Performing Test and Measurement Using LTE System Toolbox

- Analyze LTE and LTE-Advanced signals with LTE System Toolbox
- Perform signal measurements including spectrum, EVM, and constellation
- Customize the existing MATLAB based measurement source code

LTE and LTE-A offer the potential to achieve much higher data rates than previous cellular systems. This is accomplished using techniques such as MIMO and carrier aggregation, and it also presents a new set of test and measurement challenges regarding the physical layer. Flexible and customizable tools are required to address these challenges.

You can analyze LTE and LTE-Advanced signals with MATLAB® and LTE System Toolbox™. Gain insights into the characteristics of your signal using the graphical analysis capabilities, which include spectral measurements and constellation plots, to more advanced EVM measurements per subcarrier and resource block. You can analyze both uplink and downlink signals for FDD and TDD duplexing modes, and customize the existing MATLAB based measurement source code to create your own analysis capabilities.

This example shows how to use MATLAB and LTE System Toolbox to measure the EVM for a release 12 carrier aggregation (CA) scenario. Spectrum analysis tools are used to measure the characteristics of the CA waveform. We compare the measurements of the EVM versus the OFDM symbol, subcarrier, and resource block to study the effect of the filtering needed to extract a component carrier from an aggregated signal. In this paper, we focus on an intraband contiguous CA case.

EVM Analysis for Release 12 Carrier Aggregation

Carrier aggregation (CA) was introduced in release 10 to satisfy the demand for higher data rates. It aimed to increase peak data rate and throughput by combining the peak rates and throughput of different carrier frequencies. It also increased design flexibility by facilitating the use of fragmented spectrum. CA is one of the key features of LTE-A. In release 10, a maximum of two component carriers (CC) were specified. Up to three CCs were specified in release 12, with four and five CCs being considered for future releases.

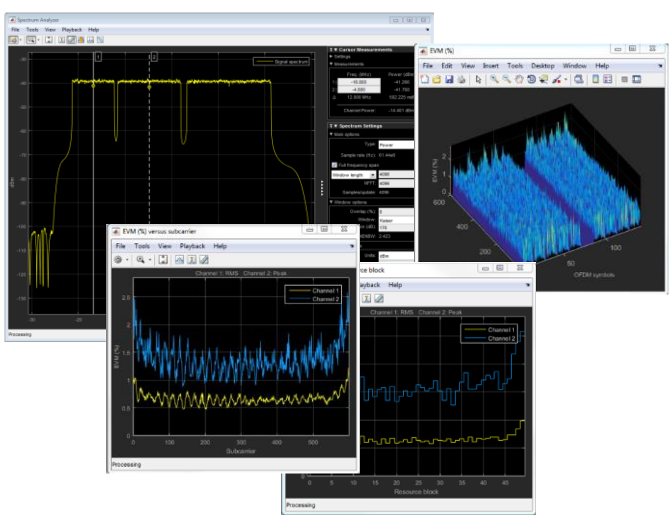


Figure 1. Test and measurement using LTE System Toolbox.

System Model

Figure 2 illustrates the model we used in this example. A waveform containing the aggregation of 3 CC is generated using LTE System Toolbox. We used a filter to extract the component carrier of interest. The choice of filter can add a level of degradation to the signal. This example analyzes degradation in terms of EVM. The filtered signal is also demodulated and the resulting CRC calculated.

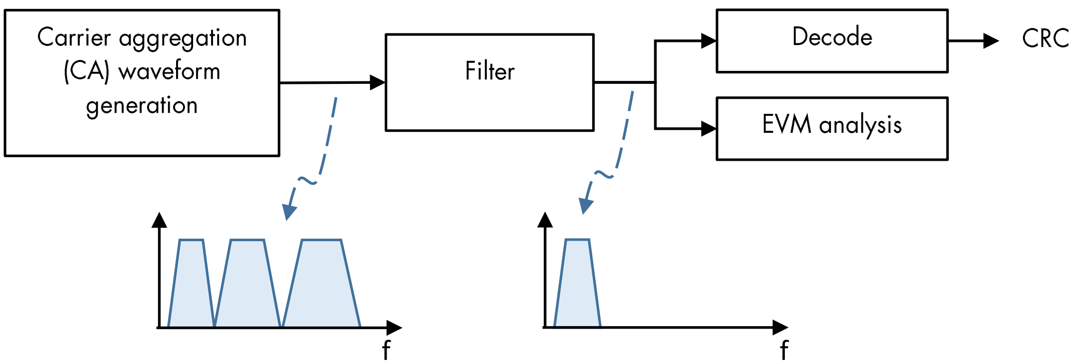


Figure 2. Example system model.

