the number of streams in the data portion of the packet. The text that describes the legacy portion of the packet or the transmission of the HT-SIG refers to transmit chains. The number of these transmit chains may be higher than the number of spatial streams that will be used in the data portion.

### 3.4.2 Transmission in the upper/lower 20MHz of a 40MHz channel

When transmitting in the upper/lower 20MHz portion of a 40MHz channel, the mathematical definition of transmission shall follow that of a 20MHz channel with $f_c$ in equation (1) replaced by $f_c \pm 10MHz$.

## *3.5 Legacy Field Transmission*

The following section describes the transmission of the legacy training field and the legacy signal field as part of a mixed mode packet.

### 3.5.1 Cyclic shift definition for the legacy fields.

In the rest of the document cyclic shift is used to prevent undesired beamforming when the same signal or similar signals are transmitted through different spatial streams. The following table specifies the values for the cyclic shift that will be applied in the legacy short training field, the legacy long training field, and legacy signal field. It also applies to the HT signal field in a mixed mode packet.

| $T_{CS}^{i_{TX}}$ values for the legacy portion of the packet | | | | |
|---|---|---|---|---|
| Number of Tx Chains | cyclic shift for Tx chain 1 | cyclic shift for Tx chain 2 | cyclic shift for Tx chain 3 | cyclic shift for Tx chain 4 |
| 1 | 0ns | - | - | - |
| 2 | 0ns | -200ns | - | - |
| 3 | 0ns | -100ns | -200ns | - |
| 4 | 0ns | -50ns | -100ns | -150ns |

**Table 5 - Cyclic shift for legacy portion of the packet**

If spatial expansion applies additional cyclic shift to the packet, the total value of cyclic shift shall not exceed the values in Table 5.

### 3.5.2 Legacy Short Training Field

The L-STF is identical to the 802.11a short training symbol. The legacy short training OFDM symbol in the 20MHz mode is

$$\begin{aligned} S_{-26,26} = \sqrt{1/2}\ \{&0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ &0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0\} \end{aligned} \quad (15)$$

The normalization factor $\sqrt{1/2}$ is the QPSK normalization.

The legacy short training OFDM symbol in 40MHz mode is based on:

$$\begin{aligned} S_{-58,58} = \sqrt{1/2}\{&0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ &0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0,0,\\ &0,0,0,0,0,0,0,0,0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,+1+j,\\ &0,0,0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,+1+j,0,0\} \end{aligned} \quad (16)$$

The tones in the upper sub-channel (sub-carriers 6-58) are phase rotated by +90º. The 90º rotation helps keep the PAPR of the STF in 40MHz comparable to that in 20MHz.

The L-STF on the $i_{TX}$'$th$ transmit chain is

$$\begin{aligned} r_{L-STF}^{(i_{TX})}(t) &= \frac{1}{\sqrt{N_{L-STF}^{Tone}}} w_{T_{L-STF}}(t)\cdot \\ &\left(\sum_{k=-N_{SR}}^{0} S_k \exp\left(j2\pi k\Delta_F\left(t-T_{CS}^{i_{TX}}\right)\right)+\right.\\ &\left.\Upsilon\sum_{k=1}^{N_{SR}} S_k \exp\left(j2\pi k\Delta_F\left(t-T_{CS}^{i_{TX}}\right)\right)\right) \end{aligned} \quad (17)$$

In the case of Mixed Mode operation $T_{CS}^{i_{TX}}$ takes values from Table 5 and in the case of Green Field operation it takes values from Table 7. The value of $\Upsilon$ is 1 for 20MHz and $j$ in 40MHz. The L-STF has a period of 0.8 µs. The entire short training field includes ten such periods, with a total duration of $T_{L-STF}$ = 8 µs.

### 3.5.3 Legacy Long Training Field

The legacy long training OFDM symbol is identical to the 802.11a long training OFDM symbol. In the 20MHz mode, the long training OFDM symbol is given by

$$\begin{aligned} L_{-26,26} = \{&1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,0,\\ &1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1\} \end{aligned} \quad (18)$$

The legacy long training OFDM signal in the 40MHz mode is based on:

$$\begin{aligned} L_{-58,58} = \{&1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,0,\\ &1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,0,0,0,0,0\\ &0,0,0,0,0,0,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,0,\\ &1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1\} \end{aligned} \quad (19)$$

The tones in the upper sub-channel (sub-carriers 6-58) are phase rotated by +90º.

It should be noted that neither the legacy fields (L-STF, L-LTF, L-SIG) nor the HT-SIG undergo any phase rotation in the lower sub-channel. The sub-carriers at ±32 in 40MHz, which are the DC sub-carriers for the legacy 20MHz transmission, are both nulled in the L-LTF. Such an arrangement allows proper synchronization of the 20MHz legacy device.

The L-LTF waveform is

$$\begin{aligned} r_{L-LTF}^{(i_{TX})}(t) = &\frac{1}{\sqrt{N_{L-LTF}^{Tone}}} w_{T_{L-LTF}}(t) \cdot \\ &\left( \sum_{k=-N_{SR}}^{0} L_k \exp\left( j2\pi k\Delta_F \left( t - T_{GI2} - T_{CS}^{i_{TX}} \right) \right) + \right. \\ &\left. \Upsilon \sum_{k=1}^{N_{SR}} L_k \exp\left( j2\pi k\Delta_F \left( t - T_{GI2} - T_{CS}^{i_{TX}} \right) \right) \right) \end{aligned} \quad (20)$$

where $T_{G12}$ = 1.6 $\mu$ sec. The value of $\Upsilon$ is 1 for 20MHz and $j$ in 40MHz.

### 3.5.4 The Legacy Signal Field

The signal field is used to transfer rate and length information. It has different meaning when used in legacy transmission and when used in a non legacy transmission. When transmitted in a legacy 20MHz mode, it is transmitted using the same method and meaning as specified in section 17.3.4 of the IEEE 802.11a standard [1].

| Rate (4 bits) | | | | R | Length (12 bits) | | | | | | | | | | | | F | Tail 6bits | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 | R2 | R3 | R4 | | | | | | | | | | | | | | | "0" | "0" | "0" | "0" | "0" | "0" |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |

**Figure 4 - The signal field**

When the transmission is not a legacy transmission the fields in the signal field have different meaning. The bits in the rate field are [1,1,0,1] – corresponding to a rate of 6Mbps in legacy representation. The value in the length field is given through the TX vector. This value is used to spoof legacy devices to defer transmission for a period of corresponding to the length of the rest of the packet. The value to be transmitted is $l = 3\left(\lceil N_{\text{data}} \rceil + N_{LTF} + 3\right) - 3$ where $N_{data}$ is the number of **4usec** symbols in the data part of the frame. While using short GI $N_{data}$ is equal to the actual number of symbols in the data part of the frame multiplied by $\frac{9}{10}$. $N_{LTF}$ is the number of HT training symbols. The symbol $\lceil x \rceil$ denotes the lowest integer greater or equal to $x$.

The length field is transmitted LSB first.

It is permissible to use a larger number than $l$ to reserve time for more than the length of the packet.

The reserved bit shall be set to 0.

The parity field will have the even parity of bits 0-16.

