

## Reed-Solomon Lab

### Background

Reed-Solomon is a forward error correction (FEC) algorithm that enables the correction of errors injected into a data stream from a noisy channel. A data stream is broken up into blocks (called data packets) of the same number of bytes (each byte is called a data symbol). These data packets are then passed to the Reed-Solomon encoder, which adds several bytes (called check symbols) to the end of each data packet. Together, the data and check symbols make up a codeword.

The Reed-Solomon decoder uses the check symbols at the end of each codeword to correct any data symbols that were corrupted during transmission. The number of errors the decoder can correct is dependent on the number of check symbols that are in the codeword. For every two check symbols in a codeword, the decoder can correct one data symbol. Therefore, if there are 16 check symbols in a codeword, the decoder can correct 8 errors.

The designer can specify the number of data symbols and check symbols in each codeword. Depending on how you configure your system, there are various trade-offs to using different numbers of data and check symbols. For example, if you want the maximum bandwidth possible, you should add the fewest number of check symbols to each data packet. In contrast, if flawless data transmission is more important than overall throughput, you should add as many check symbols to each data packet as possible.

In this lab you will build an FEC system using the Reed-Solomon compiler MegaCore® function and the Stratix™ EP1S25 DSP development board or Stratix EP1S80 DSP development board.

- *Exercise 1*—This exercise shows you how to build a Reed-Solomon encoder that conforms to the digital video broadcast (DVB) standard.
- *Exercise 2*—This exercise shows you how to build a decoder that receives the output from the encoder you built in exercise 1. You will add errors before simulation to see how the decoder handles them.
- *Exercise 3*—In this exercise, you will use an Altera-provided Windows application and the DSP development board to experiment with sending data through a Reed-Solomon encoder/decoder.

### Before You Begin

These instructions assume that you have already installed the software provided with the DSP Development Kit, Stratix Edition or DSP Development Kit, Stratix Professional Edition onto your PC. If you have not done so, refer to the *DSP Development Kit, Stratix & Stratix Professional Edition Getting Started User Guide* for installation instructions. You must also have the following software installed on your PC:

- Quartus® II version 2.2 (limited edition or a full version)



This white paper assumes that you have installed the Quartus II software into the default location.

### Exercise 1: Build a Reed-Solomon Encoder

This exercise shows you how to build a Reed-Solomon encoder that conforms to the DVB standard. You will simulate your encoder and view the results to see that the appropriate number of check symbols were added to the data packets. This exercise includes the following steps:

1. Create a new Quartus II project.
2. Generate a Reed-Solomon encoder using the wizard interface.

3. Add input and output pins to your design.
4. Compile the design.
5. Simulate the design.
6. View the simulation results.

### 1. Create a New Quartus II 2.2 Project

In the Quartus II software, a “project” consists of the complete set of design files, assignment files, simulation files, system settings (including user libraries), and hierarchy information for a design. To build a design, you must first create a project. Perform the following steps to create a Block Design File (.bdf) and a Quartus II project.

- 1-1. Choose **Programs > Altera > Quartus II 2.2 Limited Edition** (Windows Start menu).
- 1-2. Choose **File > New**.
- 1-3. Select **Block Diagram/Schematic File** in the Device Design Files tab.
- 1-4. Click **OK**. A new Block Diagram/Schematic File (.bdf) displays.
- 1-5. Choose **File > Save As**.
- 1-6. Browse to the `c:\MegaCore\stratix_dsp_kit-v1.0.0\Labs\Error_Correction\Exercise1` directory.
- 1-7. Enter `rs_encoder.bdf` in the **File name** box.
- 1-8. Make sure the **Create a new project based on this file** option is turned on (it is on by default).
- 1-9. Click **Save**.
- 1-10. Click **Yes** in the Quartus II message box that asks if you want to create a new project.
- 1-11. Click **Next** in the **New Project Wizard: Introduction**.



The **New Project Wizard: Introduction** page has the **Don't show me this introduction again** option. You will only see this page if you have not (or someone else has not) previously turned this option on.

- 1-12. The **New Project Wizard: Directory, Name, and Top-Level Entity** page should be filled in based on the name and location in which you saved your BDF. Click **Next**.
- 1-13. In the **New Project Wizard: Add Files** page, click the **User Library Pathnames** button.
- 1-14. Click the **Browse (...)** button.
- 1-15. Browse to the directory in which the Reed-Solomon compiler was installed. The default is `c:\MegaCore\reed-solomon_compiler-v3.3.4`.
- 1-16. Browse to the **lib** directory.
- 1-17. Click **Open**.
- 1-18. Click **OK**.

Page 3 is displayed. This page of the **New Project Wizard** allows you to set up EDA tools.

1-19. Because these tools are not needed at this time, click **Next** when this page is displayed.

Page 4 is displayed, and prompts you to select a device to target.

1-20. Select the **Stratix** option.

Page 5 is displayed, and prompts you to assign a particular device.

