FullMax ACI Performance

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1. Contents

2. Introduction

This document describes the FullMax system characteristics and ACI performance. The document shows that when operated in the 700 MHz “B” Guardbands (between 775 MHz to 776 MHz or 805 MHz to 806 Mhz), FullMax interference to the adjacent public safety band is negligible.

3. FullMax Overview

3.1 General

FullMAX is a cellular broadband wireless system designed to provide private, wide-area, mobile and fixed data communication services for electrical utilities over their own tower infrastructure and licensed frequencies.

Full Spectrum offers the electrical utilities multiple Sub 1 GHz licensed frequency alternatives through its arrangements with existing frequency holders.

FullMax air interface protocol is based on the IEEE802.16e-2005 standard with extensions needed to operate in narrow channels[1]. FullMax operating frequency is configurable anywhere between 40 MHz and 958 MHz.

The main FullMax characteristics are described in table 3.1-1:

[1] The use of non standard narrow channels is required to enable operation in many sub 1 GHz bands.

Parameter	**Value**	**Comments**
Duplexing mode	*TDD*	
Type of spectrum	*Paired or unpaired*	
Frequency range	*40 MHz – 958 MHz*	
Channel bandwidth	*200 KHz to 5 MHz*	
BS TX power	*6 dBm to 36 dBm*	
FS TX power	*-43 dBm to +36 dBm*	The FS TX power is adjusted automatically by the BS not to exceed the minimum power needed
Air Interface protocol	*Based on ieee802.16e-2005*	
Modulation	*OFDMA*	
# of subcarriers	*128, 512*	
Permutation scheme	*PUSC in DL and in UL*	
Individual subcarrier modulation and coding	*QPSK ½ , QPSK ¾ , 16QAM ½ ,16QAM ¾ , 64QAM ½ , 64QAM 2/3 , 64QAM ¾*	The modulation and coding is determined automatically per user in DL and UL (adaptive modulation).

Table 3.1-1: FullMax main parameters

4. FullMax operation in the 700 MHz “B” Guardband

4.1 FullMax channel configuration

FullMax will employ either a 500 KHz or 1 MHz wide channels. Due to FullMax configurable center frequency and channel size, the 700 MHz “B” guardband offers two 1 MHz wide channels with center frequencies at 775.500 MHz and at 805.500 MHz and four 500 KHz wide channels with center frequencies at 775.250, 775.750, 805.250 and 805.750 MHz Moreover, FullMax center frequency can be programmed to use other center frequencies (center frequency resolution of 10 KHz) and narrower channel size.

The FullMax air interface protocol parameters for a 500 KHz and for a 1 MHz wide channel configuration is described in tables 4.1-1, 4.1-2, 4.1-3 & 4.1-4 below:

Parameter	**Value**	**Comments**
FFT Size	*128*	
Sampling Frequency, F_s	*floor (8/7 x (500 * 1000)/8000) x 8000 = 568 KHz*	
Subcarrier Spacing, Δf	$Fs/N_{fft} = 568/128 = 4.4375$ *KHz*	
Useful Symbol Time, T_b	$1/\Delta f = 1/8.875$ *KHz = 225.35 µsec*	
Cyclic Prefix, T_g	$T_b/8 = 225.35/8 = 28.17$ *µsec*	
OFDMA Symbol time T_s	$T_g + T_b = 225.35 + 28.17 = 253.52$ *µsec*	
TTG + RTG	*214.53 µsec*	TTG, RTG, SSTTG & SSRTG are configurable. TTG > 214 *µsec* is needed to support a range of upto 20 miles.
Total Frame duration	*253.52 x 47 + 214.53 = 12.13 msec (47 symbol frame)* *253.52 x 95 + 214.53 = 24.30 msec (95 symbol frame)* *253.52 x 141+ 214.53 = 35.75 msec (141 symbol frame)*	The number of symbols is configurable.
Number of frames/sec	*1000/12.13 = 82 frames (47 symbol frame)* *1000/24.30 = 41 frames (95 symbol frame)* *1000/35.75 =27 frames (141 symbol frame)*	

