

STK Communications Filtering

Product Licenses required to complete this exercise are STK Pro and STK Communications.

The results of the tutorial may vary depending on the user settings and data enabled (online operations, terrain server, dynamic Earth data, etc.). It is acceptable to have different results.

Problem Statement

A situation has arisen where two customers are utilizing a satellite communication downlink facility located in the Southwestern United States. One transmission is routine, but important. The other transmission is urgent.

There are only two satellite reception parabolic antenna dishes available and they sit next to each other on the ground. Although the communications are coming from different locations, they are being routed through the same satellite to the ground facility.

Break It Down

You have some information that may be helpful. Here's what you know:


- The communication satellite is geostationary and is located above Brazil.
- The satellite is downlinking two streams of data to the same ground site.
- The urgent communication link is transmitting on a frequency of 25 GHz.
- The routine communication link is transmitting on a frequency of 25.2 GHz.
- Both transmissions are using a data rate of 300 Mb/Sec.
- The close proximity of the frequencies, separated by 200 MHz, is causing interference with the data streams.
- As much as possible, you want to minimize interference without reducing bandwidth.

Solution

Use STK Communications see if applying filtering to the frequencies can minimize the interference of the two transmissions on one another.

Open a Scenario

To speed things up and allow you to focus on the portion of this exercise that teaches you to create and display jammers in STK, a partially created scenario have been provided for you.

1. Ensure that the Welcome dialog is visible in the STK Workspace.
2. Click the Open a Scenario button.
3. Browse to <STK install folder>/Help/stktraining/samples.
4. Select Comm_Filters.vdf ()
5. Click Open.


When you open the scenario, a directory with the same name as the scenario will be created in the default user directory (C:/My Documents/STK 11/). The scenario will not be saved automatically.

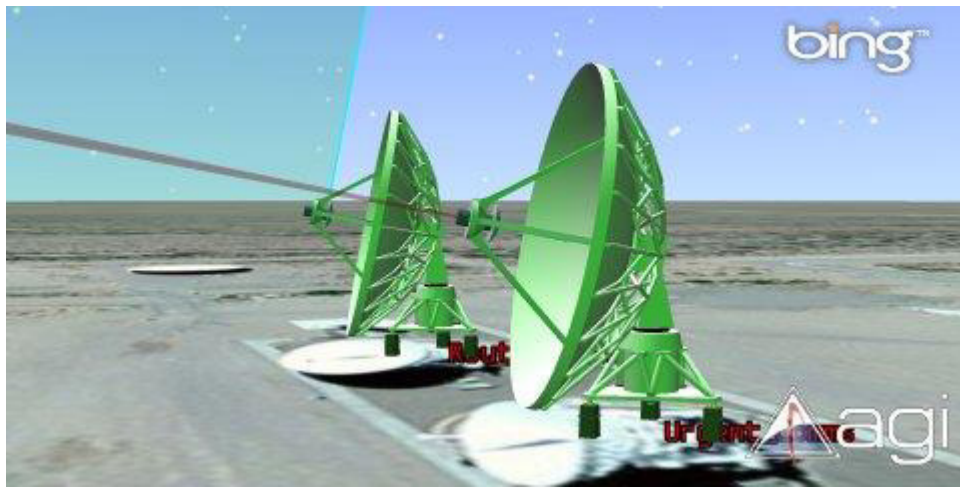
When you save a scenario in STK, it will save in the format in which it originated. In other words, if you open a VDF, the default save format will be a VDF. The same is true for a scenario file (*.sc). If you want to save a VDF as a SC file (or vice-versa), you must change the file format when you are performing the Save As procedure.

6. Open the File menu and select Save As.
7. When the Save As window appears, click STK User.
8. Click the Create New Folder icon.
9. Rename the New folder FilterAnalysis.
10. Select FilterAnalysis and click Open.
11. Change File name: to FilterAnalysis.sc and click Save.

Acquaint Yourself With the Scenario

You were provided a previously created scenario with all the objects needed for your analysis. You need to obtain situational awareness of the players in the scenario.

1. Bring the 3D Graphics window to the front.
2. Zoom To Urgent_Comms ()
3. Mouse around in the 3D Graphics window to get a better view of the ground communication site.



3D View: Communication ground site

Change Your Perspective

1. Bring the 3D Graphics window to the front.
2. Zoom To TDRS_9_27389 (📡).
3. Mouse around in the 3D Graphics window to get a better view of the satellite antennas.



3D View: TDRS satellite antennas

You'll notice the sensors for both transmitters are targeting the reception site on the ground. You may also notice that both transmitters are located on separate antenna locations on the satellite. The satellite is oriented toward the ground communication site.

Build the Constellations

Prior to analyzing filters, you need to double check if Urgent_Comms is being interfered with by Routine_Comms. You need to set up the three constellations (Receiver, Transmitter, Interference) to calculate interference. Begin with the receivers constellation.