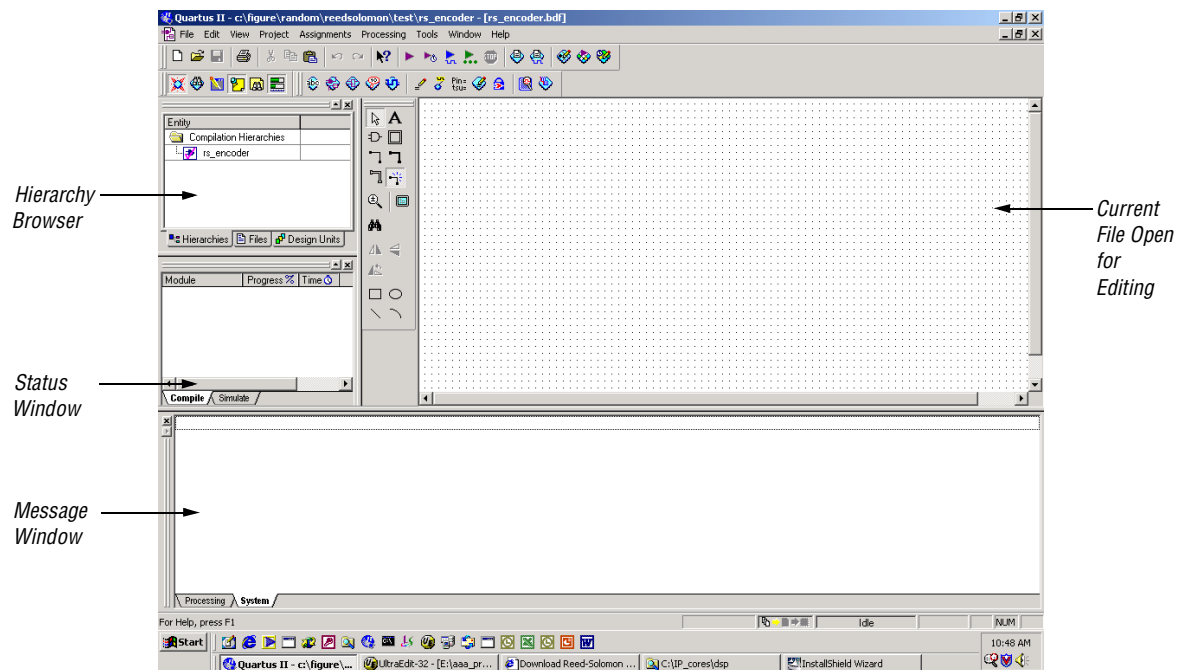
1-21. Because it's unnecessary to assign a particular device, click **Next** when this page is displayed.

1-22. Click **Next** to view a summary of your project.

1-23. Click **Finish**.


Figure 1 shows a screen shot of the Quartus II software after you have created the project.

**Figure 1. Quartus II Screen Shot**



## 2. Generate a Reed-Solomon Encoder Using the Wizard Interface

You will now build a Reed-Solomon encoder design in the blank BDF you just created. First, you will create a Reed-Solomon encoder function using a wizard interface and then you will add pins to transfer the relevant data off chip. Perform the following steps to build the design.

 If the **rs\_encoder.bdf** file that you created earlier is not open, then open it by choosing the **Open** command (File menu).

2-1. Choose the **Edit > Insert Symbol** command.

2-2. Click the **MegaWizard Plug-In Manager** button.

2-3. Turn on the **Create a new custom megafunction variation** option and click **Next**.

You can select the IP block that you would like to use and the language in which you want it to be instantiated.

- 2-4. Expand the **DSP** folder and then the **Error Detection/Correction** folder in the **Available Megafunctions** box.
- 2-5. Select **RS Compiler v3.3.1**.
- 2-6. Choose the language of the output files you want to create. The wizard creates a file in the language of your choice that instantiates the Reed-Solomon encoder.



For the purposes of this lab, it does not matter which language you choose. However, specifying a language is a convenient way to ensure compatibility within a design. For example, if you write your design in Verilog HDL, you can choose Verilog HDL for the instantiation file and, therefore, not have a file in another language instantiated in your top-level design file.

The **What name do you want for the output file?** box should contain the name of the directory in which you created your project.

- 2-7. If the **What name do you want for the output file?** box does contain the correct directory name, type `rs_encoder_block` after the directory.
- 2-8. If the **What name do you want for the output file?** box does not contain the correct directory name, click **Browse** and browse to the directory in which you created your project. Type `rs_encoder_block` in the **File name** box and click **Save**.
- 2-9. Click **Next**.

On this page you can choose the architecture of your Reed-Solomon core and whether you want an encoder or decoder.

- 2-10. Select the **Encoder** option and click **Next**.

On this page, you specify the parameters based on the type of FEC system you want to build.

- 2-11. Click the **DVB Standard** button, which automatically sets the number of codewords and check-symbols to match the DVB standard.

You are now finished choosing 'Wizard' settings.

- 2-12. Click **Finish** to exit the Wizard, or click **Next** to view the remaining wizard pages. If you click **Finish**, skip to [step 16](#).

Page 3 includes an option to create a vector file, and (if a decoder is being built) this page shows the name of the memory file and throughput calculator.

- 2-13. Click **Next**.

Page 4 shows the ordering codes you would use to purchase a license for the core you just configured.

- 2-14. Click **Next**.

Page 5 shows the Wizard output files and where they will be saved.

- 2-15. Click **Finish**.

- 2-16. Click **OK**, and then click the insertion point to insert your symbol into the Block Editor window.