Table 4.1-1: FullMax Parameters for a 500 KHz wide channel

Parameter	Value	Comments
FFT Size	*128*	
Sampling Frequency, F_s	*floor (8/7 x (1000 * 1000)/8000) x 8000 = 1.136 MHz*	
Subcarrier Spacing, Δf	Fs/N_{fft} *= 1,136/128 = 8.875 KHz*	
Useful Symbol Time, T_b	*1/Δf = 1/8.875 KHz = 112.68 μsec*	
Cyclic Prefix, T_g	$T_b/8$ *= 112.68/8 = 14.08 μsec*	
OFDMA Symbol time T_s	$T_g + T_b$ *= 112.68 + 14.08 = 126.76 μsec*	
TTG + RTG	*214.53 μsec*	TTG, RTG, SSTTG & SSRTG are configurable. TTG > 214 *μsec* is needed to support a range of upto 20 miles.
Total Frame duration	*126.76 x 47 + 214.53 = 6.17 msec (47 symbol frame)* *126.76 x 95 + 214.53 = 12.26 msec (95 symbol frame)* *126.76 x 141+ 214.53 = 18.09 msec (141 symbol frame)*	The number of symbols is configurable.
Number of frames/sec	*1000/6.17=162 Frames (47 symbol frame)* *1000/12.26 = 81 frames (95 symbol frame)* *1000/18.09 = 55 frames (141 symbol frame)*	

Table 4.1-2: FullMax Parameters for a 1 MHz wide channel

Table 445—128-FFT OFDMA downlink carrier allocations—PUSC

Parameter	Value	Comments
Number of DC Subcarriers	1	Index 64
Number of Guard Subcarriers, Left	22	—
Number of Guard Subcarriers, Right	21	—
Number of Used Subcarriers (N_{used}) including all possible allocated pilots and the DC subcarrier.	85	Number of all subcarriers used within a symbol.
Renumbering sequence	2, 3, 1, 5, 0, 4	Used to renumber clusters before allocation to subchannels.
Number of carriers per cluster	14	—
Number of clusters	6	—
Number of data subcarriers in each symbol per subchannel	24	—
Number of subchannels	3	—

Table 4.1-3: FullMax Parameters for 128 FFT and PUSC in DL

Table 458—128-FFT OFDMA UL subcarrier allocations for PUSC

Parameter	Value	Notes
Number of DC Subcarriers	1	Index 64
N_{used}	97	Number of all subcarriers used within a symbol
Guard Subcarriers: left, right	16, 15	—
PermutationBase0	2, 0, 3, 1	Used to allocate tiles to subchannels
$N_{subchannels}$	4	—
N_{tiles}	24	—
Number of subcarriers per tile	4	Number of all subcarriers used within tile
Tiles per subchannel	6	—

Table 4.1-4: FullMax Parameters for 128 FFT and PUSC in UL

4.2 FullMax Base TX power

4.2.1 Base Station Average TX power

1. The Base Station average power is determined by the peak power and the TDD DL: UL ratio. The BS peak power is 36 dBm. The DL: UL ratio is configurable and is typically reverse asymmetrical when carrying SCADA traffic. A typical DL: UL ratio is 29:66 and the average power in this case is only 30.85 dBm.

2. Assuming a 13 dBi sector antenna, the BS average power is 43.85 dBi

3. On the average, the TX power is distributed uniformly between 84 active subcarriers across the 1 MHz wide channel (see table 4.1-3 above). The average power per subcarrier is 43.85 – 19.24 = 24.61 dBm EIRP.

4.2.2 Fixed Station Average TX Power

1. The Fixed Station (FS) average TX power is determined by the peak power and the TX duty cycle in the UL. The FS peak power is 36 dBm. A typical operating scenario will have the following parameters:
   a. UL rate per FS: 50 kb/s
   b. Channel size 1 MHz wide
   c. Modulation and coding: 16QAM ¾
   d. User data throughput in the UL: 1 Mb/s
   e. Percentage of TX time per FS: 5%

2. The average FS TX power is therefore 4 watts/ 20 = 23 dBm.

3. Assuming a 13 dBi antenna gain, the average FS TX power is 36 dBm EIRP.

4. On the average, the TX power is distributed uniformly between 96 active subcarriers across the 1 MHz wide channel (see table 4.1-4). The average power per subcarrier is 36 – 19.82 = 16.18 dBm EIRP.