The signal field shall be encoded, interleaved and mapped, and have pilots inserted following the steps described in sections 17.3.5.5, 17.3.5.6, 17.3.5.8 of the IEEE802.11a standard [1]. The stream of 48, complex numbers generated by these steps is $d_k, \quad k = 0 \ldots 47$. The conversion of these into a time domain signal is described in the following table

**Table 6 - generation of the signal field**

| Modulation Method | Conversion to Time Domain signal |
|---|---|
| **20MHz transmission on several transmit chains – $i_{TX}$'th tx chain** | $$r_{L-SIG}^{(i_{TX})}(t) = w_{T_{SYM}}(t) \frac{1}{\sqrt{N_{L-SIG}^{Tone}}} \cdot \left( \sum_{k=0}^{47} d_k \exp\left(j2\pi M(k) \Delta_F \left(t - T_{GI} - T_{CS}^{i_{TX}}\right)\right) + p_0 \sum_{k=-N_{SR}}^{N_{SR}} P_k \exp(j2\pi k \Delta_F \left(t - T_{GI} - T_{CS}^{i_{TX}}\right) \right)$$ |

| | |
|---|---|
| **40MHz transmission on several transmit chains – $i_{TX}$'th Tx chain.** | $r_{L-SIG}^{(i_{TX})}(t) = w_{T_{SYM}}(t)\frac{1}{\sqrt{N_{L-SIG}^{Tones}}}\cdot \left(\sum_{k=0}^{47} d_k \exp\left(j2\pi\left(M(k)-32\right)\Delta_F\left(t-T_{GI}-T_{CS}^{i_{TX}}\right)\right)+ + j\sum_{k=0}^{47} d_k \exp\left(j2\pi\left(M(k)+32\right)\Delta_F\left(t-T_{GI}-T_{CS}^{i_{TX}}\right)\right)+ p_0 \sum_{k=-N_{SR}}^{N_{SR}} P_k\left(\exp\left(j2\pi(k-32)\Delta_F\left(t-T_{GI}-T_{CS}^{i_{TX}}\right)\right)+ j\exp\left(j2\pi(k+32)\Delta_F\left(t-T_{GI}-T_{CS}^{i_{TX}}\right)\right)\right)\right)$ |

$M(k), P_k$ are defined in section 17.3.5.9 of the 802.11a standard [1].

$p_0$ is the first pilot value in the sequence defined in section 17.3.5.9 of the 802.11a standard [1].

## *3.6 The High Throughput Preamble*

The high throughput preamble consists of the HT signal field, the HT short training field and the HT long training fields.

### 3.6.1 Cyclic shift for the High Throughput preamble

Throughout the high throughput preamble, cyclic shift is applied to prevent beamforming when similar signals are transmitted in different spatial streams. The same cyclic shift will be applied to these streams during the transmission of the data portion of the packet. The values of the cyclic shift to be used during the HT preamble and the data portion of the packet, are specified in Table 7:

| $T_{CS}^{i_{TX}}$ values for HT portion of the packet | | | | |
|---|---|---|---|---|
| Number of spatial streams | Cyclic shift for Spatial stream 1 | Cyclic shift for spatial stream 2 | Cyclic shift for spatial stream 3 | Cyclic shift for spatial stream 4 |
| 1 | 0ns | - | - | - |
| 2 | 0ns | -400ns | - | - |
| 3 | 0ns | -400ns | -200ns | - |
| 4 | 0ns | -400ns | -200ns | -600ns |

**Table 7 – Cyclic shift values of HT portion of the packet**

When spatial expansion is applied to the transmission, so that more transmit chain are used than spatial streams, the additional cyclic shift applied by the spatial expansion matrix, shall be -50ns incremental per channel.

### 3.6.2 The High Throughput Signal Field

The high throughput signal field will be used to convey information related to high throughput signaling. The high throughput signal field (HT_SIG) will include the following fields:

**Table 8 - Fields of High Throughput Signal Field**

| Field Name | Num of Bits | Explanation and coding |
|---|---|---|
| **Modulation and Coding Scheme** | 7 | Index into Table 1 - Modulation and Coding Schemes,<br>LSB first |
| **BW 20/40** | 1 | 0 if 20MHz or 40 MHz upper/lower; 1 if 40MHz |
| **Length** | 16 | The number of bytes in frame - LSB first |
| **Reserved ones** | 3 | Set to ones by transmitter, shall be ignored by receiver. |
| **Aggregation** | 1 | Set to 1 to indicate that the PPDU in the data portion of the packet contains an A-MPDU. Set to 0 otherwise |
| **STBC** | 2 | Indicates the difference between the number of transmit chains used and the number of spatial stream indicated by the MCS |
| **Advanced Coding** | 1 | 1 - advanced coding<br>0 - BCC. |
| **Short GI** | 1 | Indicate that the short GI is used after the HT training. |
| **Number of HT-LTF** | 2 | Number of HT-LTF. –b'00 – not a sounding frame LTF, b'01 – 2 LTF's, b'10 3 LTF's, b'11 4 LTF's. |
| **CRC** | 8 | CRC of bits 0-23 in HT-SIG1 and bits 0-9 in HT-SIG2 – see section 3.6.3. The first bit to be transmitted is bit C7 as explained in aforementioned section. |
| **Tail Bits** | 6 | Used to terminate the trellis of the convolution coder. Set to 0. |

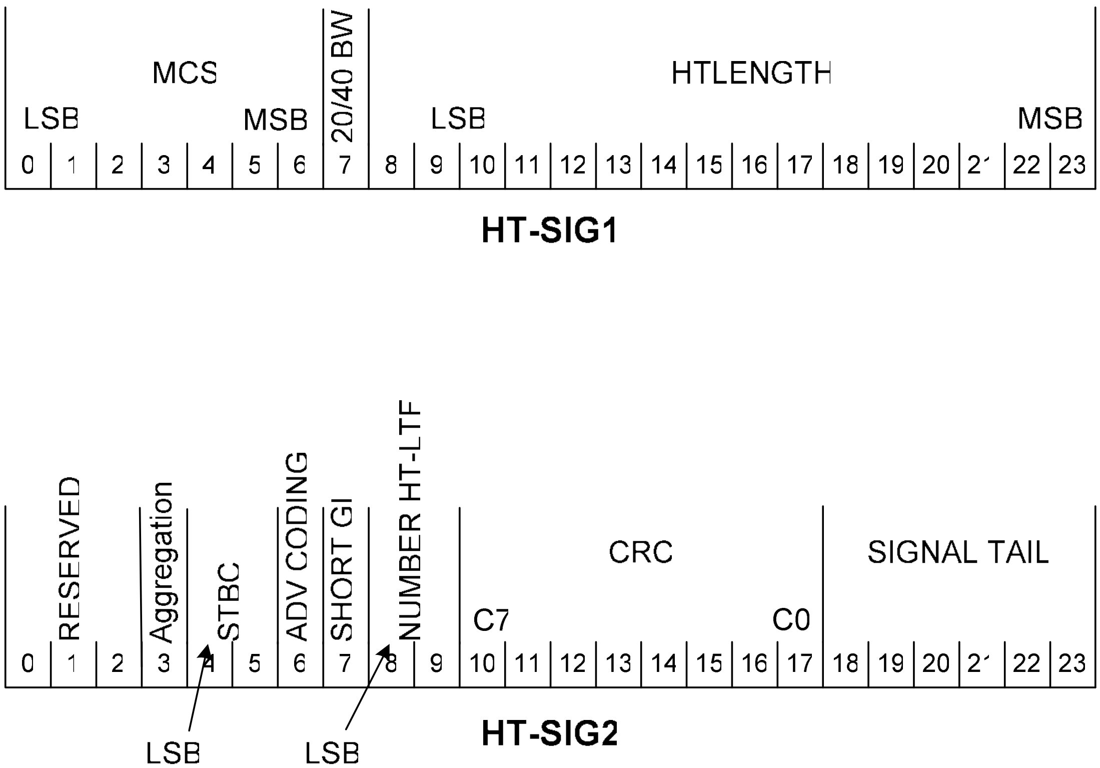


**Figure 5 - HT SIG breakdown to HT-SIG1 and HT-SIG2**

The HT-SIG is composed of two parts $HTSIG_1$ and $HTSIG_2$ each containing 24 bits. All the fields in the HT-SIG are transmitted LSB first.