### 3. Add Input & Output Pins to Your Design

Now that you have built the encoder, you must assign pins so that the signals go off chip. However, in the lab you will only simulate the signals. The Quartus II software compiles a design such that the smallest amount of logic is used to implement the functionality of the output pin signals based on the input pin signals. Therefore, if you do not add pins, your design will have no logic after compilation. Add input and output pins to the design by performing the following steps:

3-1. Choose **Edit > Insert Symbol**.

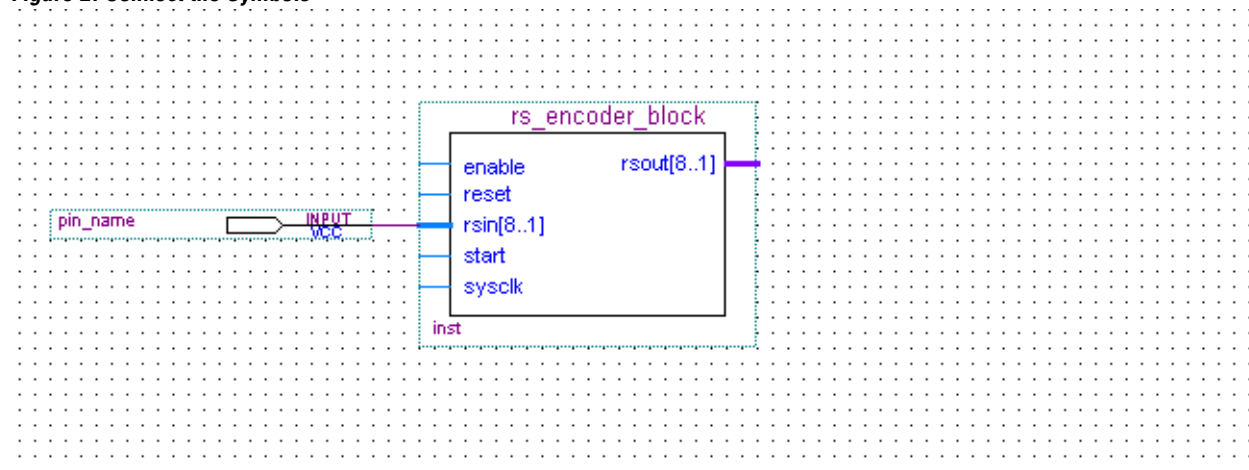
3-2. Enter `input` in the **Name** box. The Input symbol appears.

3-3. Click **OK** and click the insertion point to insert the symbol into the Block Editor window.

You can make connections in a BDF by positioning symbols next to each other so that the lines are touching (When you move one of the blocks away from the other, a connection line appears.), or by drawing a line between the two ports you want to connect. When you point to the line on an input/output port, it turns into a drawing tool and allows you to draw a line.

3-4. Connect the input port `rsin[8..1]` to the Input symbol at the top left of the Reed-Solomon block. See [Figure 2](#).

**Figure 2. Connect the Symbols**




 Search for “Choosing a Line Style” in Quartus II Help for information on how to change the line weight.

3-5. Double-click the Input symbol next to the **pin\_name** label in the Block Editor window.

This will highlight the **pin\_name** text, allowing you to change the pin name.

3-6. Enter the input name into the **Input Pin** symbol.

 The input pin name **Must** be the same name as the corresponding port on the Reed-Solomon symbol to work with the Altera-provided vector files (in a later step). For example, if the Reed-Solomon symbol signal name is `rsin[8..1]`, you must name the input pin `rsin[8..1]`.

3-7. Click **OK**. The default voltage is the pin voltage if no external device drives it to another value. Leave this value at the default, which is VCC.

3-8. Add input pins for all of the Reed-Solomon block inputs.

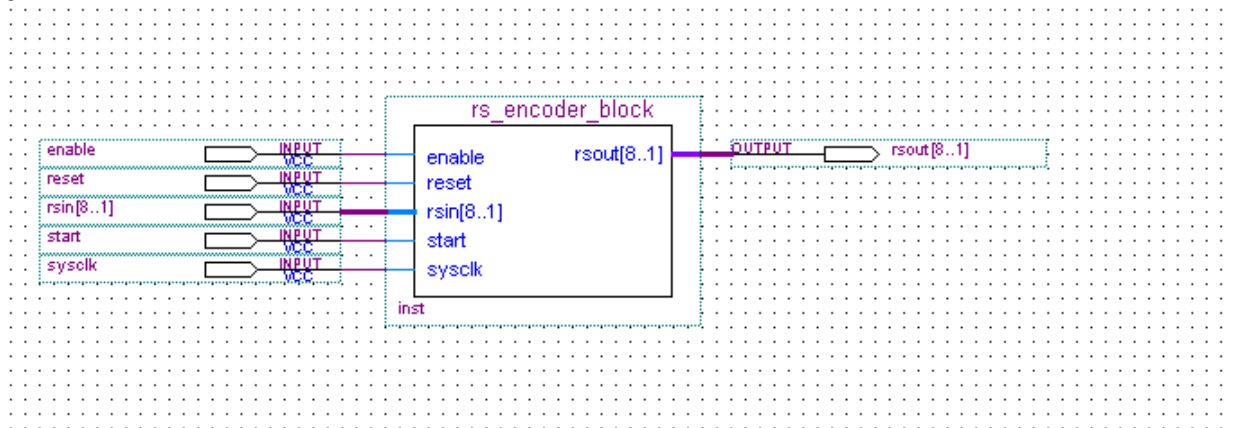
 Ensure that all pin names match those on the Reed-Solomon symbol.