4.2.3 FullMax power leakage into the public safety band

1. FullMax BS and FS TX signal is filtered through a programmable 720 tap FIR filter. The overall power leakage into the public safety band depends on the configuration of this filter and on the symbol rate[2]. The estimate below is based on the tap coefficients designed for operation in the AMTS and IVDS bands as per FCC Part 80 (the FCC Part 80.211 Spectral mask is shown in fig. 4.2-1 below).

[2] FullMax symbol rate is programmable.

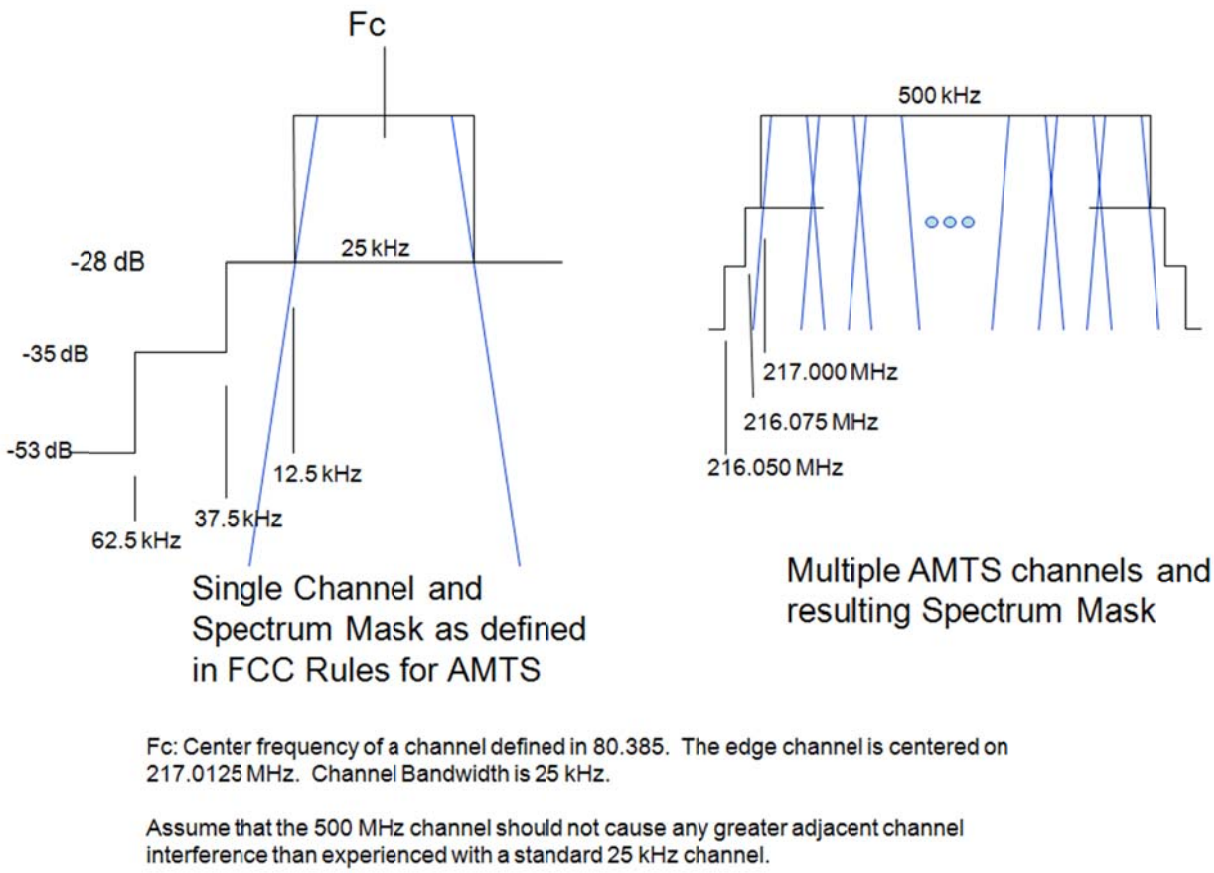

Fig. 4.2-1: Spectral mask as per FCC Part 80.211

2. FullMax BS/FS max TX power leakage estimate for a 500 KHz wide channel with 568 ksymbol/sec:
    a. FIR filter attenuation at the edge of the channel > 28 dB
    b. Total DL power leakage to the public safety band at the BS < 43.85 dBm – 28 dB = 15.85 dBm EIRP.
    c. Total UL power leakage to the public safety band at the FS < 36 dBm – 28 dB = 8 dBm EIRP.
3. The ACI performance can be reduced by reducing the symbol rate. For example, if the symbol rate is reduced by 50 KHz (i.e., a symbol rate of 518 ksymbol/sec) the DL and UL leakage are bounded by:
    a. FIR filter attenuation at the edge of the channel > 53 dB
    b. Total DL power leakage to the public safety band < 43.85 dBm –53 dB = - 9.15 dBm EIRP.
    c. Total UL power leakage to the public safety band < 36 dBm – 28 dB = - 17 dBm EIRP.

4.3 FullMax sectorization and its impact on ACI

In conventional frequency planning, a number of distinct carrier frequencies are reused in different cells and sectors for a multicell deployment with an acceptable level of self interference. With FullMax, frequency planning can be done with subchannels instead of channels. 128 FFT has 3 downlink subchannels and 4 uplink subchannels.

In DL PUSC, each subchannel includes 24 distinct data transport subcarriers and 4 pilot carrier for channel estimation. The data transport subcarrier are selected across the channel (i.e., they are not adjacent to each other) for frequency diversity.

In UL PUSC, each subchannel includes 24 distinct data and pilot subcarriers.

In the DL, each sector can be allocated one subchannels or all subchannels while in the UL, each sector can be allocated 1 to 4 of subchannels as long as the total number of sub channels does not exceed 4.

Figure 4.2-1 below illustrates 3 adjacent cells with a single sector in each of the cells. A single subchannel is used in each of the cells for DL and UL.