Create the Receiver Constellation

1. Add a Constellation (📡) to the scenario using the Object Catalog.
2. Name it Receiver.
3. Open Receiver's (📡) properties (📄).
4. Move (➡️) Urgent_Rcv (📡) to the Assigned Objects list.
5. Click OK.

Create the Transmitter Constellation


1. Add a Constellation (📡) to the scenario using the Object Catalog.
2. Name it Transmitter.
3. Open Transmitter's (📡) properties (📄).
4. Move (➡️) Urgent_Xmt (📡) to the Assigned Objects list.
5. Click OK.

Create the Interference Constellation






1. Add a Constellation () to the scenario using the Object Catalog.
2. Name it Interference.
3. Open Interference's () properties ().
4. Move () Routine_Xmt () to the Assigned Objects list.
5. Click OK.

Build the Comm System

Now that you have grouped the objects into constellations, you can build the CommSystem object.



1. Using the Insert STK Objects tool, add a CommSystem () object to the scenario using the Insert Default method.

If the Comm System object does not appear in the Insert Objects tool, click the Edit Preferences... button and add it.

2. Open the CommSystem object's () properties ().
3. On the Basic - Transmit page, move () the Transmitter constellation to the Selected Constellation column.
4. Select the Receive page.
5. Move () the Receiver constellation to the Selected Constellation column.
6. Select the Interference page.
7. Move () the Interference constellation to the Selected Constellation column.
8. Click Apply.



Set the Time Step for the CommSystem

The default Start and Stop times for the CommSystem interval correspond to the scenario's time period. You want the communication link to be calculated every 60 seconds, but the default step size is one (1) second.

1. Select the Basic - Interval page.
2. Set the Step Size to 60 sec.
3. Click OK.
4. Save () the scenario ().

Calculating Interference




You'll perform two calculations. The first is a graph depicting carrier wave interference. The second calculation is a detailed link budget.

1. Select the CommSystem object () in the Object Browser.
2. Click the Report & Graph Manager button () on the Data Providers toolbar.
3. Make the following changes:

Option	Value
Show Reports	Off
Show Graphs	On

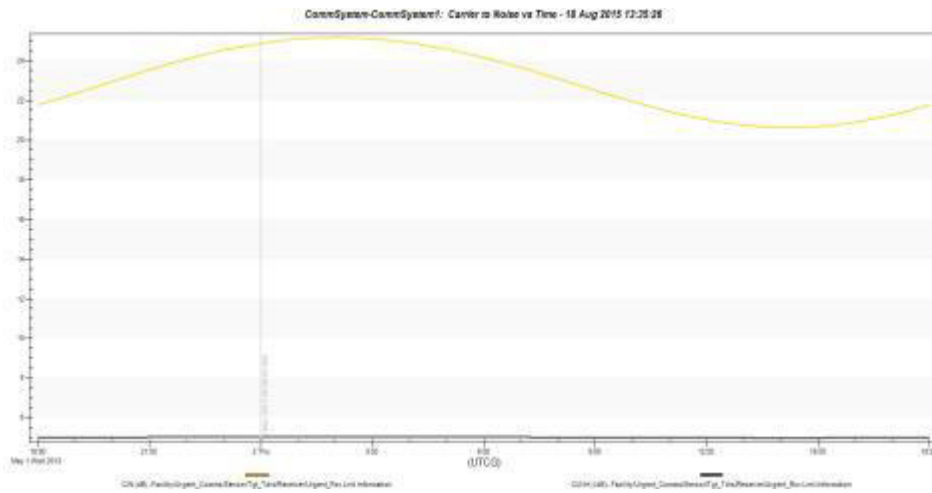
Change the Carrier to Noise Graph Properties

Create a custom graph that represents the carrier to noise and carrier to noise with interference on the same axis. By default, they are on different axes.

1. Select Carrier to Noise vs Time graph in the Installed Styles directory.
2. Click the Properties () button.
3. Move () the Link Information - C/(N + I) data provider from the Y2 axis.
4. Move () the Link Information - C/(N + I) data provider to the Y axis.
5. Click OK.
6. When the Information window appears, click OK.
7. Expand the My Styles folder.
8. Rename the graph My Carrier to Noise vs Time.

Generate the Graph

1. Select My Carrier to Noise vs Time.
2. Click Generate...
3. Leave the graph open.



My Carrier to Noise vs Time

As you can see the line representing the clean carrier wave (C/N (dB)) and the line representing the wave that is receiving interference (C/N + I (dB)) are different. There is interference against the carrier wave.

Calculate the Link Budget

You have determined there is interference on the carrier wave, but sometimes with interference you can still communicate. Determine how good the quality of the communication is by looking at the Bit Error Rate (BER).

1. Bring the Report & Graph Manager to the front.
2. Make the following changes:

Option	Value
Show Reports	On
Show Graphs	Off
Style	Link Information - Detailed
Generate as	Report/Graph

3. Click Generate...
4. Locate the BER and BER+I columns. The BER column shows the link performance without interference while the BER + I shows the link performance with interference.
 - o Can you see how interference is affecting your link?
5. Leave the report open.