The HT-SIG parts will be encoded, interleaved, mapped, and have pilots inserted following the steps described in sections 17.3.5.5, 17.3.5.6, 17.3.5.8 of the IEEE802.11a standard [1]. The stream of 96, complex numbers generated by these steps will be divided into two groups of 48 complex numbers: $d_{k,n}, \quad k = 0 \ldots 47, n = 0,1$ see Figure 5. The conversion of these into the time domain signal will be according to the next table:

**Table 9 - Modulation for the High Throughput Signal Field**

| Modulation Method | Conversion to Time Domain signal |
|---|---|
| **20MHz transmission - $i_{TX}$ 'th stream** | $r^{i_{TX}}_{HT-SIG}(t) = \frac{1}{\sqrt{N^{Tones}}} W_{(i_{TX},1)} \sum_{n=0}^{1} w_{T_{SYM}}(t - nT_{SYM}) \cdot \left( j \sum_{k=0}^{47} d_{k,n} \exp\left( j2\pi M(k) \Delta_F \left( t - nT_{SYM} - T_{GI} - T_{CS}^{i_{TX}} \right)\right) + p_{n+z} \sum_{k=N_{SR}}^{N_{SR}} P_k \exp\left( j2\pi k \Delta_F \left( t - nT_{SYM} - T_{GI} - T_{CS}^{i_{TX}} \right)\right)\right)$ |
| **40MHz Tx on several streams – $i_{TX}$'th stream** | $r^{i_{TX}}_{Signal}(t) = \frac{1}{\sqrt{N^{Tones}}} W_{(i_{TX},1)} \sum_{n=0}^{1} w_{T_{SYM}}(t - nT_{SYM}) \cdot \left( j \sum_{k=0}^{47} d_{k,n} \exp\left( j2\pi (M(k)-32) \Delta_F \left( t - nT_{SYM} - T_{GI} - T_{CS}^{i_{TX}} \right)\right) - \sum_{k=0}^{47} d_{k,n} \exp\left( j2\pi (M(k)+32) \Delta_F \left( t - nT_{SYM} - T_{GI} - T_{CS}^{i_{TX}} \right)\right) + p_{n+z} \sum_{k=-N_{SR}}^{N_{SR}} P_k \exp\left( j2\pi (k-32) \Delta_F \left( t - nT_{SYM} - T_{GI} - T_{CS}^{i_{TX}} \right)\right) + jp_{n+z} \sum_{k=-N_{SR}}^{N_{SR}} P_k \exp\left( j2\pi (k+32) \Delta_F \left( t - nT_{SYM} - T_{GI} - T_{CS}^{i_{TX}} \right)\right)\right)$ |

$M(k), p_n, P_k$ are defined in section 17.3.5.9 of the 802.11a standard. [1]

$N^{Tones}$ is equal to the number of tones in the HT-SIG if the packet is a mixed mode packet. If the packet is a GF packet, $N^{Tones}$ is equal to the number of tones in the HT-LTF that precedes the HT-SIG.

The value of *z* is zero in a GF packet and 1 in a mixed mode packets.

$W_{(i_{TX},1)}$ is always 1 in the case of a mixed mode packet and is equal to the $i_{TX}$ 'th element of column 1 of the matrix $P$ defined in section 3.6.5.2. in the case of a green field packet. Values for $T_{CS}^{i_{TX}}$ are taken from Table 5 in the case of MM and from Table 7 in the case of GF packet.

It should be noted that this could be transmitted in the same way as the legacy signal field if the constellation of the data points is rotated by 90º**.**

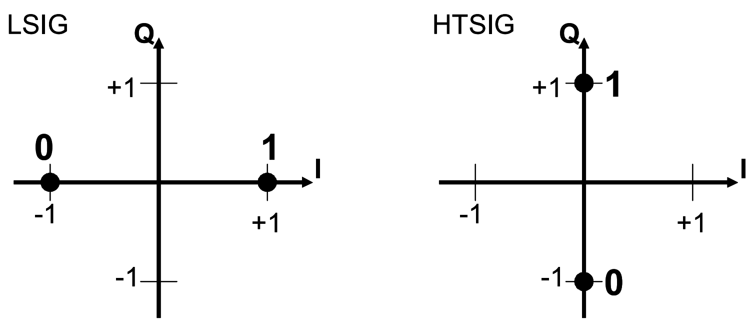


**Figure 6 - constellation for the legacy signal field and the HT signal field**

### 3.6.3 CRC calculation

The CRC will cover bits 0-33 of the HT-SIG. The value of the CRC field will be the ones complement of

$crc(D)=M(D)D^8$ modulo $G(D)$

where the shift register is initialized to all ones and

$M(D)=m_0D^{k-1}+m_1D^{k-2}+\ldots+m_{k-2}D+m_{k-1}$ is the HT-SIG represented as polynomial

$G(D)=D^8+D^2+D+1$ is the CRC generating polynomial, and

$crc(D)=c_0D^7+c_1D^6+\ldots+c_6D+c_7$

The CRC field is transmitted with $c_7$ first

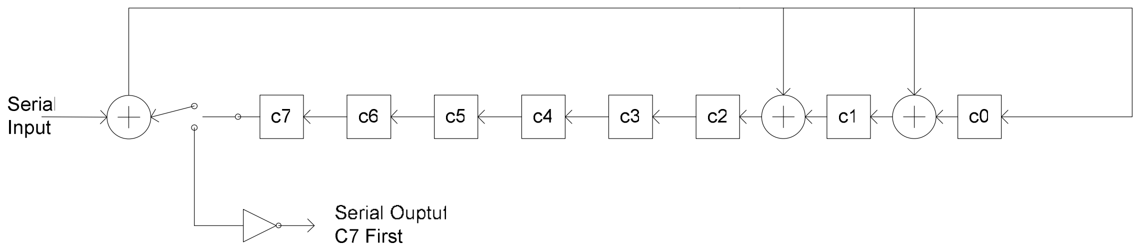


**Figure 7 - HT-SIG CRC calculation**

Figure 7 shows the operation of the CRC. First the shift register is reset to all ones. The bits are then passed through the XOR at the input. When the last bit have entered, the bits are outputted, C7 first, through an inverter.

### 3.6.4 The HT STF training symbol

The purpose of the HT STF training field is to improve AGC training in a multi-transmit and multi-receive system. The duration of the HT-STF is 4μsec; the frequency sequence used to construct the HT-STF in 20MHz transmission is identical to legacy STF; in 40MHz transmission the HT-STF is constructed from the 20MHz version by frequency shifting and duplicating, and rotating the upper sub-carriers by 90°. The frequency sequences are:

For 20MHz:

$$\begin{aligned} HTS_{-28,28} = \sqrt{1/2}\ \{&0,0,0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ &0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0\} \end{aligned}$$

The HT-STF in 40MHz is based on:

$$\begin{aligned} HTS_{-58,58} = \sqrt{1/2}\,\{&0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ &0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0,0,\\ &0,0,0,0,0,0,0,0,0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,+1+j,\\ &0,0,0,0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,+1+j,0,0\} \end{aligned}$$

The time domain representation of the transmission in the $i_{SS}{}^{th}$ spatial stream is:

$$r_{HT-STF}^{i_{SS}}\left(t\right)=w_{\Upsilon_{HT-STF}}\left(t\right)\frac{1}{\sqrt{N_{HT-STF}^{Tones}}}g$$
$$\left(\sum_{k=-N_{SR}}^{0}HTS\left(k\right)\exp\left(j2\pi k\Delta_F\left(t-T_{CS}^{i_{SS}}\right)\right)\right.$$
$$\left.+\Upsilon\sum_{k=1}^{N_{SR}}HTS\left(k\right)\exp\left(j2\pi k\Delta_F\left(t-T_{CS}^{i_{SS}}\right)\right)\right)$$

The value of $\Upsilon$ is 1 for 20MHz and $j$ in 40MHz. The values for $T_{CS}^{i_{TX}}$ are given in Table 7.