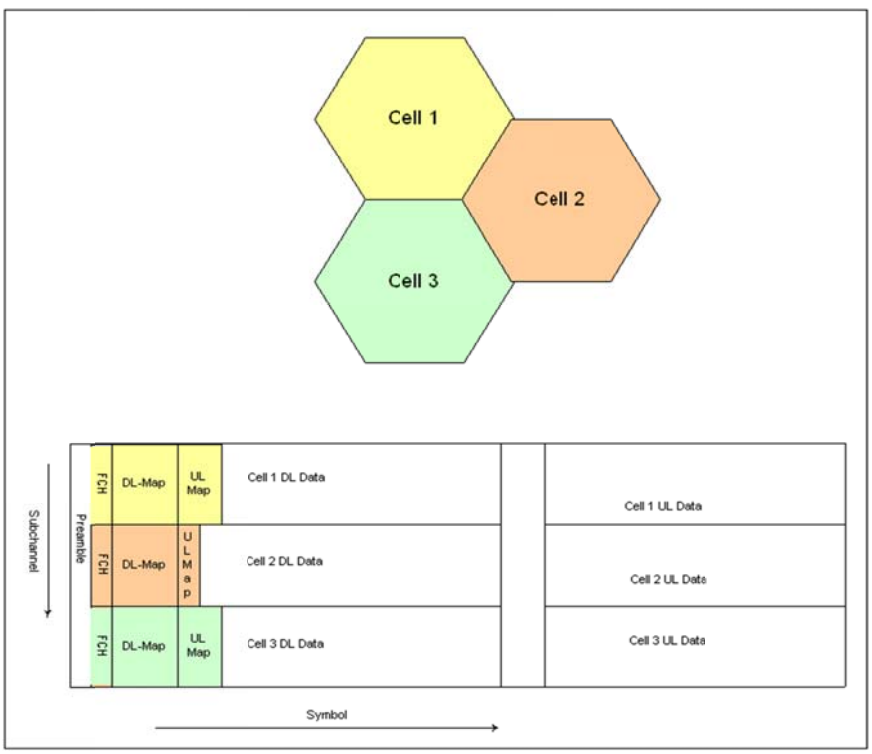

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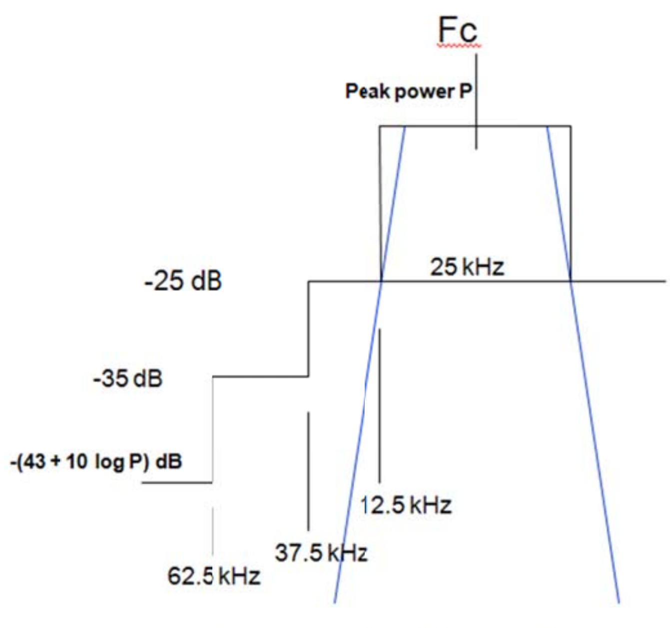
Table 4.2-1: FullMax use of subchannels for frequency reuse

In the case of sectorization, each FullMax transmitter (at the BS or FS) transmits upto the maximum power (36 dBm) into a smaller number of subcarriers (28 subcarriers in the DL and 24 subcarriers in the UL). This is however offset by the increased spacing between the subcarriers (3 times in the DL and 4 times in the UL). The overall impact of sectorization on ACI is therefore not significant.

5. Comparison with FCC Part 90

1. A radio receiver operating in a 25 KHz wide or 12.5 KHz wide channel in the public safety band near the 700 MHz "B" Guardband (i.e., directly below 775 MHz or directly below 805 MHz), is subject to interference from adjacent public safety transmitters operating according to FCC Part 90. These transmitters include:
    a. A public safety base station which may transmit at upto 50 dBm (100 watts) with a 13 dBi sector antenna, i.e., 63 dBm EIRP.
    b. A public safety mobile transmitter employing an onmi antenna. This transmits upto 35 watts, i.e., 45 dBm EIRP.

2. The applicable spectral mask is defined in FCC Part 90.210.



Spectral mask for a 25 KHz wide channel as per FCC Part 90.210

3. The transmitter at the adjacent channel will be attenuated at the channel edge by 25 dB. The TX power leakage into the adjacent channel will be:

    a. TX power from the BS < 38 dBm EIRP
    b. TX power from the MS < 29 dBm EIRP

4. **Conclusion: An adjacent channel interference from one or more narrow band public safety transmitters to a public safety receiver is significantly higher than the adjacent channel interference from a FullMax transmitter operating in the 700 MHz "B" Guardband. This is because of two main reasons:**
    a. **Public safety transmitters at the BS and MS use much higher power than FullMax**
    b. **Public safety transmitters use a much higher power density than FullMax. This is because FullMax employs the same power regardless of channel size (e.g., same power when operating at 500 KHz and at 1 MHz wide channel) while the total transmit power in the public safety band increases as the number of channels increases.**

6. FullMax Characteristics for improved ACI Performance

6.1 General

FullMax BS and FS have Software Defined Radio (SDR) architecture. As such, most characteristics of the FullMax radio can be reconfigured or reprogrammed to meet a very wide range of new requirements. The paragraph below, highlight a number of characteristics of the FullMax radio that can be used to further reduce ACI as needed.