When you compare the BER values with and without interference, you can see that interference has a major impact on the communications.

You can use this Link Information - Detailed report throughout the analysis to see how filtering affects the link.

Power Spectral Density

You have determined that there is considerable interference being caused by both transmissions in close proximity to each other. The engineering team has been tasked to model the filtering and mitigate the interference.

Bandwidth Analysis

The transmitted spectrum is modeled as a flat spectrum with unity magnitude across the transmitter's bandwidth. The receiver's frequency response is also modeled as a flat response across the receiver's bandwidth. Therefore, the bandwidth ratio is computed as just a simple ratio of the receiver's bandwidth to the transmitter's bandwidth.

If the transmitter's bandwidth is totally contained within the receiver's bandwidth, the ratio will be one (1.0). For a receiver that has an auto scaled bandwidth and an auto tracked frequency, this value will be one (1). Otherwise, the value may be less than one (1.0) if the receiver center frequency and the transmitter frequency are not the same or the receiver's bandwidth is totally contained within the transmitter's bandwidth.



1. Bring the Link Information - Detailed report to the front.
2. Locate the Bandwidth (MHz) and Bandwidth Overlap (units) columns.

Note that the Bandwidth Overlap is one (1.0). This shows that you are capturing all the energy from the transmitted signal at the receiver.

The bandwidth is 300 MHz, which is what it should be.

Change the Receiver's Bandwidth

Before using filters, experiment and change the receiver's bandwidth to determine the effect that change might have on signal quality. Remember, the smaller the bandwidth, the less information that can be sent or received.

1. Open Urgent_Rcv's  properties (.
2. Select the Basic - Definition page.
3. Select the Filter tab.

Auto Scale

The Bandwidth Auto Scale option is available for the noise equivalent bandwidth of the receiver. This feature allows the receiver to adjust its bandwidth to that of the current transmitter as you switch from one transmitter to another. Since you're receiving from a transmitter utilizing a bandwidth of 300 MHz, the receiver will automatically adjust with this option enabled.

1. Disable the Auto Scale option.
2. Set the Bandwidth to 150 MHz. That is half the transmitter's bandwidth.
3. Click OK.
4. Refresh the Link Information - Detailed report.
 - What is the Bandwidth Overlap?
 - Did the Bandwidth Overlap change?
 - If so, by how much?

Theory

The Power Spectral Density (PSD), which describes how the power of a signal or time series is distributed with frequency. Here power can be the actual physical power, or more often, for convenience with abstract signals, can be defined as the squared value of the signal. This assumes the actual power of a signal is a 1-ohm voltage load.

The units of power spectral density are commonly expressed in watts per hertz (W/Hz). A spectral filter allows only a specific bandwidth of the electromagnetic spectrum to pass.

Signal PSD



Up until now, the power has been spread equally across frequency bands. In reality, the power is concentrated around the band center. Power Spectral Density allows you to model the reality case.

The PSD option allows the scenario to model the actual spectral shape of the transmitted signal based on the modulation, data rate, etc.

The Use Signal PSD option uses the modulation's power spectral density to determine the Bandwidth Overlap Factor. If this option is not selected, the PSD will be modeled as a flat spectrum with unity magnitude across the transmitter's bandwidth.

You have modeled a flat signal magnitude over the entire bandwidth which is sufficient fidelity for most conventional analysis. You are going to increase the fidelity by applying the appropriate signal shape over the entire bandwidth based on the modulation type.

You can apply filters to enhance the magnitude over certain frequencies content while suppressing the magnitudes over other frequencies. The use of Spectral Filters on transmitters modifies the spectral shape. The use of Spectral Filters on receivers helps reduce the impact of out of band signals from jammers and other sources.

1. Open Routine_Xmt's  properties (.
2. Select the Basic - Definition page.
3. Select the Modulator tab.
4. Enable the Use Signal PSD option.
5. Click OK.

The Use Signal PSD uses the modulation's power spectral density to determine the Bandwidth Overlap Factor. If this option is not selected, the PSD will be modeled as a flat spectrum with unity magnitude across the transmitter's bandwidth.

Enable PSD for the Transmitter

1. Follow the same steps to enable Use Signal PSD for Urgent_Xmt.
2. Bring the Carrier to Noise vs Time graph to the front.
3. Refresh the graph.
 - Can you still see interference to the carrier wave?
4. Close the My Carrier to Noise vs Time Jam graph.

Check the Bandwidth Overlap Factor



Let's check the Bandwidth Overlap Factor now that you have enabled Signal PSD.

1. Bring the Link Information - Detailed report to the front.
2. Refresh the report.
3. Locate the Bandwidth Overlap column.
 - Does the bandwidth overlap?
 - If so, how much?