3-9. Repeat [step 3-1.](#) through [step 3-7.](#) for the output pin (entering `output` in the **Symbol** dialog box **Name** box). [Figure 3](#) shows the completed design.

3-10. In a .bdf, thick lines represent a bus of two or more bits, and thin lines represent a single-bit bus. The `rsin` and `rsout` pins must be connected by using the “bus line” style, as follows:

- Place your mouse cursor over the line connecting the `rsin (8..1)` pin, with the `rsin (8..1)` port on the RS symbol.
- While the cursor is over that line, right-click your mouse and choose the **Busline** option.
- Repeat steps (a) and (b) for the output pins connection.

**Figure 3. Reed-Solomon Encoder BDF**




#### 4. Compile the Design

The next step is to analyze and synthesize the design so that you can perform functional simulation. During this step, the Quartus II software synthesizes your design but does not perform place-and-route. Perform the following steps to compile.

- 4-1. Choose **Processing > Start Analysis & Synthesis.**
- 4-2. If you have not saved your .bdf file, a message will be displayed, stating “Save changes to `rs_encoder.bdf.`”

Compilation stops if the Compiler issues any errors. The Status window shows the compilation progress and the Message window displays messages and errors. You can find help on any error message by right clicking on the message and choosing **Help**. To locate an error in your design, double-click on the error message.

 For a more detailed explanation on how to compile a design, refer to “Session 8: Compile the Design” in the Quartus II Tutorial.

[Figure 4](#) shows the messages you receive while compiling.

**Figure 4. Reed-Solomon Encoder Compilation Messages**

```

Info: Found 1 design units and 1 entities in source file c:\quartuswb\qdesigns\reed-solomon\rs_encoder.bdf
Info: Found 1 design units and 1 entities in source file c:\quartuswb\qdesigns\reed-solomon\rs_encoder_block.tdf
Info: Found 1 design units and 1 entities in source file c:\megacore\reed-solomon_compiler-v3.2.0\lib\RS_enc.tdf
Info: Assertion information: Compiling ALTERA's Reed-Solomon Encoder MegaCore Function
Info: Found 1 design units and 1 entities in source file C:\quartusWB\libraries\megafunctions\lpm_counter.tdf
Info: Found 1 design units and 1 entities in source file C:\quartusWB\libraries\megafunctions\alt_synch_counter.tdf
Info: Found 1 design units and 1 entities in source file c:\megacore\reed-solomon_compiler-v3.2.0\lib\gfmul_cnt.tdf
Info: Implemented 232 device resources
Info: Implemented 8 output pins
Info: Automatically selected device EP20K30ETC144-1 for design rs_encoder
Info: Started 1 fitting attempt on Thu Aug 30 2001 at 14:18:22
Warning: Found pins functioning as undefined clocks and/or memory enables
Info: Clock sysclk has Internal fmax of 108.8 MHz between source register
rs_encoder_block:inst|RS_enc:RS_enc_component|lpm_counter:count|alt_synch_counter:wysi_counter[q[5] and destination register
rs_encoder_block:inst|RS_enc:RS_enc_component|reg[12][1] (period= 9.191 ns)
Info: Design rs_encoder: Full compilation was successful. 0 errors, 3 warnings

```



If you are evaluating the Reed-Solomon core using the OpenCore feature, you will also receive warning messages that the Compiler cannot generate programming files. These warnings do not affect the lab.

### 5. Simulate the Design

In this step, you will use an Altera-provided vector file to simulate the design.

- 5-1. Choose **Assignments > Settings**.
- 5-2. Click the **Mode** option, under the **Simulator** settings, on the left side of the window.
- 5-3. Select **Functional** from the **Simulation mode** drop-down list.
- 5-4. Select the **Time/Vectors** option, under the **Simulator** settings, on the left side of the window.
- 5-5. Click the **Browse (...)** button in the **Vectors** box.
- 5-6. Browse to the **c:\MegaCore\stratix\_dsp\_kit-v1.0.0\Labs\Error\_Correction\Exercise1** directory.
- 5-7. Select the **RS\_Encoder.vwf** file and click **Open**.

The signal names in the vector file correspond to the input/output pin names that you specified in "3. Add Input & Output Pins to Your Design" on page 5. The stimuli in this file will exercise the Reed Solomon encoder.

The data bus (`rsin[8..1]`) consists of 188 bytes (1 through 188), which is the data to which the encoder adds check symbols.

The `start` bit is only held high for the first valid byte of each block of data.

The file has clock, reset and enable signals. The core resets once at the beginning of the file and is enabled for the rest of the simulation. The simulation output appears on the `rsout[8..1]` bus.

- 5-8. Click **OK**.
- 5-9. Choose **Run Simulation** (Processing menu). The Quartus II software analyzes and elaborates the design, and then performs simulation.