Generated Waveform

LTE System Toolbox can be used to parameterize and generate LTE waveforms. In this article, we generated three contiguous CCs (i.e., CA bandwidth Class D as specified in Table 5.6A-1 in [1] and summarized in Table 1). The bandwidths for each CC can be configured. In this example, we selected the bandwidths 10 MHz, 15 MHz, and 20 MHz (50, 75, and 100 resource blocks (RBs) respectively). This is one of the allowed combinations (CA_41D) specified in Table 5.6A.14-1[1]-.

	Bandwidth	
Component carrier 1	10 MHz	50 RBs
Component carrier 2	15 MHz	75 RBs
Component carrier 3	20 MHz	100 RBs

Table 1. Component carrier bandwidth.

The CA signal was generated using LTE System Toolbox. The individual CCs were generated independently and upsampled to a common rate before we applied a carrier offset. We then aggregated the resulting waveforms. The frequency parameters used in this signal (carrier spacing, frequency offsets, and nominal guard bands) were calculated as specified in TS 36.101 Sections 5.6 and 5.7. These are summarized in Figure 3.

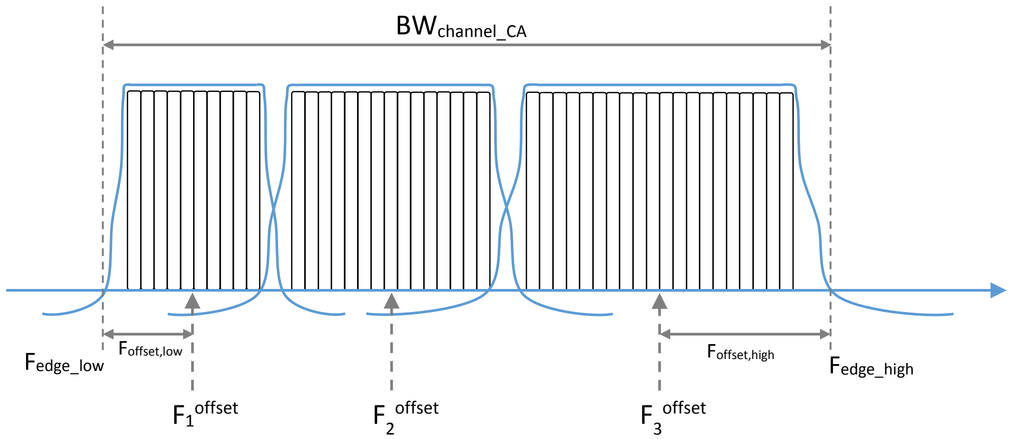


Figure 3. Definition of aggregated channel bandwidth and aggregated channel edges.

The corresponding values are:

Aggregated channel bandwidth $BW_{Channel\_CA}$	44.6 MHz
Lower bandwidth edge F_{edge_low}	-22.3 MHz
Upper bandwidth edge F_{edge_high}	22.3 MHz
Lower frequency offset $F_{offset,low}$	5.5 MHz
Upper frequency offset $F_{offset,high}$	10 MHz
Component carrier 1 offset F_1^{offset} (relative to baseband)	-16.8 MHz
Component carrier 2 offset F_2^{offset} (relative to baseband)	-4.8 MHz
Component carrier 3 offset F_3^{offset} (relative to baseband)	12.3 MHz

Table 2. Bandwidth and frequency values summary.

The spectrum of the CA signal centered at baseband is shown in Figure 4. We plotted this spectrum using the MATLAB spectrum analyzer tool (`dsp.SpectrumAnalyzer`). Note that the frequency spacing between the first two CCs is measured at 12 MHz. A similar measurement provides a spacing of 17.1 MHz between the second and the third CCs. These are the values expected based on the above carrier frequency offsets.