Notice the Bandwidth Overlap is ~ 0.78 , which is greater than when the Use Signal PSD was disabled for the same bandwidth. The Spectral Power is spread over an infinite bandwidth - more densely towards the center of the band than at the band edges. In the Use Signal PSD enabled case, the power is spread over a wider range and the 150 MHz receiver captures approximately 78% of the signal instead of 50% when it was disabled.

Change the Modulation Type



One way to minimize bandwidth costs is to change the modulation to Phase Shift Keying with 16 Constellation Points (16PSK). Change the modulation to 16PSK and see if this has an effect on your signal quality.

1. Open Urgent_Xmt's () properties ()
2. Select the Basic - Definition page.
3. Select the Modulator tab.
4. Set the Modulation Type to 16PSK.
5. Enable the Use Signal PSD option.
6. Click Apply.
7. Refresh the Link Information - Detailed report.
 - Does the bandwidth overlap?
 - If so, how much?



Notice that changing the modulation to 16PSK has the nearly same effect as increasing the receiver bandwidth to 300 MHz with QPSK modulation. 16PSK has a bandwidth ratio of 0.5 Hz/bps. QPSK has a bandwidth ratio of one (1.0) Hz/bps.

Reset the Transmitter's Modulation

Return the transmitter's modulation back to QPSK.


1. Bring Urgent_Xmt's () properties () to the front.
2. Select the Basic - Definition page.
3. Select the Modulator tab.
4. Set the Modulation Type to QPSK.
5. Enable the Use Signal PSD option.
6. Click OK.

Reset the Receiver's Auto Scale

1. Open Urgent_Rcv's () properties ()
2. Select the Basic - Definition page.
3. Select the Filter tab.
4. Enable the Auto Scale option.
5. Click OK.
6. Refresh the Link Information - Detailed report.

Spectrum and Filter Graph

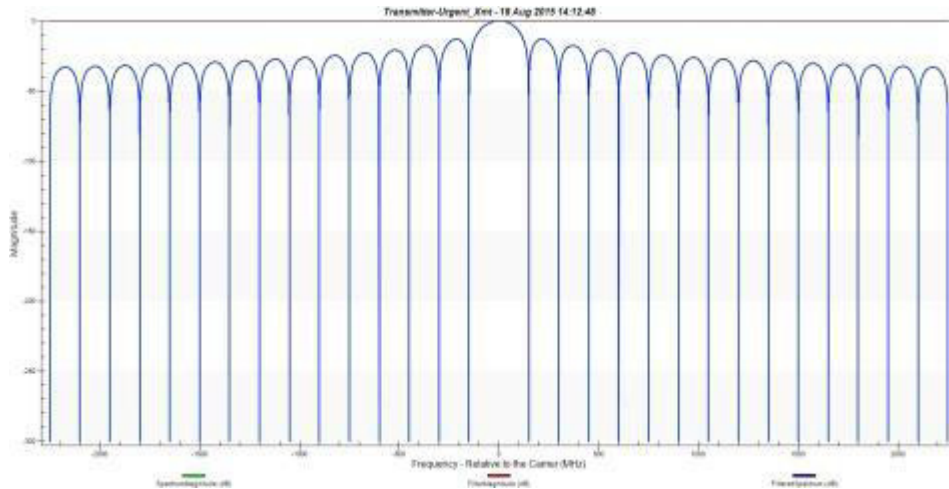
The first filter you will use is the Butterworth filter. You will run a spectrum and filter graph to determine the cutoff frequency of the interference transmitter (Noise_Xmt). Using the graph, you'll enable the Butterworth filter to see how it affects the link.

1. Bring the Report & Graph Manager () to the front.
2. Make the following changes:

Option	Value
Object Type	Transmitter
Object (Below Object Type)	Satellite/TDRS_9_27389/Sensor/Tgt_Uc/Urgent_Xmt
Show Reports	Off
Show Graphs	On
Style	Transmitter Spectrum and Filter
Generate as	Report/Graph

3. Click Generate...

4. Right-click inside the graph.
5. Select Grid Options.
6. Select Show X Axis Grid Lines.



Transmitter Spectrum

Looking at the graph, you can see the bandwidth encompasses 4500 MHz. The main beam is 300 MHz.

Butterworth Filters

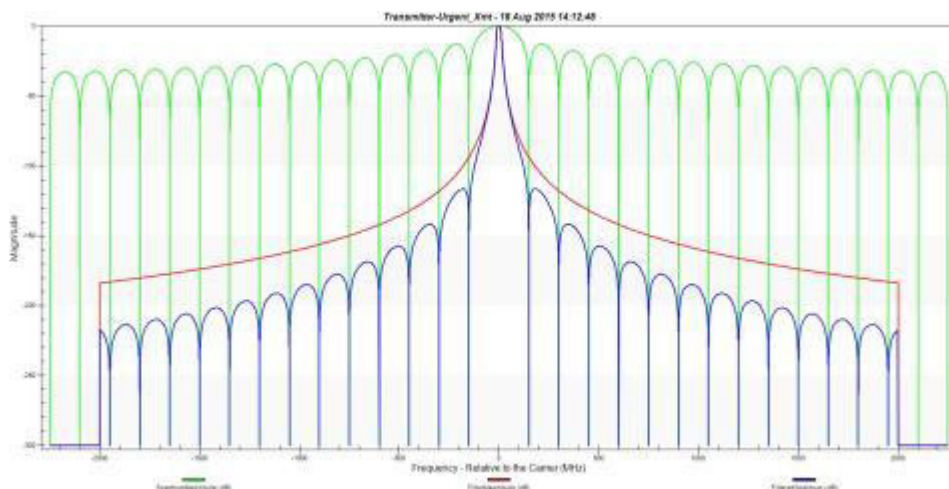
The filter cutoff frequency controls where you want the signal to start being suppressed and the filter order (rolloff) controls how steep you want the filter magnitude to drop or how fast you want the signal to get suppressed.