## 6. View the Simulation Results

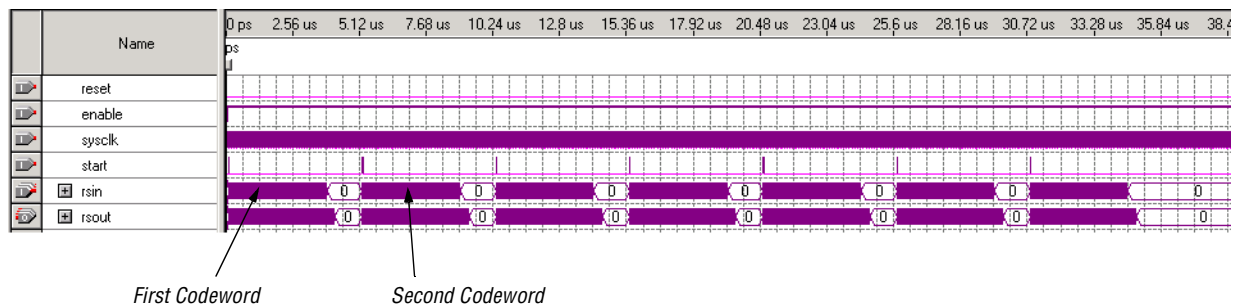
View the simulation results to see the 16 check symbols that were added to the end of each codeword.

6-1. Choose **View > Full Screen** to expand the simulation view.


You can zoom in by pressing the Ctrl + Space Bar keys; zoom out by pressing the Ctrl, Shift + Space Bar keys.

6-2. Zoom all the way out. See [Figure 5](#).

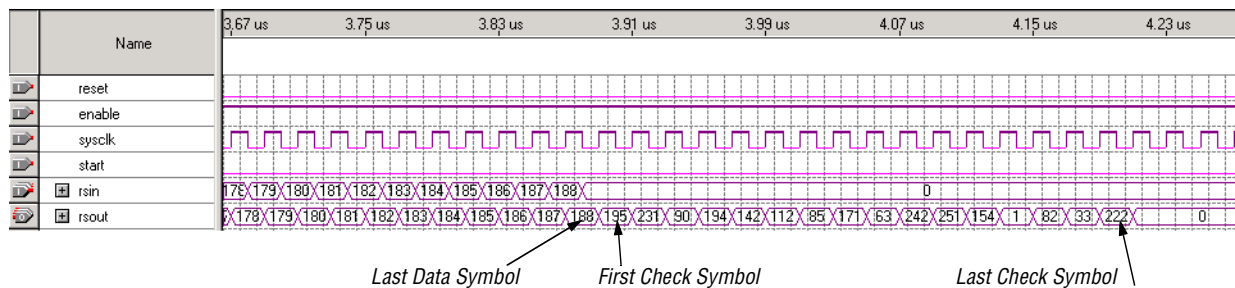
**Figure 5. Simulation Zoomed Out**



6-3. Zoom in on the first codeword to see the check symbols. The data symbols in this project are the numbers 1 through 188. The first check symbol immediately follows the 188 value. See [Figure 6](#).

 To locate a particular codeword, zoom out so that the codewords appear as shown in [Figure 5](#). Highlight the codeword you want to view and zoom in using the Control + Space Bar keys.

**Figure 6. Zoom in to See Check Symbols**



## Exercise 2: Build a Reed-Solomon Decoder

In this exercise you will create a Reed-Solomon decoder and verify the functionality of the encoder and decoder. The decoder corrects up to 8 different errors in the encoded codewords. This exercise involves the following steps:

1. Create a Quartus II project.
2. Generate a Reed-Solomon decoder using the Wizard interface.
3. Add input and output pins to your design.
4. Compile the design.
5. Simulate the design.

6. View the simulation results.
7. Analyze the throughput.
8. Analyze the effective silicon cost.

### 1. Create a Quartus II Project

Follow these steps to create a new project. This process is similar to the one in "1. Create a New Quartus II 2.2 Project" on page 2.

- 1-1. If you have a project open, choose **File > Close Project**.
- 1-2. Create a new BDF named **rs\_decoder.bdf** and save it into the **c:\MegaCore\stratix\_dsp\_kit-v1.0.0\Labs\Error\_Correction\Exercise2** directory.
- 1-3. Create a new project based on this file and add the Reed-Solomon user library.

### 2. Generate a Reed-Solomon Decoder Using the Wizard Interface


Create a Reed-Solomon decoder. This process is similar to the one in "2. Generate a Reed-Solomon Encoder Using the Wizard Interface" on page 3.

- 2-1. Launch the MegaWizard Plug-In Manager and create a new megafunction variation.
- 2-2. Select the Reed-Solomon core, specify a language, and name the output file **rs\_decoder\_block** (save it into the **c:\MegaCore\stratix\_dsp\_kit-v1.0.0\Labs\Error\_Correction\Exercise2** directory).
- 2-3. On page 1, make the following selections:
  - Choose the **Decoder** option.
  - Choose **Architecture > Streaming**.
  - Choose **Keysize > Half**.

- 2-4. On page 2, click the **DVB Standard** button.

You have now finished choosing Wizard settings.

- 2-5. Click **Finish** to exit the Wizard, or click **Next** to view the remainder of the Wizard windows.

 Wizard page 3 contains a throughput calculator, which you will use in "7. Analyze Throughput" on page 13 to calculate the decoder's throughput.

- 2-6. Insert the symbol into your BDF.