### 3.6.5 The HT-LTF long training Field

The HT long training field provides means for the receiver to estimate the channel between each spatial stream transmitter and receive chain; the number of training symbols $N_{LTF}$ is equal or greater than the number of spatial streams and is provided within bits in the HT-SIG (see 3.6.2); the first symbol HT-LTF1 is defined in 3.6.5.1 below; the additional HT-LTF symbols HT-LTF2, HT-LTF3 and HT-LTF4 are defined in 3.6.5.2.

#### 3.6.5.1 First HT training symbol - HT-LTF1

HT-LTF1 is the first part of the HT training sequence. The following sequence will be transmitted in the case of 20MHz transmission:

$$HTLTF1_{-28:28}=\begin{bmatrix}1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,0,\\ 1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,-1,-1\end{bmatrix}$$

Note that this sequence is extension of the legacy LTF where the 4 extra sub-carriers are filled with +1 for negative frequencies and -1 for positive frequencies

In a 40MHz transmission the sequence to be transmitted is based on:

$$
\begin{aligned}
HTLTF1_{-58,58} = \{&1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,\\
&1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,-1,-1,-1,1,0\\
&0,0,-1,1,1,-1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,\\
&1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1\}
\end{aligned}
$$

Note that this sequence is also constructed by extending the legacy LTF in the following way: first of all, the legacy LTF is shifted and duplicated as explained in 3.5.3 for the duplicate legacy mode; then the missing sub-carriers are filled: sub-carriers [-32 -5 -4 -3 -2 2 3 4 5 32] are filled with the values [1 -1 -1 -1 1 -1 1 1 -1 1] respectively.

This sequence is used even if the HT-duplicate mode (MCS 32 in Table 1) mode is used in the data.

The duration of the long training field HT-LTF1 is 4µsec in the case of a mixed mode transmission and 8µsec in the case of green field transmission. In case of multiple spatial streams cyclic shift will be invoked. as specified in Table 7

The HT-LTF1 for the $i_{SS}$*'th* spatial stream is

$$
\begin{aligned}
r_{HT-LTF1}^{i_{SS}}(t) = w_{T_{HT-LTF1}}(t)\sqrt{\frac{1}{N_{HT-LTF}^{Tone}}}\cdot\\
\Bigg(\sum_{k=-N_{SR}}^{0} P_{HTLTF}(i_{SS},1)\,HTLTF1(k)\exp\left(j2\pi k\Delta_F\left(t-2T_{GI}-T_{CS}^{i_{SS}}\right)\right)\\
+\Upsilon\sum_{k=1}^{N_{SR}} P_{HTLTF}(i_{SS},1)\,HTLTF1(k)\exp\left(j2\pi k\Delta_F\left(t-2T_{GI}-T_{CS}^{i_{SS}}\right)\right)\Bigg)
\end{aligned}
$$

Where $\Upsilon$ is 1 for 20MHz and $j$ in 40MHz. The values for $T_{CS}^{i_{SS}}$ are given in Table 7. If more than one spatial stream exists, the sequence transmitted in the $i_{ss}$'th spatial stream is multiplied by $P_{HTLTF}(i_{SS},1)$, the $i_{ss}$'th element from the first column of the matrix $P_{HTLTF}$ defined in section 3.6.5.2 below.

### 3.6.5.2 Additional HT training symbols HT-LTF2, HT-LTF3, HT-LTF4

The subsequent HT training symbols use the same sequences as the first symbol HT-LTF1, however for some of the spatial streams the sequence polarity is inverted. The polarity pattern is defined by a 4x4 matrix $P_{HTLTF}$ below where $P_{HTLTF}(i,n)$ represents polarity of the $i^{th}$ spatial stream in the $n^{th}$ HT training symbol.

$$P_{HTLTF} = \begin{pmatrix} 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 \end{pmatrix}$$

Training symbols 2..4 includes single repetition of the sequence and single GI.

When three spatial streams are used, 4 LTF's shall be transmitted.

The time domain representation of the waveform transmitted in the $i^{th}$ spatial stream during the $n^{th}$ training symbol ($2 \le n \le 4$) is:

$$\begin{aligned} r_{HT-LTF}^{n,i_{SS}}(t) = w_{T_{HT-LTFs}}(t)\sqrt{\frac{1}{N_{HT-LTF}^{Tone}}}\cdot \\ \left(\sum_{k=-N_{SR}}^{0} P_{HTLTF}(i_{SS},n)HTLTF1(k)\exp\left(j2\pi k\Delta_F\left(t-T_{GI}-T_{CS}^{i_{SS}}\right)\right)+\right. \\ \left.\Upsilon\sum_{k=1}^{N_{SR}} P_{HTLTF}(i_{SS},n)HTLTF1(k)\exp\left(j2\pi k\Delta_F\left(t-T_{GI}-T_{CS}^{i_{SS}}\right)\right)\right) \end{aligned}$$

The value of $\Upsilon$ is 1 for 20MHz and $j$ for 40MHz. The values for $T_{CS}^{i_{SS}}$ are given in Table 7.

# 4 The Data Field

The data field will include the service field, the PSDU, the pad bits, and the tail bits.

The number of symbols in the data field is computed using the formula:

$$N_{SYM} = \left\lceil \frac{8\cdot length + 16 + 6\cdot N_{ES}}{N_{DBPS}} \right\rceil$$

The number of “zero” pad bits is thus $N_{SYM}\cdot N_{DBPS} - length\cdot 8 - 16 - 6N_{ES}$.

## *4.1 The service field*

The service field will be used for scrambler initialization. The service field will be composed of 16bits, all set to zero before scrambling. In legacy and legacy duplicate transmission the service field will be the same as in section 17.3.5.1 of the 11a standard. In HT modes, the service field will be composed of 16 zeros bits, scrambled by the scrambler, as defined in the next section.

## 4.2 Scrambler

The data field will be scrambled by the scrambler defined in section 17.3.5.4 of the 802.11a standard [1].

## 4.3 Coding

The data will be encoded using the convolutional encoder defined in section 17.3.5.5 of the 802.11a standard [1]. A single FEC encoder will be used in 20MHz transmission and in 40MHz transmission when $N_{SS}$=1 or $N_{SS}$=2; Two FEC encoders will be used when $N_{SS}$=3 or $N_{SS}$=4.

### 4.3.1 Encoder Parsing operation

If two encoders are used, the data scrambled bits will be divided between the encoders by sending alternating bits to different encoders. The $i^{th}$ bit to the $j^{th}$ encoder, denoted $x_i^{(j)}$, is:

$$x_i^{(j)} = b_{N_{ES} \cdot i + j} \quad ; \quad 0 \le j \le N_{ES} - 1$$

Following the parsing operation, 6 scrambled "zero" bits following the end of the message bits in each FEC input sequence are replaced by unscrambled "zero" bits, as described in 17.3.5.2 of the 802.11a standard [1].

The replaced bits are:

$$x_i^{(j)} \quad : \quad 0 \le j \le N_{ES} - 1 \quad ; \quad \frac{length \cdot 8 + 16}{N_{ES}} \le i \le \frac{length \cdot 8 + 16}{N_{ES}} + 5$$

### 4.3.2 Coding and puncturing

The encoder parser output sequences $\left\{x_i^0\right\}$ and $\left\{x_i^1\right\}$ where applicable will each be encoded by a rate ½ convolutional encoder defined in section 17.3.5.5 of the 802.11a standard [1]. After encoding, the encoded data will be punctured by the method defined in section 17.3.5.6 of the 802.11a standard to achieve the rate selected by the modulation and coding scheme.