The Butterworth filter is less complex and maintains a flat profile over the filter bandwidth, but doesn't have as steep a rolloff as Chebyshev. However, the Chebyshev is more complex and uses recursive equations (not a closed formula) and there is a ripple in the passband. This means you do not have a flat profile over the filter bandwidth. The Butterworth filter has a frequency response with flat pass and stop bands.

1. Open Urgent_Xmt's (🔧) properties (📄).
2. Select the Basic - Definition page.
3. Select the Filter tab.
4. Enable the Use option.
5. Ensure the Butterworth Filter is enabled.
6. Set the following options:

Option	Value
Upper Bandwidth Limit	2000 MHz
Lower Bandwidth Limit	-2000 MHz

7. Click Apply.
8. Refresh the Transmitter Spectrum and Filter graph.



Transmitter and Spectrum Filtering with Butterworth

You have removed 500 MHz of bandwidth. Using the default frequency cutoff, you've narrowed the cutoff at ten (10) MHz on both sides of the carrier wave. You can see from the graph that the bandwidth has been suppressed on both sides of the carrier wave. Let's see how this affects the BER.

Refresh the Link Information Detailed Report

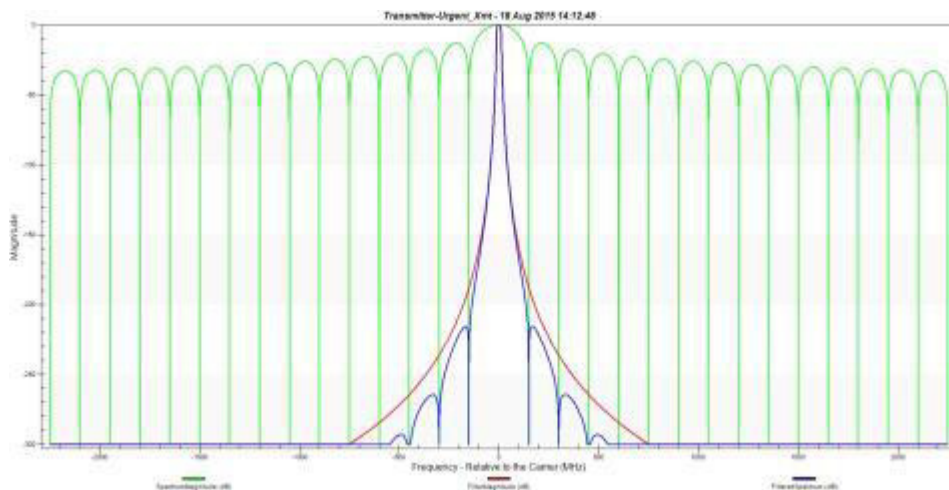
1. Bring the Link Information - Detailed report to the front.
2. Refresh the report.
3. Locate the BER column.
 - Did you remove some interference?
 - Are your BER rates better or worse?

Although your filter is working, you now have a new problem. You caused the BER to drop below acceptable levels during periods of your analysis. You have increased the BER with interference as well. This indicates your communication link is still poor.

Change the Filter Order

You would like to have a steeper roll off at the cutoff frequency. To ensure the filter has a steeper roll off, you can increase the filter order.

1. Bring Urgent_Xmt's (🔍) properties (📄) to the front.
2. Select the Basic - Definition page.
3. Select the Filter page.
4. Set the Filter Order to 8.
5. Click Apply.
6. Refresh the Transmitter Spectrum and Filter graph.



Butterworth with higher Frequency Order

You will notice the steep roll off in the filter profile. The steeper the roll off the better, but there are tradeoffs. One tradeoff is the steeper the roll off, the more complex the filter function. The more complex the filter function, the harder it is to implement, due to the complexity.