### 3. Add Input & Output Pins to Your Design

Add input and output pins to the design by performing the following steps:

- 3-1. Insert a VCC symbol into your design using the same method described in "3. Add Input & Output Pins to Your Design" on page 5 for Input symbols except type VCC instead of Input in the **Name** box. Connect the VCC symbol to the Reed-Solomon **dsout** input.
- 3-2. Insert a GND symbol (search for GND instead of VCC) and connect it to the Reed-Solomon **bypass** input.

### 3-3. Add input and output pins.

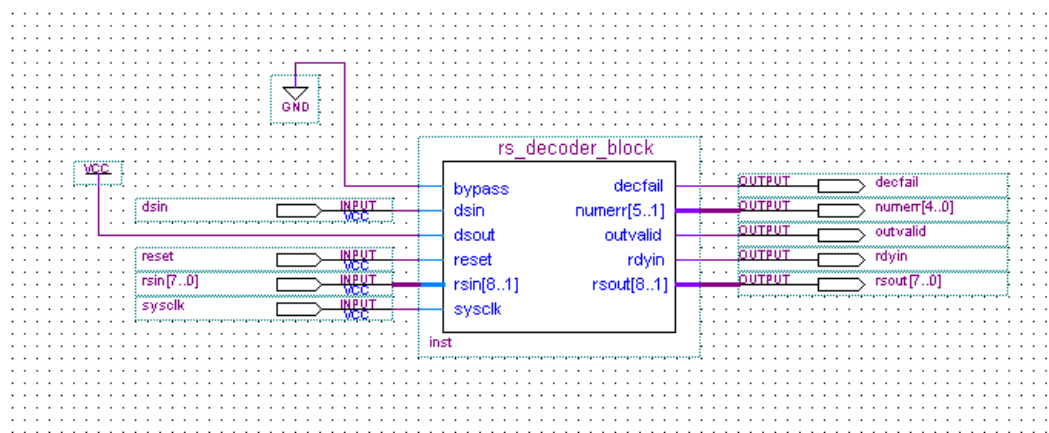


For the encoder all inputs and outputs must have the same name as the ports in the symbol. However, for the decoder, only the single-bit signals must have the same name. The buses must have the same number of bits but the bit numbers can be different.

Name the buses so that the least significant bit is a zero, which makes it simpler to view the simulation results. For example, the port `rsin[8..1]` on the decoder should connect to an input pin named `rsin[7..0]`. In a typical FEC system, the least significant bit is used to determine when valid data is on the data bus. It could be used, for example, to synchronize other blocks such as an interleaver.

Figure 7 shows the completed decoder BDF.

**Figure 7. Decoder BDF**



## 4. Compile the Design

The next step is to analyze and synthesize the design, making it possible to run a functional simulation on the Reed-Solomon decoder design.

4-1. In the **Processing** menu, choose the **Start > Start Analysis & Synthesis** command.

## 5. Simulate the Design

In this section you will add errors into the Altera-provided Vector Waveform File (**.vwf**) and then simulate the decoder.


5-1. Choose **Open** (File menu).

5-2. Select **Waveform/Vector Files (\*.vwf, \*.vec, \*.tbl)** from the **Files of type** drop-down list box.

5-3. Browse to the **c:\MegaCore\stratix\_dsp\_kit-v1.0.0\Labs\Error\_Correction\Exercise2** directory.

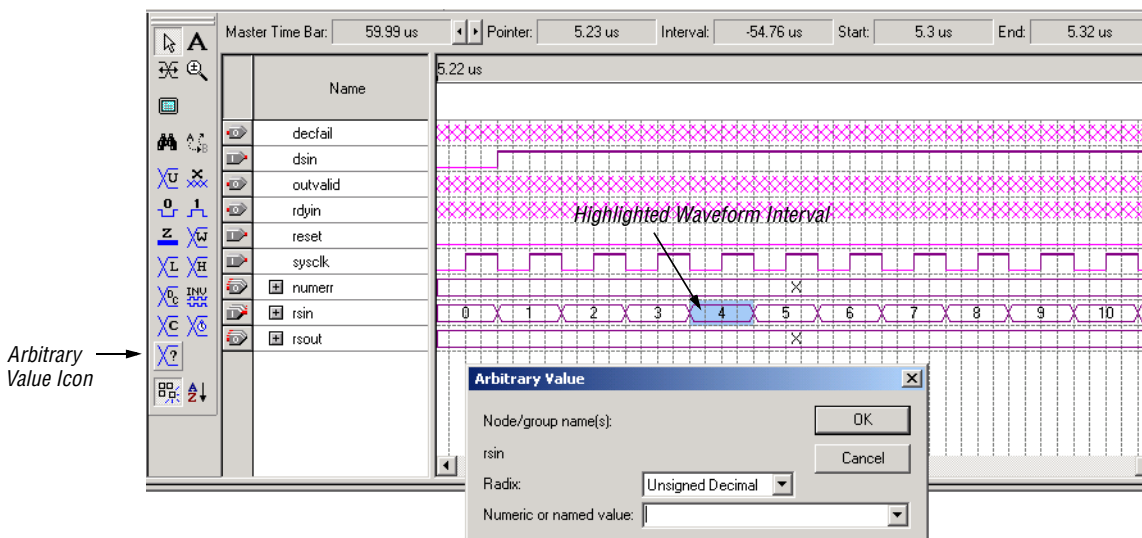
5-4. Select the **RS\_Decoder.vwf** file and click **Open**. The encoder you built in exercise 1 works together with the decoder you just built. The decoder expects to receive the encoder data and check symbols on the input port `rsin[8..1]`. The **RS\_Decoder.vwf** `rsin[7..0]` node contains the simulation output from the encoder. The codewords, given in the `rsin` node, all consist of the same data symbols (1 through 188) plus the corresponding check symbols.