In the case that rate 5/6 coding is selected, the puncturing scheme will be as follows:

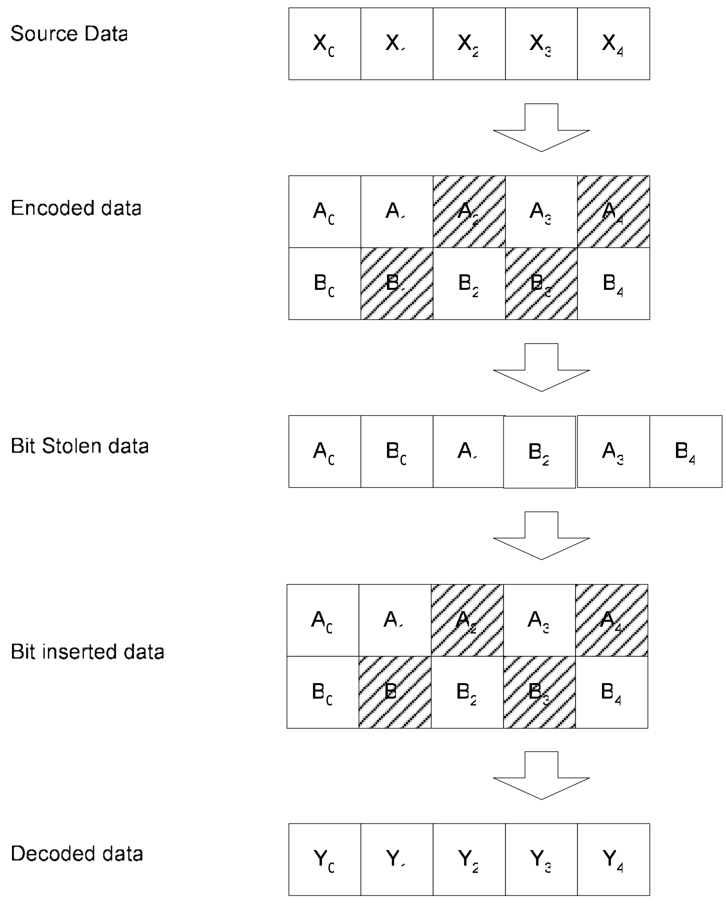


**Figure 8 - Puncturing at rate 5/6**

## 4.4 Data Interleaver

After coding and puncturing, the data bit stream at the output of the FEC encoders are re-arranged into blocks of $N_{CBPSS}$ bits. This operation is referred to as "stream parsing" and is described in 4.4.1 below. Each of these blocks is then interleaved by an interleaver that is a modification of the 802.11a interleaver.

### 4.4.1 Stream Parser

The bits at the output of the encoders are divided into block of *s* bits where

$$s = \max\{1, N_{BPSC}/2\}$$

is the number of bits assigned to a single axis (real or imaginary) in a constellation point.

Consecutive blocks of *s* bits are assigned to different spatial streams (if they exist) in a round robin fashion.

If two encoders are present, the output of each encoder will be used alternately for each round robin cycle, i.e. at the beginning $N_{SS} \cdot s$ bits from the output of first encoder are fed into all spatial streams, then $N_{SS} \cdot s$ bits from the output of second encoder are used and so on.

The $k^{th}$ input to the $i_{SS}{}^{th}$ spatial stream is $y_i^{(j)}$, which is the $i^{th}$ output bit of the $j^{th}$ encoder, where:

$$j = \left\lfloor \frac{k}{s} \right\rfloor \oplus N_{ES}$$

and

$$i = s \cdot i_{SS} + s \cdot N_{SS} \cdot \left\lfloor \frac{k}{N_{ES} \cdot s} \right\rfloor + k \oplus s$$

### 4.4.2 Frequency interleaver

The bits at the output of the stream parser are divided into block of $N_{CBPSS}$, each block is interleaved by an interleaver based on the 802.11a interleaver. This interleaver, which is based on entering the data in rows, and outputting it in columns, has a different number of columns and rows when a 20MHz channel is used and when a 40MHz channel is used. The numbers are described in the table below:

**Table 10 - Number of rows and columns in the interleaver**

| | 20MHz | 40MHz |
|---|---|---|
| $N_{\mathrm{COL}}$ | 13 | 18 |
| $N_{\mathrm{ROW}}$ | $4N_{BPSC}$ | $6N_{BPSC}$ |
| $N_{ROT}$ | 11 | 29 |

After the 11a like operation have been applied, if more than one spatial stream exists, a third operation called frequency rotation is applied to the additional spatial streams. The parameter for the frequency rotation is $N_{ROT}$.

An additional parameter is the spatial stream index $i_{ss}$=0,..,$N_{SS}$-1. The output of the third permutation is a function of the spatial stream index.

The interleaving is defined using three permutations. The first permutation is defined by the rule:

$$i = N_{ROW}\left(k \bmod N_{\mathrm{COL}}\right) + \mathrm{floor}\left(k / N_{\mathrm{COL}}\right) \qquad k = 0,1,\mathrm{K}\ , N_{\mathrm{CBPSS}} - 1$$

The second permutation is defined by the rule

$$j = s \times \text{floor}(i/s) + \left(i + N_{\text{CBPSS}} - \text{floor}(N_{\text{COL}} \times i / N_{\text{CBPSS}})\right) \bmod s \qquad i = 0,1,\ldots,N_{\text{CBPSS}} - 1$$

The value of *s* is determined by the number of code bits per sub carrier:

$$s = \max(N_{\text{BPSC}}/2, 1)$$

If more that one spatial stream exists, a frequency rotation is applied to the output of the second permutation

$$r = \left(j - \left((i_{ss} \times 2) \bmod 3 + 3 \times \text{floor}\left(i_{ss}/3\right)\right) \times N_{ROT} \times N_{BPSC}\right) \bmod N_{CBPSS} \qquad j = 0,1,\ldots,N_{\text{CBPSS}} - 1$$

where $i_{ss} = 0,1,\ldots,N_{ss} - 1$ is the index of the spatial steam on which this interleaver is operating.

The deinterleaver uses the following operations to perform the inverse rotation. We denote by *r* the index of the bit in the received block (per spatial stream). The first permutation reverses the third (frequency rotation) permutation of the interleaver

$$j = \left(r + \left((i_{ss} \times 2) \bmod 3 + 3 \times \text{floor}\left(i_{ss}/3\right)\right) \times N_{ROT} \times N_{BPSC}\right) \bmod N_{CBPSS} \qquad r = 0,1,\ldots,N_{\text{CBPSS}} - 1$$

The second permutation reverses the second permutation in the interleaver.

$$i = s \times \text{floor}(j/s) + \left(j + \text{floor}(N_{COL} \times j / N_{\text{CBPSS}})\right) \bmod s \qquad j = 0,1,\ldots,N_{\text{CBPSS}} - 1$$

$s$ is defined as above.

The third permutation reversed the first permutation of the interleaver:

$$k = N_{COL} \times i - (N_{CBPSS} - 1) \times \text{floor}(i / N_{ROW}) \qquad i = 0,1,\ldots,N_{CBPSS} - 1$$

## *4.5 QAM Mapping and Spatial Mapping*

The mapping between bits and complex constellation points follows exactly the rules defined in section 17.3.5.7 of the 802.11a standard [1]. The streams of complex numbers should be denoted as $d_{k,l,n}$, $k = 0,1,\ldots,N_{\text{DS}} - 1$, $l = 0,1,\ldots,N_{\text{SS}} - 1$, $n = 0,1,\ldots,N_{\text{SYM}} - 1$. The transmitter may choose to rotate the transmitted vector $\mathbf{d}_{k,n} = \left[d_{k,1,n}, d_{k,2,n}, \ldots, d_{k,N_{SS},n}\right]^T$ by multiplying by a matrix $Q$ to produce $\Delta_{k,n} = \left[\delta_{k,1,n}, \delta_{k,2,n}, \ldots, \delta_{k,N_{TX},n}\right]^T$. The same type of rotation shall be applied to the pilots of vector for each pilot frequency in all spatial streams. This multiplication should be transparent to the receiver as long as the same operation is applied to the HT-STF and HT-LTF fields in a Mixed mode packet and to all the preceding fields in a Green Field Packet.