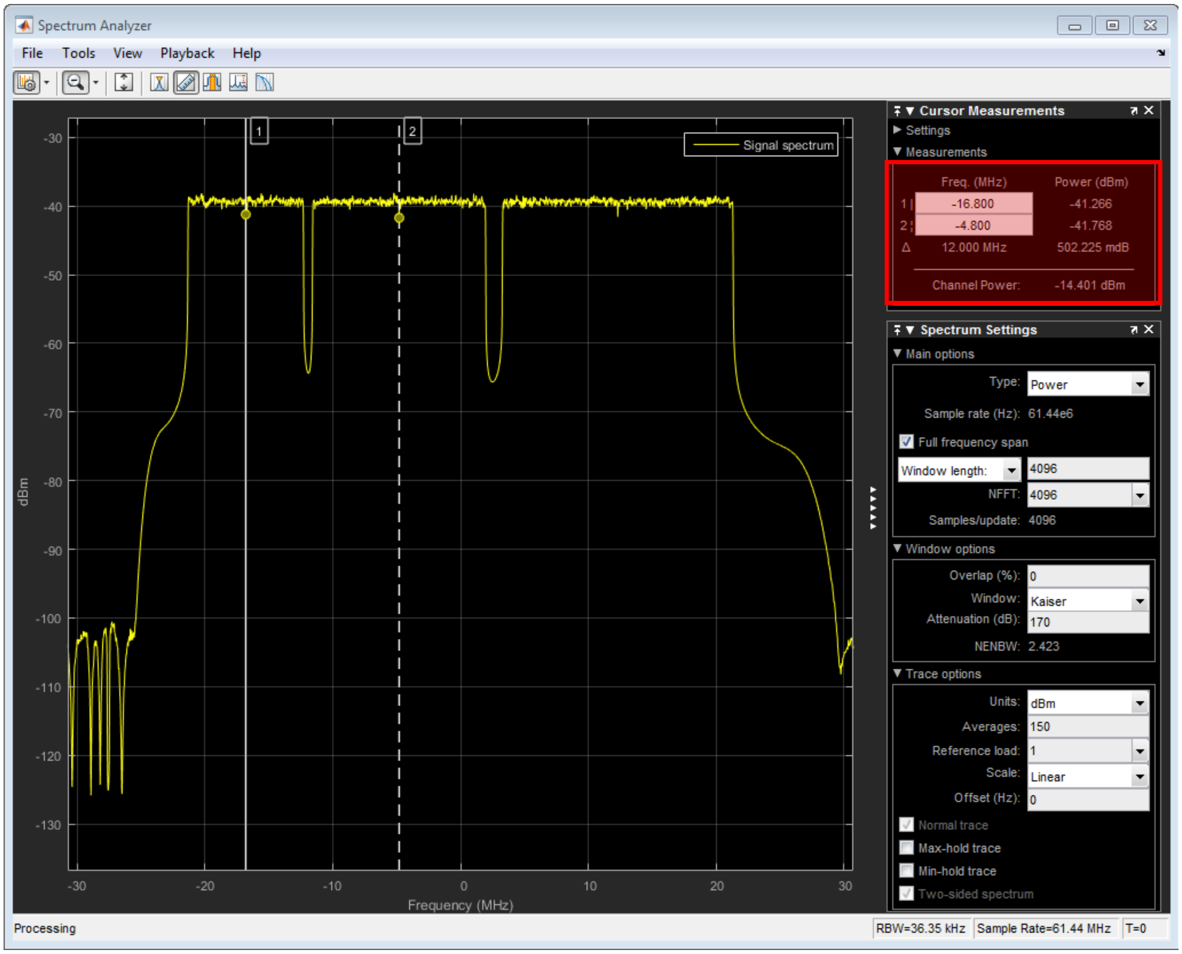


Figure 4. CA signal spectrum centered at the baseband.

Using the spectrum analyzer, we can measure the bandwidth of the aggregated signal that contains a percentage of the total power. Figure 5 shows that the bandwidth, using 99% of the total power, is 42.2229 MHz. This is slightly less than the aggregated channel bandwidth $BW_{Channel\_CA}$ of 44.6 MHz, due to the use of guard bands.