Refresh the Link Information Detailed Report

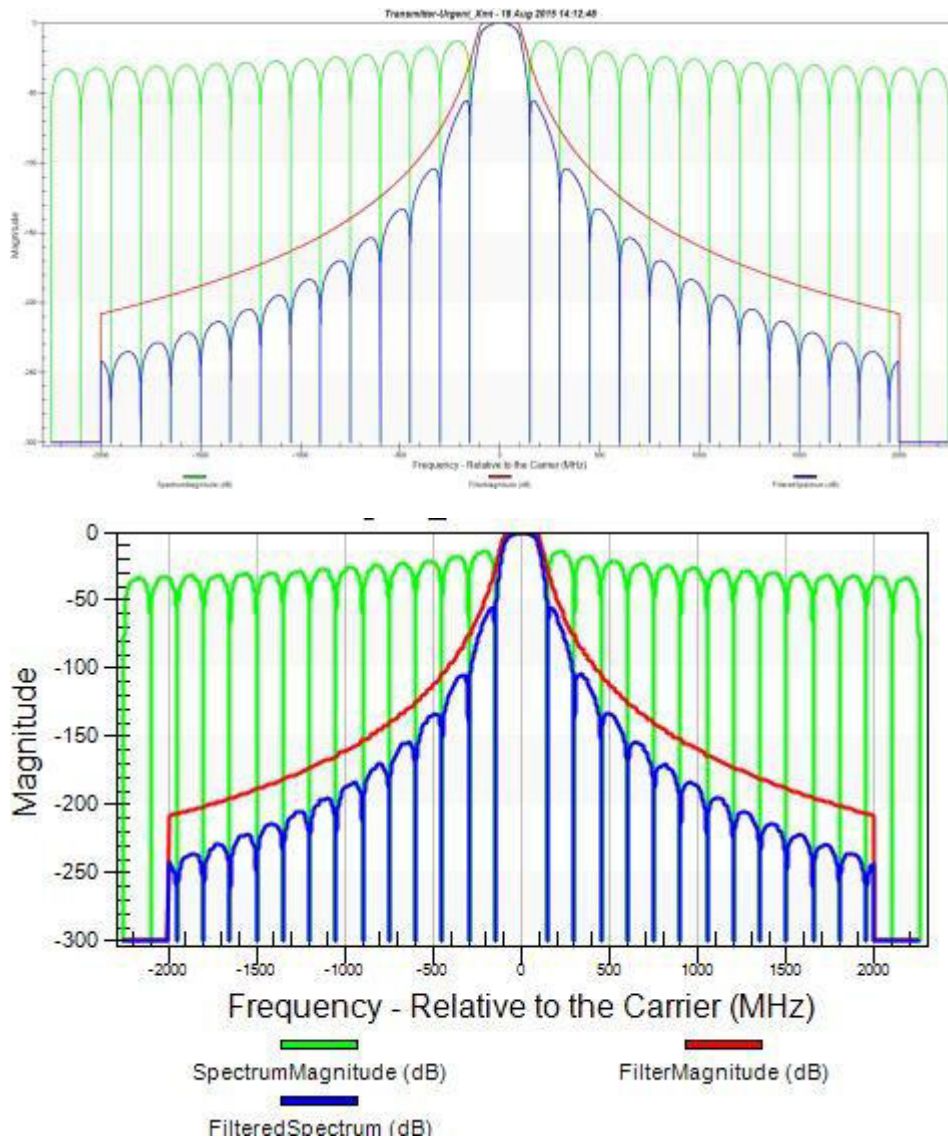
1. Bring the Link Information - Detailed report to the front.
2. Refresh the report.
3. Locate the BER column.
 - Did you notice an increase in BER and BER + I values?

The change is minimal but the BER is still too high.

Change the Cutoff Frequency

Earlier, you determined that your center beam is 300 MHz wide. Your frequency cutoff is only ten (10) MHz. Widen the cutoff to -100 MHz to 100 MHz (200 MHz).

1. Bring Urgent_Xmt's (🔍) properties (📄) to the front.
2. Select the Basic - Definition page.
3. Select the Filter page.
4. Set the Cut-off Frequency to 100 MHz.
5. Click Apply.
6. Refresh the Transmitter Spectrum and Filter graph.
 - Can you see how your filter is allowing more bandwidth through?



Butterworth with Cutoff Frequency

Refresh the Link Information - Detailed Report

1. Bring the Link Information - Detailed report to the front.
2. Refresh the report.
3. Locate the BER column.
 - Did you notice an increase in BER and BER + I values?

The BER has dramatically improved, but the interference (BER + I) is still affecting the link.