## 4.6 Pilot Subcarriers

4 pilot tones are inserted;

in the case of 20MHz, pilot signals will be inserted in the same sub-carriers used in 802.11a standard, i.e. in sub-carriers -21, -7, 7 and 21; the pilot sequence for the $n^{\mathrm{th}}$ symbols and $i_{SS}{}^{th}$ spatial stream is defined as follows:

$$\begin{aligned} P_{(i_{SS},n)}^{-28,28} = \{&0,0,0,0,0,0,0,\Psi_{i_{SS},n\oplus 4}^{(n_{SS})},0,0,0,0,0,0,0,0,0,0,0,0,0,\Psi_{i_{SS},(n+1)\oplus 4}^{(n_{SS})},0,0,0,0,0,0,0, \\ &0,0,0,0,0,0,\Psi_{i_{SS},(n+2)\oplus 4}^{(n_{SS})},0,0,0,0,0,0,0,0,0,0,0,0,0,\Psi_{i_{SS},(n+3)\oplus 4}^{(n_{SS})},0,0,0,0,0,0,0\}\end{aligned} , \quad (21)$$

In the case of 40MHz transmission pilot signals will be inserted in sub-carriers -53, -25, -11, 11, 25, 53; the pilot sequence for the $n^{\mathrm{th}}$ symbols and $i_{SS}{}^{\mathrm{th}}$ spatial stream is defined as follows:

$$\begin{aligned} P_{i_{SS}}^{(-58..58,n)} = \{&0,0,0,0,0,\Psi_{i_{SS},n\oplus 6}^{(n_{SS})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0, \\ &\Psi_{i_{SS},(n+1)\oplus 6}^{(n_{SS})},0,0,0,0,0,0,0,0,0,0,0,0,0,\Psi_{i_{SS},(n+2)\oplus 6}^{(n_{SS})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0, \\ &0,\Psi_{i_{SS},(n+3)\oplus 6}^{(n_{SS})},0,0,0,0,0,0,0,0,0,0,0,0,0,\Psi_{i_{SS},(n+4)\oplus 6}^{(n_{SS})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0, \\ &0,0,0,0,0,0,0,0,0,\Psi_{i_{SS},(n+5)\oplus 6}^{(n_{SS})},0,0,0,0,0\}\end{aligned}$$

, (22)

Where $n\oplus 4$ indicates symbol number modulo 4;

Note that for each spatial stream there is a different pilot pattern and the pilot patterns are cyclically rotated over symbols.

The basic patterns are also different according to the total number of spatial streams for the packet.

The patterns $\Psi_{i_{SS},n}^{(n_{SS})}$ are defined in the following tables The first table (Table 11) defines the values for 20MHz transmission and the second table (Table 12) defines the values for 40MHz transmission

Table 11 - pilot values for 20MHz transmission

| Nss | iss | $\Psi_{i_{SS},0}^{(n_{SS})}$ | $\Psi_{i_{SS},1}^{(n_{SS})}$ | $\Psi_{i_{SS},2}^{(n_{SS})}$ | $\Psi_{i_{SS},3}^{(n_{SS})}$ |
|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 | -1 |
| 2 | 0 | 1 | 1 | -1 | -1 |
| 2 | 1 | 1 | -1 | -1 | 1 |
| 3 | 0 | 1 | 1 | -1 | -1 |
| 3 | 1 | 1 | -1 | 1 | -1 |
| 3 | 2 | -1 | 1 | 1 | -1 |
| 4 | 0 | 1 | 1 | 1 | -1 |
| 4 | 1 | 1 | 1 | -1 | 1 |
| 4 | 2 | 1 | -1 | 1 | 1 |
| 4 | 3 | -1 | 1 | 1 | 1 |

Table 12 - Pilots values for 40MHz transmission

| Nss | iss | $\Psi_{i_{SS},0}^{(n_{SS})}$ | $\Psi_{i_{SS},1}^{(n_{SS})}$ | $\Psi_{i_{SS},2}^{(n_{SS})}$ | $\Psi_{i_{SS},3}^{(n_{SS})}$ | $\Psi_{i_{SS},4}^{(n_{SS})}$ | $\Psi_{i_{SS},5}^{(n_{SS})}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 | -1 | -1 | 1 |
| 2 | 0 | 1 | 1 | -1 | -1 | -1 | -1 |
| 2 | 1 | 1 | 1 | 1 | -1 | 1 | 1 |
| 3 | 0 | 1 | 1 | -1 | -1 | -1 | -1 |
| 3 | 1 | 1 | 1 | 1 | -1 | 1 | 1 |
| 3 | 2 | 1 | -1 | 1 | -1 | -1 | 1 |
| 4 | 0 | 1 | 1 | -1 | -1 | -1 | -1 |
| 4 | 1 | 1 | 1 | 1 | -1 | 1 | 1 |
| 4 | 2 | 1 | -1 | 1 | -1 | -1 | 1 |
| 4 | 3 | -1 | 1 | 1 | 1 | -1 | 1 |

In the duplicate mode there will be 8 pilots in the bins -53, -39, -25, -11, 11, 25, 39, 53.

The pilot values are the same as the values on bins -21, -7, 7, 21 in the 20MHz mode, repeated on the negative and positive bins and rotated in the upper bins.

## 4.7 OFDM Modulation

The time domain signal will be composed from the stream of complex numbers

$$\delta_{k,l,n},\ k = 0,1,\ldots,N_{\mathrm{DS}}-1,\ i_{SS} = 0,1,\ldots,N_{\mathrm{SS}}-1,\ n = 0,1,\ldots,N_{\mathrm{SYM}}-1$$

and from the pilot signals. In the case of 40MHz transmission the upper sub-carriers are 90° rotated.

### 4.7.1 20MHz HT transmission

The signal from the $i_{ss}$ spatial stream is:

$$r_{HT-DATA}^{i_{SS}}(t) = \frac{1}{\sqrt{N_{HT-DATA}^{Tones}}} \sum_{n=0}^{N_{SYM}-1} w_{T_{SYM}}(t - nT_{SYM}) \left( \sum_{k=0}^{N_{SD}-1} \delta_{k,i_{SS},n} \exp\Big( j2\pi M(k)\Delta_F \left(t - T_{GI} - nT_{SYM} - T_{CS}^{i_{SS}}\right)\Big) + p_{n+z} \sum_{k=-N_{SR}}^{N_{SR}} P_{i_{SS}}^{(k,n)} \exp( j2\pi k\Delta_F \left(t - T_{GI} - nT_{SYM} - T_{CS}^{i_{SS}}\right) \right)$$

*z* is 3 in a mixed mode packet and 2 in a Green Field Packet. $p_n$ is defined in section 17.3.5.9 of the 802.11a standard.

M(k) in the 20MHz case is

$$M(k) = \begin{cases} k-28 & 0 \le k \le 6 \\ k-27 & 7 \le k \le 19 \\ k-26 & 20 \le k \le 25 \\ k-25 & 26 \le k \le 31 \\ k-24 & 32 \le k \le 44 \\ k-23 & 45 \le k \le 51 \end{cases}, \quad (23)$$

$P_{i_{SS}}^{(k,n)}$ are defined in equation (21) above.