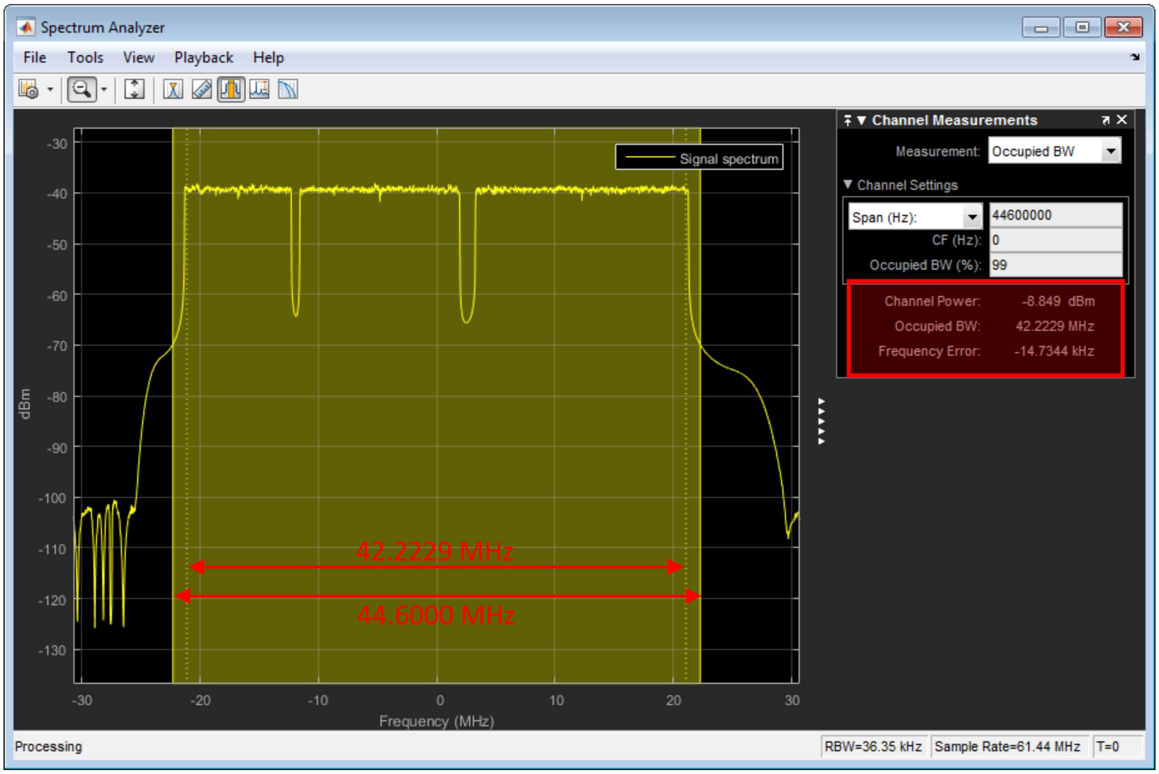


Figure 5. CA signal bandwidth measurement.

CC Filtering

Our next step is to extract one of the CCs and perform EVM measurements in order to analyze the degradation introduced by the filter imperfection. The CC of interest has to be demodulated to baseband and filtered out. For this example, we studied the effect of this filtering process on the quality of the signal using EVM measurements. No other impairments were considered.

The lowpass filter used to extract the CC of interest, is designed using MATLAB's `firpm` command. We designed the initial filter using 201 coefficients. Figure 6 shows the magnitude response of the designed filter. Later in the example, we show the effect of different filter lengths on the quality of the recovered signal.

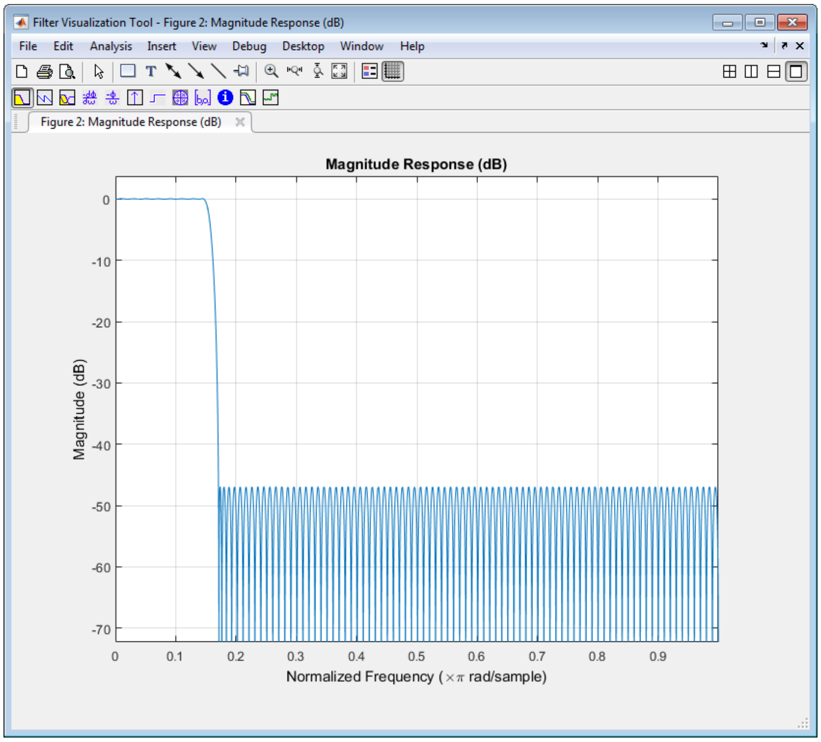


Figure 6. Filter manager response.

This filter is used to recover the first CC. Figure 7 shows the spectrum of the carrier aggregated signal with the first CC centred at baseband before and after the filtering operation.