Leave the first codeword as is: it will be used to ensure that all of the signals have the appropriate check symbols appended to them. This decoder input (the `rsin` node) has exactly the same values as the encoder `rsout` node in [Figure 6 on page 8](#).

 To locate a particular codeword, zoom out so that the codewords appear as shown in [Figure 5 on page 8](#). Highlight the codeword you want to view and zoom in using the Control + Space Bar keys.

- 5-5. In the second codeword, change any 8 of the values. You can make the values all zeros, all ones, or any value except the current one. After simulating, you will check the values to make sure the decoder is correcting up to 8 errors per codeword—because the decoder has 16 check symbols, they should all be corrected. Refer to [Figure 6 on page 8](#) to see where the codewords are located. To change a value, perform the following steps.
- The Waveform Editor toolbar should be visible. If it is not, choose **Toolbars** (Tools) menu and ensure that the **Waveform Editor** option is turned on. Click **OK**. The tool bar buttons are grayed out until you highlight a signal in the waveform.
  - Select the portion of the waveform value you want to change by double-clicking on the waveform interval (you can also select it with the mouse). The interval is highlighted. Only select the node that you want to change—the simulations do not work properly if you select portions of the waveform that are above or below the `rsin[7..0]` signal. See [Figure 8](#).

**Figure 8. Editing the Waveform**




- Click the **Arbitrary Value** icon in the Waveform Editor toolbar.
  - Enter a number between 0 and 255 in the **Numeric or named value** box.
  - Click **OK**. The new value displays in the waveform.
- 5-6. In the third codeword, change more than 8 values using the same process as described for the second codeword. After simulating you will view this codeword to see how the decoder fails when it receives too many errors per codeword.
- 5-7. Choose **Save As** (File menu).
- 5-8. Browse to the `c:\MegaCore\stratix_dsp_kit-v1.0.0\Labs\Error_Correction\Exercise2` directory.
- 5-9. Type `my_RS_Decoder.vwf` in the **File name** box.

- 5-10. Click **Save**.
- 5-11. Choose **Assignment > Settings**.
- 5-12. Under the **Simulator Settings** (on the left of the window), click the **Mode** option.
- 5-13. Select the **Simulation mode** drop-down list, and select **Functional**.
- 5-14. Under the **Simulator Settings** (on the left of the window), click the **Time/Vectors** tab.
- 5-15. Click the **Browse (...)** button in the **Vectors** box.
- 5-16. Browse to the `c:\MegaCore\stratix_dsp_kit-v1.0.0\Labs\Error_Correction\Exercise2` directory.
- 5-17. Select the `my_RS_Decoder.vwf` file and click **Open**.

The signal names in the vector file correspond to the input/output pin names that you specified in "3. Add Input & Output Pins to Your Design" on page 9.

- 5-18. Click **OK**.
- 5-19. Choose **Run Simulation** (Processing menu). The simulation runs for five to ten minutes, depending on the speed of your PC. You will receive a message when simulation is complete.

 You will receive warning messages regarding asynchronous resets during the simulation. These are due to the internal operation of the Reed-Solomon Decoder, and they will not affect the simulation results.

## 6. View the Simulation Results

The decoder uses the check symbols that the encoder appended to the data symbols to correct any errors that were introduced into the data stream; it can correct 1 error for every 2 check symbols. The decoder asserts a signal (`outvalid`) when valid data is output on the `rsout[8..1]` port. The decoder has a three codeword latency, i.e., it must receive three codewords before the first one is output. Refer to the *Reed-Solomon MegaCore Function User Guide* for complete information on the Reed-Solomon compiler core operation. Table 1 describes the functionality of the decoder signals used in this exercise.

**Table 1. Reed-Solomon Decoder Signals**

Signal	Direction	Description
<code>sysclk</code>	Input	System clock.
<code>reset</code>	Input	Decoder reset. The discrete decoder must be reset between each codeword.
<code>rsin[]</code>	Input	$m$ -bit wide input data bus.
<code>bypass</code>	Input	When asserted, the decoder outputs the uncorrected input data instead of the corrected data. All other operations are unaffected and the decoder's latency remains the same.
<code>rsout[]</code>	Output	$m$ -bit wide output data bus.
<code>decfail</code>	Output	Asserted at the beginning of a data output when the decoder has detected errors and cannot correct them.
<code>numerr[]</code>	Output	Number of symbol errors found. Displays up to the maximum number of correctable errors.
<code>dsin</code>	Input	Data input control. Data input only takes place in clock cycles when <code>dsin</code> is asserted. In the discrete and streaming decoders <code>dsin</code> must remain de-asserted for at least one clock cycle after <code>reset</code> is de-asserted.
<code>dsout</code>	Input	Data output control. Data can be output when <code>dsout</code> is asserted. If <code>dsout</code> is not asserted, data is not output. There is a three-cycle latency between a change in <code>dsout</code> and the time when the output starts and stops.
<code>rdyin</code>	Output	Indicates the decoder is ready to accept a new codeword.
<code>outvalid</code>	Output	Asserted when the decoder outputs a codeword.