### 4.7.2 Transmission in 40MHz HT mode

In the case of 40MHz, the signal from the $i_{ss}$ th spatial stream is:

$$r_{HT-DATA}^{i_{SS}}(t) = \frac{1}{\sqrt{N_{HT-DATA}^{Tones}}} \sum_{n=0}^{N_{SYM}-1} w_{T_{SYM}}(t - nT_{SYM}) \cdot$$

$$\left( \sum_{k=0}^{N_{SD}/2-1} \delta_{k,i_{SS},n} \exp\left( j2\pi M(k)\Delta_F \left( t - T_{GI} - nT_{SYM} - T_{CS}^{i_{SS}} \right) \right) + \right.$$

$$p_{n+z} \sum_{k=-N_{SR}}^{0} P_{i_{SS}}^{(k,n)} \exp\left( j2\pi k\Delta_F \left( t - T_{GI} - nT_{SYM} - T_{CS}^{i_{SS}} \right) \right) +$$

$$j \sum_{k=N_{SD}/2}^{N_{SD}-1} \delta_{k,i_{SS},n} \exp\left( j2\pi M(k)\Delta_F \left( t - T_{GI} - nT_{SYM} - T_{CS}^{i_{SS}} \right) \right) +$$

$$\left. jp_{n+z} \sum_{k=1}^{N_{SR}} P_{i_{SS}}^{(k,n)} \exp\left( j2\pi k\Delta_F \left( t - T_{GI} - nT_{SYM} - T_{CS}^{i_{SS}} \right) \right) \right)$$

Where $M(k)$ is given below:

$$M(k) = \begin{Bmatrix} k-58 & 0 \le k \le 4 \\ k-57 & 5 \le k \le 31 \\ k-56 & 32 \le k \le 44 \\ k-55 & 45 \le k \le 53 \\ k-52 & 54 \le k \le 62 \\ k-51 & 63 \le k \le 75 \\ k-50 & 76 \le k \le 102 \\ k-49 & 103 \le k \le 107 \end{Bmatrix}$$

- The pilot sequence $P_{i_{SS}}^{(k,n)}$ is defined in equation (22) for 40MHz.

It should be noted that the 90º rotation that is applied to the upper part of the 40MHz channel is applied in the same fashion as for the HT-STF, HT-LTF and HT-SIG. The rotation applies to both pilots and the data in upper part of the 40MHz channel.

### 4.7.3 Transmission in HT duplicate mode.

If duplicate mode transmission is used the following formula is used for the signal (note that duplicate mode is not used with more than one spatial stream and only with BPSK coding and rate ½ coding).

$$r_{HT-DATA}(t) = \frac{1}{\sqrt{N_{Duplicate}^{Tones}}} \sum_{n=0}^{N_{SYM}-1} w_{T_{SYM}}(t - nT_{SYM})$$
$$\Bigg( \sum_{k=0}^{47} d_{k,n} \exp\Big(j2\pi\big(M(k)-32\big)\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big) +$$
$$j\sum_{k=0}^{47} d_k \exp\Big(j2\pi\big(M(k)+32\big)\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big) +$$
$$p_{n+z} \sum_{k=-N_{SR}}^{N_{SR}} P_k \exp\Big(j2\pi(k-32)\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big) +$$
$$jp_{n+z} \sum_{k=-N_{SR}}^{N_{SR}} P_k \exp\Big(j2\pi(k+32)\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big)\Bigg)$$

*z* is defined in section 4.7.1. $M(k)$, $P_k$ is defined in section 17.3.5.9 of the 802.11a standard [1]. $N_{SR}$ has the value defined for legacy 20MHz transmission.

### 4.7.4 Transmission with a short guard interval

If a short guard interval is used, the same formula for the formation of the signal is used with the exception of $T_{GI}$ replaced by $T_{GIS}$ and $T_{SYM}$ is replaces with $T_{SYMS}$.

## *4.8 Legacy duplicate transmission*

Legacy duplicate transmission will be used to transmit to legacy 802.11a devices in the upper and lower channels of the 40MHz channel. The L-STF, L-LTF and L-SIG will be transmitted in the same way they are transmitted in the HT 40MHz transmission. There will be no HT-SIG, HT-STF or HT-LTF. Data transmission will be according to the next formula:

$$r_{LEG-DUP}(t - nT_{SYM}) = \frac{1}{\sqrt{N_{Duplicate}^{Tones}}} w_{TSYM}(t - nT_{SYM})$$
$$\Bigg( \sum_{k=0}^{47} d_{k,n} \exp\Big(j2\pi\big(M(k)-32\big)(\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big) +$$
$$j\sum_{k=0}^{47} d_k \exp\Big(j2\pi\big(M(k)+32\big)(\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big) +$$
$$p_n \sum_{k=-N_{SR}}^{N_{SR}} P_k \exp\Big(j2\pi(k-32)\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big) +$$
$$jp_n \sum_{k=-N_{SR}}^{N_{SR}} P_k \exp\Big(j2\pi(k+32)\Delta_F\left(t - nT_{SYM} - T_{GI}\right)\Big)\Bigg)$$

$P_k, M(k)$ are the ones defined at 11a standard at section 17.3.5.9.

# 5 Channel Numbering and Channelization

The device will operate both in the 5GHz band and 2.4GHz band. When using 20MHz channels it will use the same channels as in the 11a/11g. When using the 40MHz channel, it can operate in the channels defined in sections 5.1 and 5.2.

## 5.1 Channel Allocation in the 5 GHz Band

Channel center frequencies are defined at every integral multiple of 5 MHz above 5 GHz (for 20 MHz channels). The relationship between center frequency and channel number is given by the following equation:

Channel center frequency = 5000 + 5 · $n_{ch}$ (MHz), Where $n_{ch}$ = 0,1,…200.

The 40MHz channels in 5GHz are specified by two fields: ($N_{control\_ch}$, extension). The first field represents the channel number of the control channel, and the second one indicates whether the extension channel is above or below the control channel (1 -> above, -1 -> below). For example, a 40MHz channel consisting of channel 36 and 40 where channel 36 is the control channel shall be specified as (36,1).

The following table lists the valid settings of these two fields in the 5 GHz band.

**Table 13 - 40MHz channel allocation in the 5GHz band**

| Regulatory domain | Band (GHZ) | $N_{control\_ch}$ | | Center Frequency (MHz) |
|---|---|---|---|---|
| | | Extension=1 | Extension=-1 | |
| United States | U-NII lower band (5.15-5.25) | 36<br>44 | 40<br>48 | 5190<br>5230 |
| United States | U-NII middle band (5.25-5.35) | 52<br>60 | 56<br>64 | 5270<br>5310 |
| Europe | ETSI (5.5-5.7) | 100<br>108<br>116<br>124<br>132 | 104<br>112<br>120<br>128<br>136 | 5510<br>5550<br>5590<br>5630<br>5670 |
| United States | U-NII upper band (5.725-5.825) | 149<br>157 | 153<br>161 | 5755<br>5795 |

### *5.2 Channel Allocation in the 2.4 GHz Band*

Channel center frequencies are defined at every integral multiple of 5 MHz in the 2.4 GHz band. The relationship between center frequency and channel number is given by the following equation: Channel center frequency = 2407 + 5 · $n_{ch}$ (MHz), Where $n_{ch}$ = 1,2,…11.

The 40MHz channels in 2.4GHz are specified in the same way as in 5GHz: ($N_{control\_ch}$, extension). The first field represents the channel number of the control channel, and the second one indicates whether the extension channel is above or below the control channel (1 -> above, -1 -> below). For example, a 40MHz channel consisting of channel 2 and channel 6 where channel 6 is the control channel shall be specified as (6, -1).

The following table lists the valid settings of these two fields in the 2.4 GHz band.