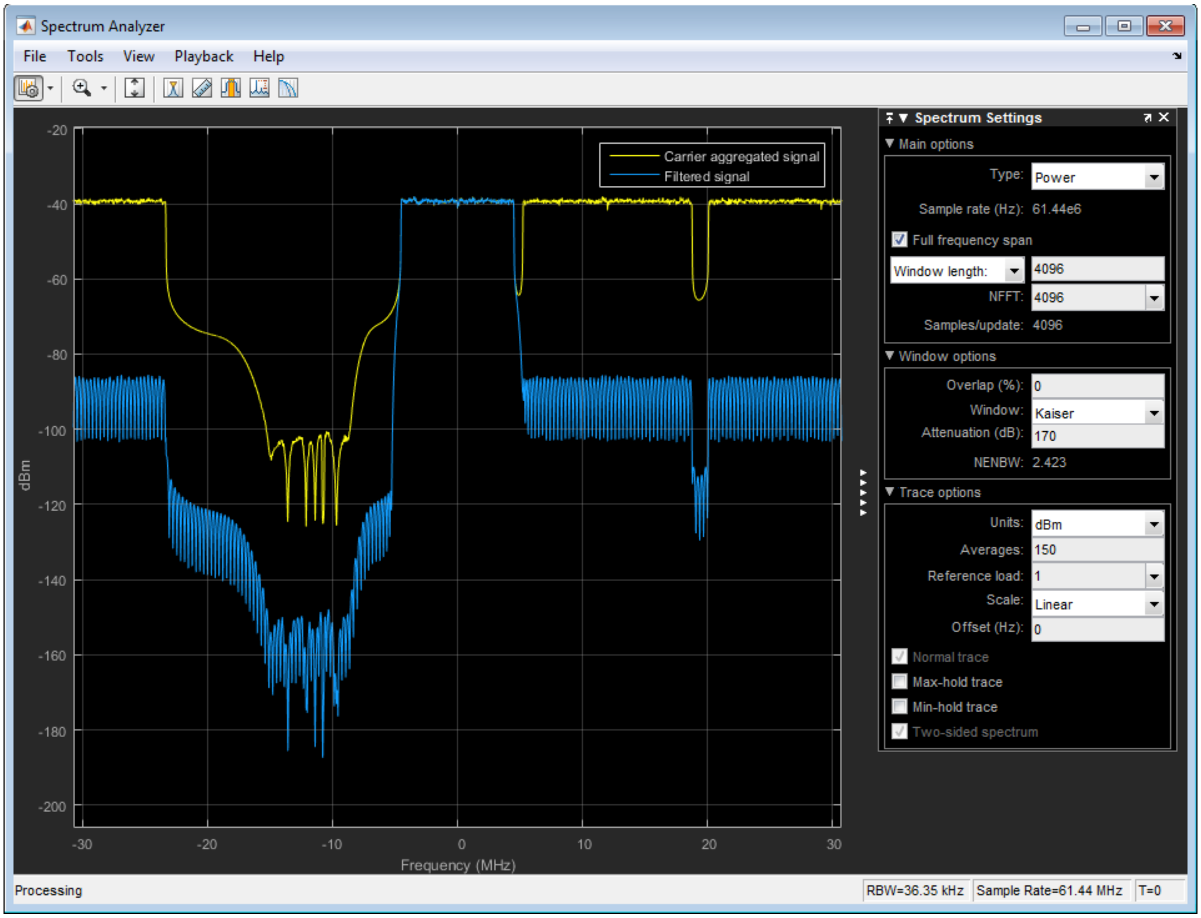


Figure 7. Spectrum of the carrier aggregated signal pre and post filtering.

A detail of the guardband between CC is shown in Figure 8. The filter has frequency band edges of 4.5 MHz and 5.25 MHz. We obtained the passband frequency using the following equation $(0.18 * N_{RB} + \Delta f_1)/2$ where N_{RB} is the bandwidth in number of resource blocks and Δf_1 is the subcarrier spacing in MHz. The chosen stopband frequency offered enough attenuation of the neighboring component carrier so as to provide an acceptable level of EVM.