6.2 Guard subcarriers

When operating at 500 KHz and 1 MHz wide channels, FullMax employs the IEEE802.16e-2005 128 FFT OFDMA waveform as described in figure 6.2-1 below. This waveform consists of 128 sub carriers including data transport sub-carriers, pilot subcarriers, a DC subcarrier and guard subcarriers. The objective of the guard subcarriers is to reduce ACI. FullMax supports a number of OFDMA waveform structures with different number of guard subcarriers which may be selected to satisfy the specific ACI requirement.

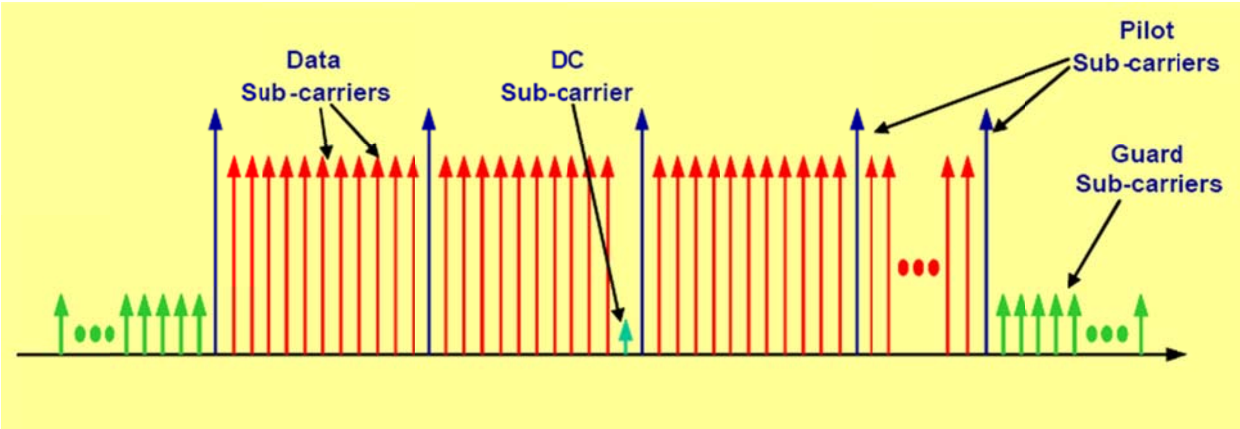


Figure: 6.2-1: FullMax 128 FFT subcarrier structure

6.3 FullMax Symbol rate

FullMax BS and MS has a sampling clock synthesizer used to synthesize any symbol rate as needed to fit the waveform into a channel size between 200 KHz and 5 MHz. In the case of the 700 MHz "B" Guardband, two 1 MHz wide channels are available. Considering FullMax subchannel reuse scheme as outlined in paragraph 4.3 above, it makes most sense to use in each sector a complete 1 MHz wide channel. The symbol rate synthesizer can be used to reduce the symbol rate in order to backoff from the edge of the channel as much as needed to meet the ACI requirements. As outlined in paragraph 4.2.3, a reduction in the symbol rate frequency of 50 KHz will reduce the ACI by 25 dB.

6.4 Digital filter design

FullMax BS and MS has a programmable, 720 tap digital filters at the output of the digital transmit signal processing section. This filter is implemented in FPGA and is programmed to meet the spectral mask requirement. Full Spectrum developed a design tool which simulates the TX spectrum and plots it on top of the spectral mask to verify that the spectral mask met. The output of the tool is shown in figure 6.4-1 below.