**Table 14 - 40Mhz channel alocation in the 2.4GHz and**

| Regulatory domain | $N_{control\_ch}$ | | Center Frequency (MHz) |
|---|---|---|---|
| | Extension=1 | Extension=-1 | |
| United States<br>Canada<br>Europe | 1 | 5 | 2422 |
| | 2 | 6 | 2427 |
| | 3 | 7 | 2432 |
| | 4 | 8 | 2437 |
| | 5 | 9 | 2442 |
| | 6 | 10 | 2447 |
| | 7 | 11 | 2452 |

# 6 Transmit Spectrum Mask

When using a 20MHz the transmitted spectrum shall have a 0 dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 18 MHz, –20 dBr at 11 MHz frequency offset, –28 dBr at 20 MHz frequency offset and –45 dBr at 30 MHz frequency offset and above. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in Figure 9. The measurements shall be made using a 100 kHz resolution bandwidth and a 30 kHz video bandwidth.

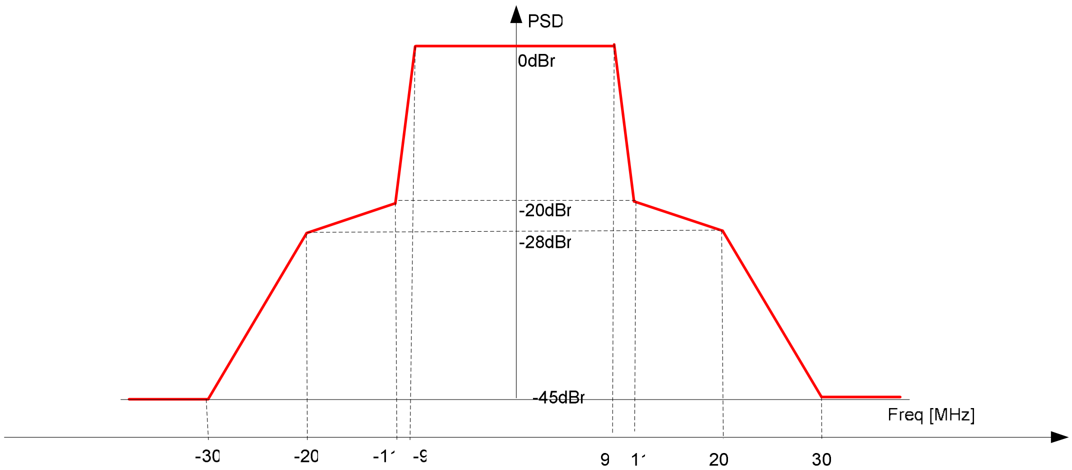


**Figure 9 - Transmit spectral mask for 20MHz Transmission**

When using the 40MHz channel the transmitted spectrum shall have a 0 dBr bandwidth not exceeding 38 MHz, –20 dBr at 21 MHz frequency offset, -28 dBr at 40 MHz offset and –45 dBr at 60 MHz frequency offset and above. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in Figure 10 - Transmit spectral mask for a 40MHz channel.

Transmit spectral mask for 20MHz transmission in upper and lower 20Mhz channels of a 40MHz is the same mask that is used for the 40MHz channel.

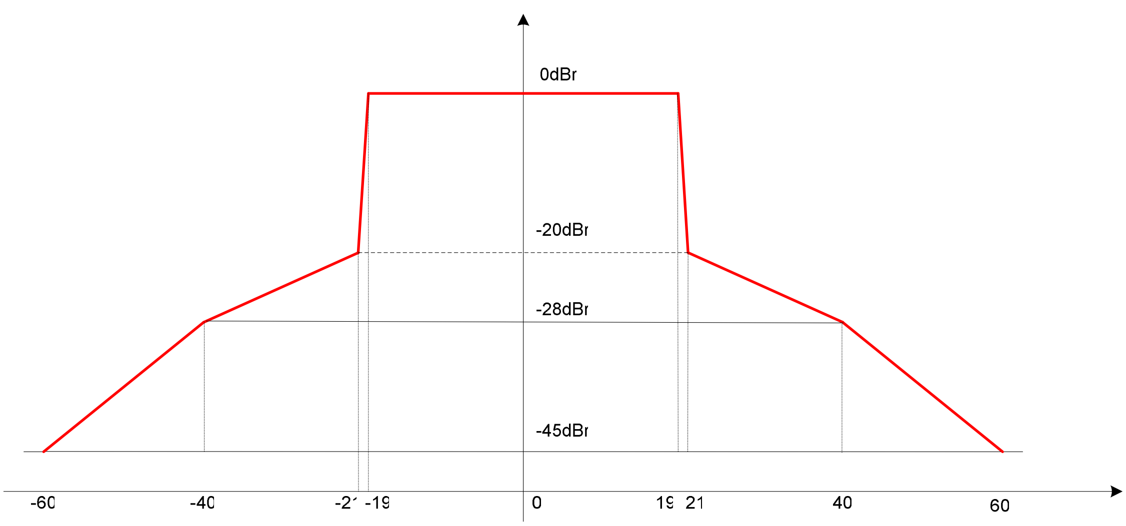


**Figure 10 - Transmit spectral mask for a 40MHz channel**

## 6.1 Spectral Flatness

In a 20MHz channel and in corresponding 20MHz transmission in a 40MHz channel, the average energy of the constellations in each of the spectral lines –16.. –1 and +1.. +16 will deviate no more than ± 2 dB from their average energy.

The average energy of the constellations in each of the spectral lines –28.. –17 and +17.. +28 will deviate no more than +2/–4 dB from the average energy of spectral lines –16.. –1 and +1.. +16.
In a 40 MHz transmission the average energy of the constellations in each of the spectral lines –42.. –2 and +2.. +42 will deviate no more than ± 2 dB from their average energy. The average energy of the constellations in each of the spectral lines –43.. –58 and +43.. +58 will deviate no more than +2/–4 dB from the average energy of spectral lines –42.. –2 and +2.. +42.
The data for this test will be based on the channel estimate step.

## *6.2 Transmit Power*

The maximum allowable output power of the device is the same as in legacy 802.11a or 802.11g transmitter. If more than one transmit chain is used, the total power in all transmit chains shall be equal to the total power possible for a legacy 802.11a/g transmitter. If a 40MHz channel is used, the total transmitted power in the 40MHz bandwidth shall be equal to the total transmitted power allowed for a legacy 802.11a transmitter in a 20MHz channel.

# 7 Frame alignment

## *7.1 Frame alignment*

The receiver will assert PHY-CCA.indicate(idle).(12.3.5.10) at the 4µsec boundary following the reception of the last symbol of the packet. The transmitter will assert PHY-TXEND.confirm (12.3.5.7) at the trailing boundary of the last symbol of the packet on the air.

## *7.2 Reduced Interframe Space (RIFS)*

The transmitter shall be able to transmit a packet 2usec after PHY-TXEND.confirm is asserted. The receiver shall be able to decode a packet if it starts 2µsec after PHY-RXEND.indication is asserted for the previous packet.

# 8 Optional Features

This section assembles the main features that are optional

- Green Field mode is optional at both receive and transmit
- Short GI is optional at both receive and transmit
- STBC is optional at both receive and transmit
- Beam Forming is optional at both receive and transmit
- 40MHz Channel processing is optional at both transmit and receive.

# 9 References

[1] IEEE Std 802.11a-1999 – Part 11 Wireless Land Medium Access control (MAC) and Physical Layer (PHY) specification: High Speed Physical Layer in the 5 GHZ Band.

[2] IEEE Std 802.11b-1999 – Part 11 Wireless Land Medium Access control (MAC) and Physical Layer (PHY) specification: Higher-Speed Physical Layer Extension in the 2.4 GHz Band.

[3] IEEE Std 802.11g-1999 – Part 11 Wireless Land Medium Access control (MAC) and Physical Layer (PHY) specification: Amendment 4: Further Higher Data Rate Extension in the 2.4 GHz Band