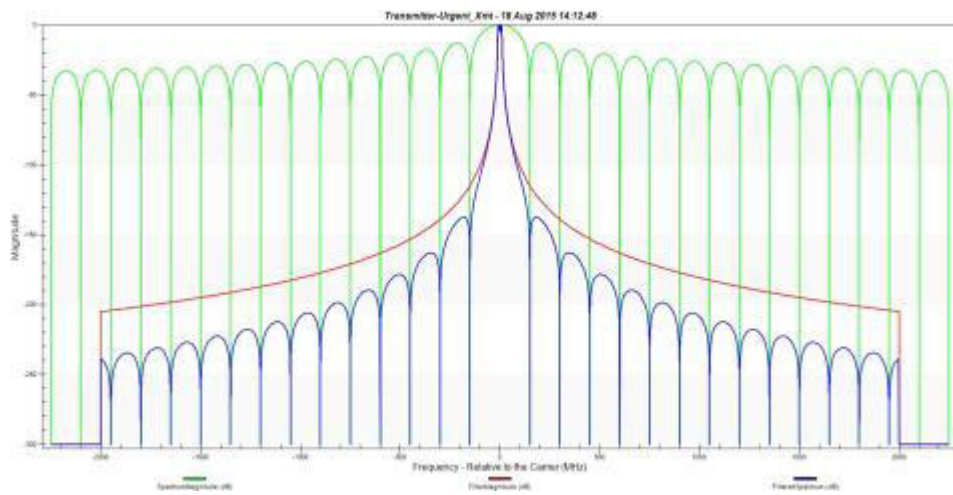
Chebyshev Filter

The Chebyshev filter has a frequency response with equal ripple in the pass band.

1. Bring Urgent_Xmt's (🔗) properties (📄) to the front.
2. Select the Basic - Definition page.
3. Select the Filter tab.
4. Select Chebyshev as the Filter Type.
5. Set the following options:

Option	Value
Upper Bandwidth Limit	2000 MHz
Lower Bandwidth Limit	-2000 MHz

6. Click OK.
7. Refresh the Transmitter Spectrum and Filter graph.
 - Do you notice the five (5) dB ripple in the filter and filtered spectrum?



Chebyshev Filter

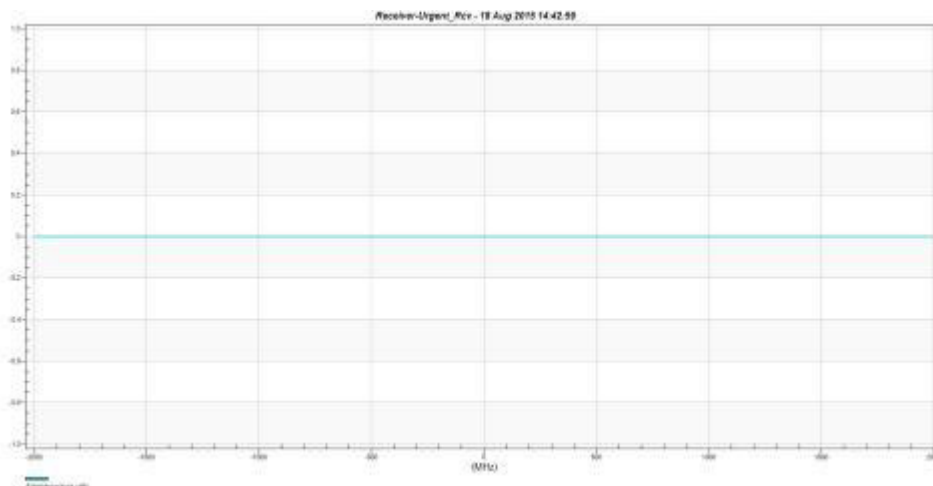
Refresh the Link Information - Detailed Report

1. Bring the Link Information - Detailed report to the front.
2. Refresh the report.
3. Locate the BER column.
 - Did you notice an increase in BER and BER + I values?
4. Close the Transmitter Spectrum and Filter graph.

The Chebyshev filter tightened up the difference between the BER and BER + I values, but the communication link is still poor. It's time to apply a filter to the receiver.

Graph the Receiver Filter

1. Bring the Report & Graph Manager (📄) to the front.
2. Set the Object Type to Receiver.
3. Select Facility/Urgent_Comms/Sensor/Tgt_Tdrs/Urgent_Rcv.
4. Select Receiver Filter graph style.
5. Generate the graph.
6. Right-click inside the graph.
7. Select Grid Options.
8. Right click on the graph, click Grid Options, and select Show X and Y Axis Grid Lines.



No Receiver filtering

Currently, you are not using a filter, so there is no effect against the receiver.

Apply the Chebyshev Filter to the Receiver

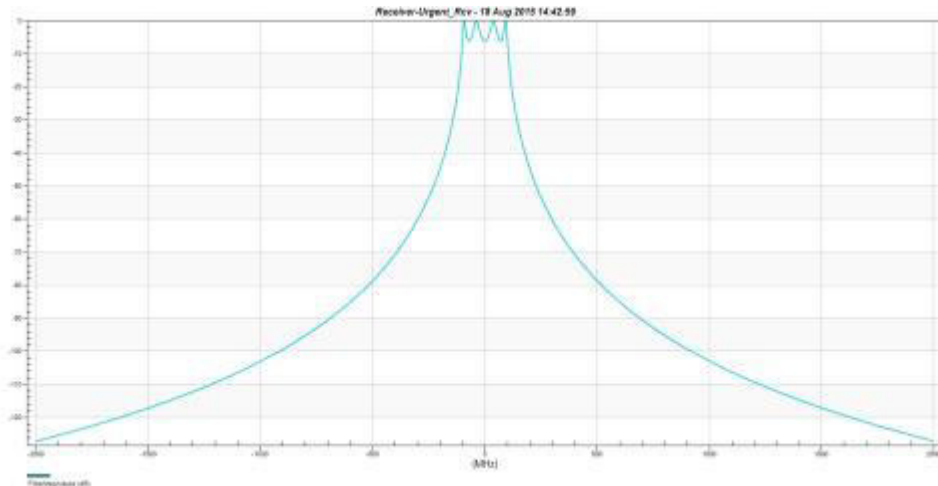
You tried both filters on the transmitter, let's try the Chebyshev filter on the receiver. Then you see what effect the filter might have on the communication link.