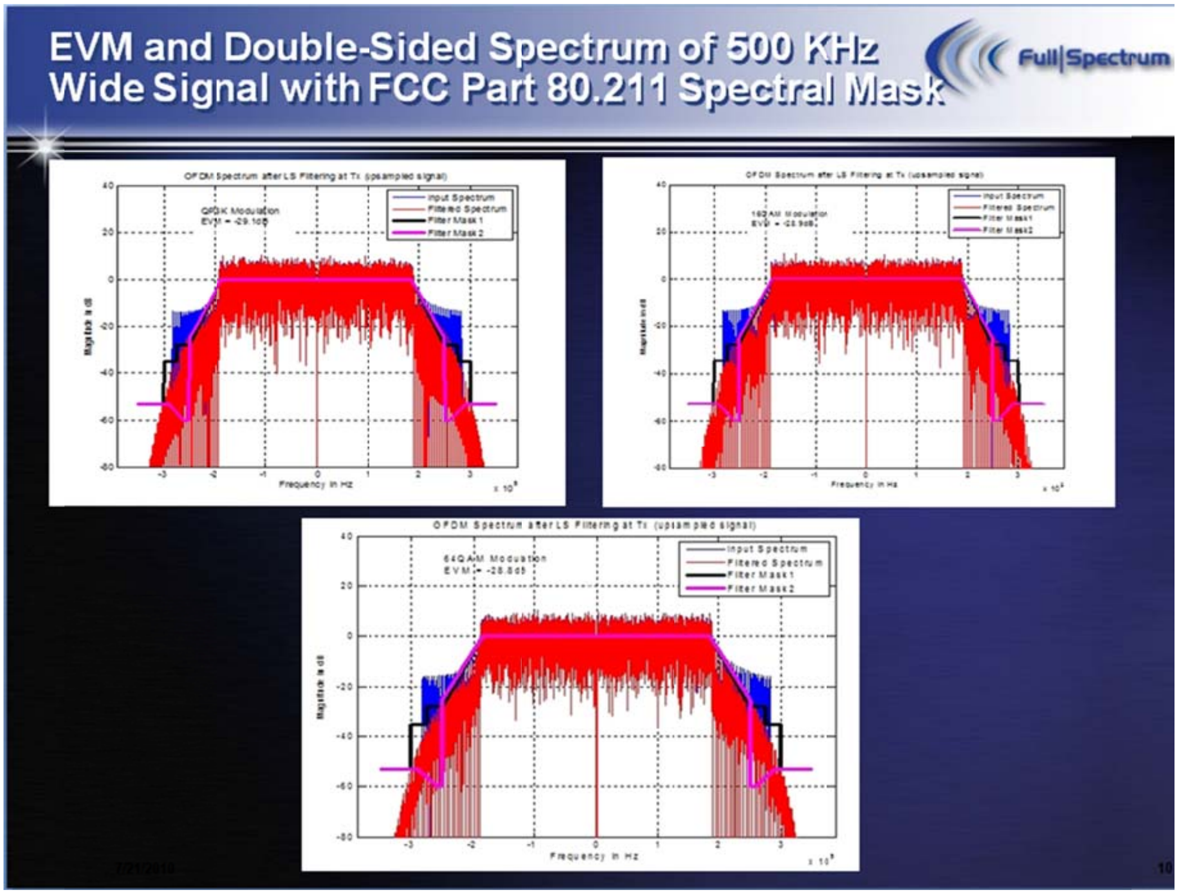


Figure 6.4-1: Simulation tool for digital filter design

6.5 Power backoff and Digital Pre Distortion (DPD) equalizer

FullMax BS and FS employ a Power Amplifier (PA) with a P1dB of 44 dBm. The BS and FS however are operated at a maximum TX power of 36 dBm, i.e., a backoff of 8 dB, to maintain PA operation in its linear region.

Any outstanding spectral re-growth is removed by a Digital Pre Distortion (DPD) Equalizer

6.6 Configurable center frequency and channel size

FullMax BS and FS can be operated at any frequency between 40 MHz and 958 MHz with a resolution of 10 KHz. This capability along with the programmable symbol rate capability described in paragraph 6.3 above, can be used to position the TX waveform anywhere within the available band to meet any ACI requirement.

6.7 Location based TX power and frequency (GPS)

FullMax BS and FS has a GPS which can be used along with the programmable center frequency capability, to implement location based policies with regard to the TX power and the operational ferqueny.