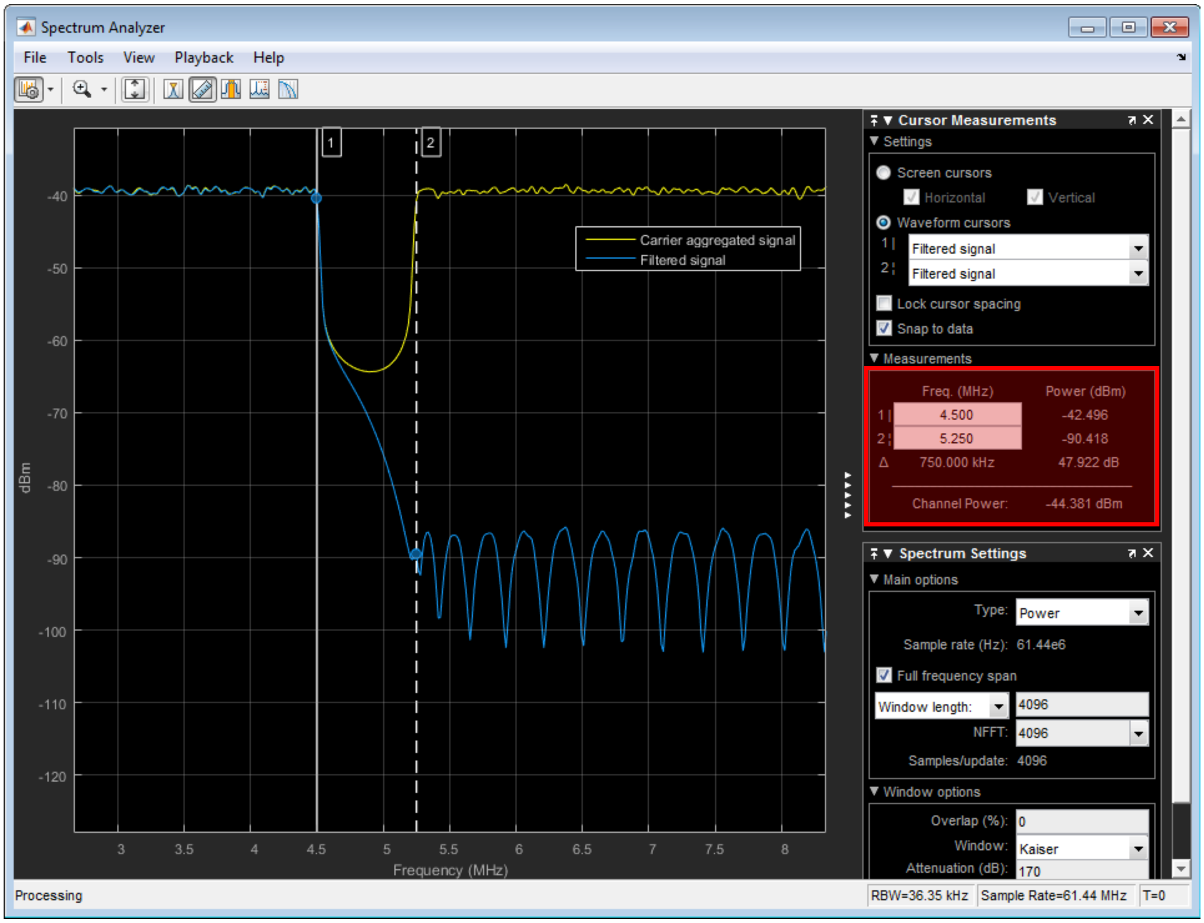


Figure 8. Details of the guardband between CCs.

EVM Measurement

Figure 9 shows the filtered CC's EVM measurements generated using LTE System Toolbox. These measurements include:

- EVM vs. OFDM symbol
- EVM vs. resource block
- EVM vs. subcarrier
- EVM vs. subcarrier and OFDM symbol

Peak and RMS values are provided for all measurements.