1. Open Urgent_Rcv (🔧) properties (📄).
2. Select the Basic - Definition page.
3. Select the Filter tab.

4. Disable the Auto Scale option.
5. Enable the Filter Model - Use option.
6. Select Chebyshev as the Filter Type.
7. Set the following options:

Option	Value
Upper Bandwidth Limit	2000 MHz
Lower Bandwidth Limit	-2000 MHz
Cut-off Frequency	100 MHz
Ripple	5 dB

8. Click Apply.
9. Refresh the Receiver Filter graph.
 - Do you notice the five (5) dB ripple in the filter and filtered spectrum?



Chebyshev receiver Cutoff Frequency

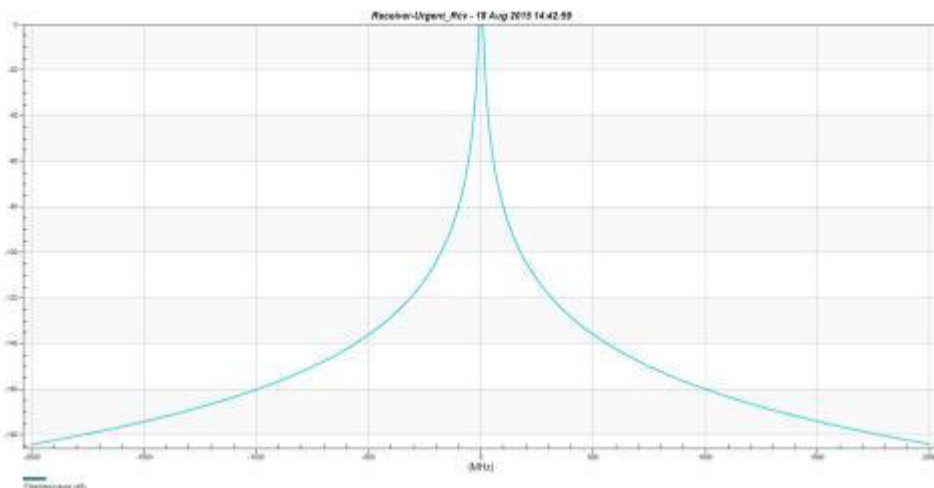
You can see how the filter is suppressing noise on both sides of the carrier wave.

Change the Receiver Filter to a Butterworth

1. Bring Urgent_Rcv (🔊) properties (📄) to the front.
2. Select the Basic - Definition page.
3. Select the Filter tab.
4. Select Butterworth as the Filter Type.
5. Set the following options:

Option	Value
Upper Bandwidth Limit	2000 MHz
Lower Bandwidth Limit	-2000 MHz
Cut-off Frequency	10 MHz

6. Click OK.
7. Refresh the Receiver Filter graph.





Butterworth Receiver Cutoff Frequency

8. Close the Receiver Filter graph.

You can see that the ripple disappears and the frequency cutoff isn't so steep. Apply the Butterworth filter to Urgent_Xmt.

Set the Filter for the Transmitter

You can apply the Butterworth filter to the transmitter to try and improve performance even more.

1. Open Urgent_Xmt's () properties () properties.
2. Select the Basic - Definition page.
3. Select the Filter tab.
4. Enable the Use option.
5. Set the Filter to Butterworth.
6. Set the following options:

Option	Value
Upper Bandwidth Limit	2000 MHz
Lower Bandwidth Limit	-2000 MHz
Cut-off Frequency	100 MHz

7. Click OK.



Refresh the Link Information Detailed Report

1. Bring the Link Information - Detailed report to the front.
2. Refresh the report.
3. Locate the BER column.
 - Did your communication link improve?
 - Do you still have interference?
 - Are the BER + I values acceptable?

You have determined that you will need to filter both the transmitter and the receiver in order to minimize interference on your communication link. The Chebyshev filter removes the greatest amount of interference, but it increases the BER values.

The Butterworth filter decreases the BER values, but there's a bit more interference in the communication link. Both filters require you to decrease bandwidth and the amount of information that can be transmitted over the communication link.

Save Your Work

1. Close the Link Information - Detailed report.
2. Close the Report & Graph Manager ()
3. Save () your work.

Systems Tool Kit (STK), v11.1; Latest Help Update: September, 2016

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