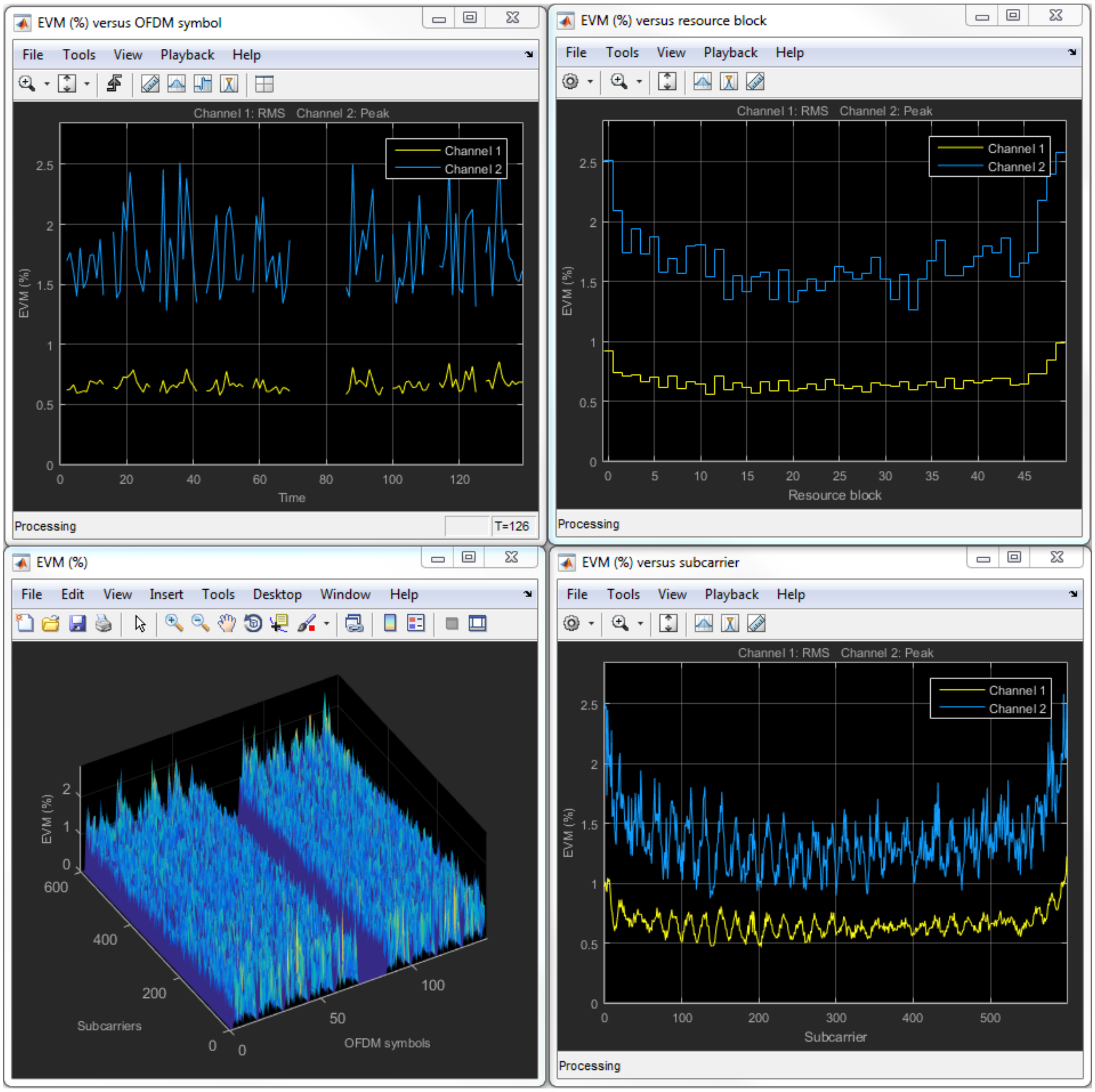


Figure 9. EVM measurements from left to right: EVM vs. OFDM; EVM vs. resource block; EVM; EVM vs. subcarrier.

Note that the EVM increases towards the band edges due to the filtering effects. We also generated a numerical output (Figure 10). This includes the EVM per subframe and a total averaged value. An average overall EVM measurement of 0.669% is reported.

```
Extracting CC number 1:
Low edge EVM, subframe 0: 0.647%
High edge EVM, subframe 0: 0.634%
Low edge EVM, subframe 1: 0.683%
High edge EVM, subframe 1: 0.649%
Low edge EVM, subframe 2: 0.666%
High edge EVM, subframe 2: 0.683%
Low edge EVM, subframe 3: 0.656%
High edge EVM, subframe 3: 0.641%
Low edge EVM, subframe 4: 0.640%
High edge EVM, subframe 4: 0.621%
Low edge EVM, subframe 6: 0.671%
High edge EVM, subframe 6: 0.642%
Low edge EVM, subframe 7: 0.649%
High edge EVM, subframe 7: 0.655%
Low edge EVM, subframe 8: 0.700%
High edge EVM, subframe 8: 0.665%
Low edge EVM, subframe 9: 0.704%
High edge EVM, subframe 9: 0.676%
Averaged low edge EVM, frame 0: 0.669%
Averaged high edge EVM, frame 0: 0.652%
Averaged EVM frame 0: 0.669%
Averaged overall EVM: 0.669%
CRC passed
```

Figure 10. Numerical output of EVM measurement results for a filter with a length of 201 coefficients.

Using a filter with 121 coefficients and repeating the EVM measurement provides an averaged overall EVM of 2.747% (Figure 11):

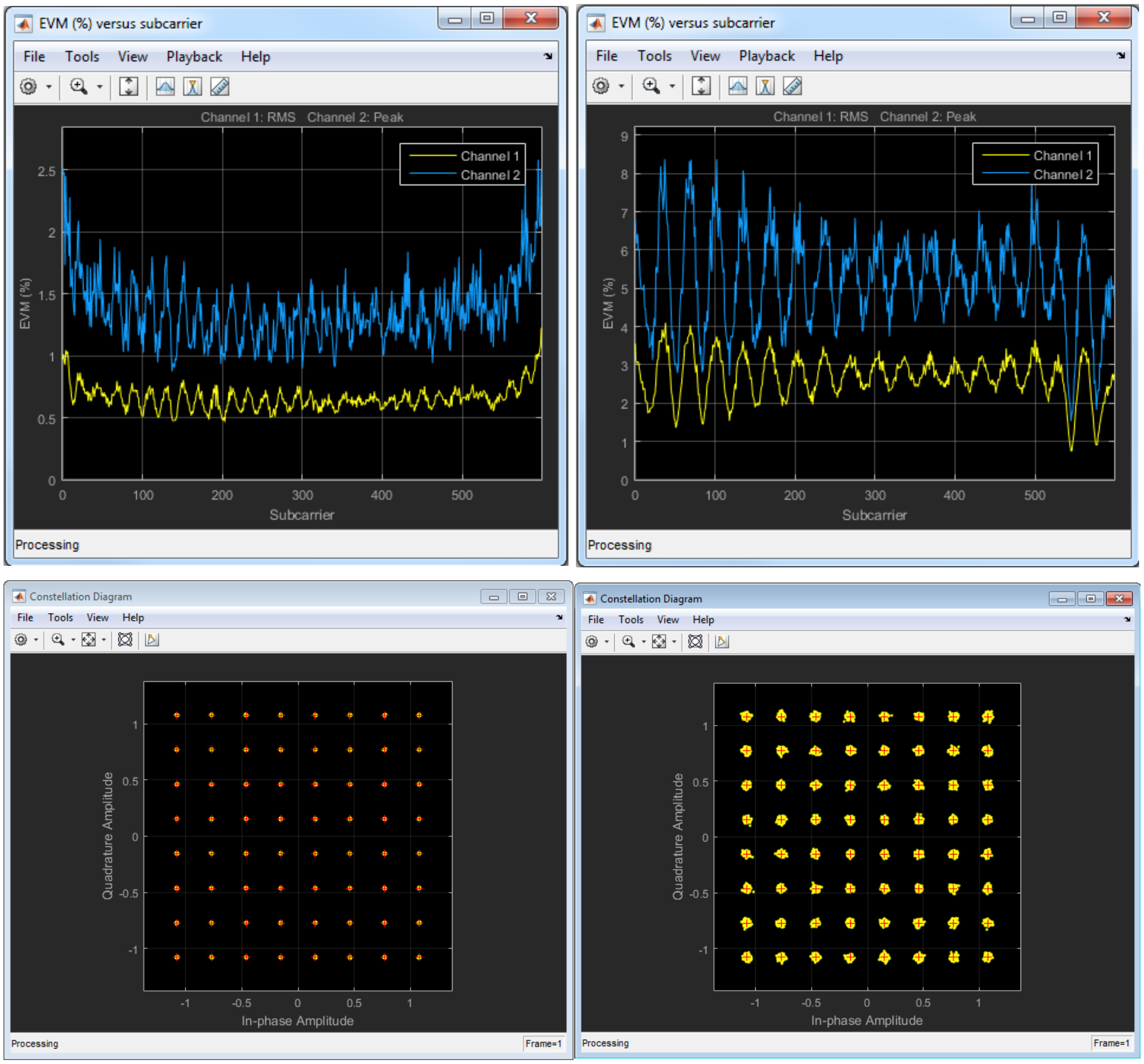
```
Extracting CC number 1:
Low edge EVM, subframe 0: 2.697%
High edge EVM, subframe 0: 2.697%
Low edge EVM, subframe 1: 2.752%
High edge EVM, subframe 1: 2.742%
Low edge EVM, subframe 2: 2.751%
High edge EVM, subframe 2: 2.751%
Low edge EVM, subframe 3: 2.757%
High edge EVM, subframe 3: 2.754%
Low edge EVM, subframe 4: 2.730%
High edge EVM, subframe 4: 2.727%
Low edge EVM, subframe 6: 2.773%
High edge EVM, subframe 6: 2.776%
Low edge EVM, subframe 7: 2.737%
High edge EVM, subframe 7: 2.737%
Low edge EVM, subframe 8: 2.758%
High edge EVM, subframe 8: 2.750%
Low edge EVM, subframe 9: 2.763%
High edge EVM, subframe 9: 2.761%
Averaged low edge EVM, frame 0: 2.747%
Averaged high edge EVM, frame 0: 2.744%
Averaged EVM frame 0: 2.747%
Averaged overall EVM: 2.747%
CRC passed
```

Figure 11. Numerical output of EVM measurement results for a filter with a length of 121 coefficients.

The table below shows the averaged overall EVM for the considered filters.

	201 filter weights	121 filter weights
Averaged overall EVM (%)	0.669%	2.747%

For comparison, we show the EVM measurements per subcarrier and the constellation plot for both filter lengths (Figure 12). As expected, the shorter filter results in an increased level of EVM and a noisier constellation. Note that for the larger filter, most of the EVM degradation occurs at the band edges, while the shorter filter shows similar EVM degradation over the whole band.



201 filter weights 121 filter weights

Figure 12. Comparison of filter weights as they affect the signal quality. The top images show EVM vs. subcarrier diagrams. The bottom images show constellation diagrams.

The filter design can be refined by modifying its length and adjusting the pass-band and stop-band values. You can use the tools in this example to find a compromise between filter complexity and signal degradation.

Summary

This example presents some of the test and measurement capabilities of LTE System Toolbox and MATLAB in terms of EVM measurements, spectrum analysis, and constellation plots. It illustrates how to measure the impact of filter selection on the quality of recovered aggregated carriers. A release 12 multicarrier LTE signal is generated using LTE System Toolbox. Filters to extract the CC are designed and analysed using DSP System Toolbox™. We measured the quality of the extracted component carrier using EVM and other analysis capabilities available in LTE System Toolbox and MATLAB.

About LTE System Toolbox

LTE System Toolbox provides standard-compliant functions and apps for the design, simulation, and verification of LTE and LTE-Advanced communications systems. The toolbox accelerates LTE algorithm and physical layer (PHY) development, supports golden reference verification and conformance testing, and enables test waveform generation. With the toolbox, you can configure, simulate, measure, and analyze end-to-end communication links. You can also create and reuse a conformance test bench to verify that your designs, prototypes, and implementations comply with the LTE standard.

References

[1] *TS 36.101 – User Equipment Radio Transmission and Reception.*