Perform the following steps to view the simulation results, verifying whether the decoder is working properly.

- 6-1. **Choose Processing > Open Simulation Report.**
- 6-2. Search through the Simulation Report (.vwf) to find where the `outvalid` signal goes high for the first time. Confirm that the values 1 through 188, plus the check symbols, all occur while the `outvalid` signal is high.
- 6-3. Check the second codeword. Confirm that the values 1 through 8 that you changed in [step 5](#) are corrected. Confirm that the `numerr` signal appropriately reports the number of errors that were corrected.
- 6-4. Check the third codeword. Confirm that the decoder did fail, and that the `numerr` signal is correct.

### 7. Analyze Throughput

In this portion of the lab you will determine the throughput of the FEC system using the decoder simulation results. The first step is to specify a specific device in which to implement the design and run a full compile. After compilation, the Quartus II software reports the design's  $f_{MAX}$ , which is the maximum clock frequency the decoder can achieve without setting design constraints. To determine the decoder throughput, perform the following steps.


- 7-1. Choose **Assignments > Device.**
- 7-2. Select **Stratix** in the **Family** drop-down list box.
- 7-3. Click **No** if you are asked if you want to allow the Compiler to select a device automatically.
- 7-4. Select the **EP1S25F780C5** or **EP1S80B956C6** device under **Available devices**, depending on which board you are using.
- 7-5. Click **OK.**
- 7-6. Choose **Start Compilation** (Processing menu) to begin a full compilation.

The Quartus II v2.2 software analyzes and elaborates the design, and fits it into the target device. The Quartus II Timing Analyzer reports the fastest clock speed at which the logic runs. The design's  $f_{MAX}$  is displayed in the Message Window. You can also perform the following steps to view the  $f_{MAX}$ .

- a. Choose **Open Compilation Report** (Processing menu).
- b. Expand **Timing Analyses.**
- c. Click **fmax (not incl. delays to/from pins).**
- d. Scroll all the way to the right to view the  $f_{MAX}$  for `sysclk`.

You will use this speed for the throughput analysis.

- 7-7. Page 3 of the decoder wizard has a throughput calculator. Using the clock frequency you found in step 8, calculate your system throughput, as follows.
  - a. Launch the decoder Megawizard.
  - b. Open your .bdf file and double-click the Reed-Solomon symbol to launch the MegaWizard.
  - c. Click **Next** to page 3.

 The throughput calculator expects the  $f_{MAX}$  to be in MHz.

The following steps explain how the calculator calculates the throughput, assuming a 150-MHz  $f_{MAX}$ . The design has 204 bytes (188 data symbols and 16 check symbols) that are processed at the rate of one byte per clock cycle. The throughput of the system can be found by multiplying the clock frequency times the size of the codewords, and then dividing by the number of clock cycles needed to process a codeword. In this example the Reed-Solomon throughput calculator assumes that there will be a sixteen-clock cycle gap between codewords. Thus,  $(204 \times 150 \text{ MHz}) / (204 + 16) = 139.09$  mega-symbols per second.

### 8. Analyze the Effective Silicon Cost

In this portion of the lab you will determine the effective silicon cost of the FEC system. Altera Stratix devices are made up of logic elements (LEs) that perform the necessary digital logic manipulation. The more LEs a design uses, the bigger the device needed. Therefore, the amount of logic in a design dictates the effective silicon cost. You can determine the number of LEs your design uses by looking at the Quartus II Report File when compilation completes.

8-1. Determine the resource usage for the decoder.

- a. Choose **Open Compilation Report** (Processing menu)
- b. Expand **Resource Section**.
- c. Click **Resource Usage Summary** to view the number of LEs used. (The design uses roughly **2,171 LEs**.)
- d. Choose **Close Project** (File menu) when you are done.

8-2. Determine the resource usage for the encoder.

- a. Open the encoder project.
- b. Perform a full compilation (you can specify the same device you used for the encoder or let the Quartus II Compiler choose one automatically).
- c. Open the compilation report and view the LEs used. (The design uses roughly 209 LEs.).

8-3. Add the LEs used for the encoder and decoder. This number is the total number of LEs required for the entire FEC system.

8-4. You can calculate the effective silicon cost by multiplying the percentage of LEs used times the device price. For example, you can implement the 983 Mbit/second, 2,171-LE decoder design on an Altera EP1C3 Cyclone™ device (which has 2,910 LEs) for \$7.

## Exercise 3: The Reed-Solomon Demonstration

The Altera Reed-Solomon demonstration shows the benefits of using Altera's forward error correction (FEC) solutions. The demonstration consists of a Windows application in which you specify a picture to transmit over a channel using the Reed-Solomon encoder/decoder. You can use this application to alter the type and intensity of errors inserted into the data as it passes through the channel. The DSP development board implements the hardware portion of the design, which includes the encoder, decoder, and channel.

After you select the picture and error type, the bytes representing the colors of the pixels within the picture are transmitted to the board via an RS-232 port. The data is loaded into a Nios™ embedded processor, which stores it in a FIFO buffer. The data is read out of the FIFO buffer and processed in two ways, as follows.

- One data path goes through the selected channel only and the picture is displayed in the GUI with the errors visible.

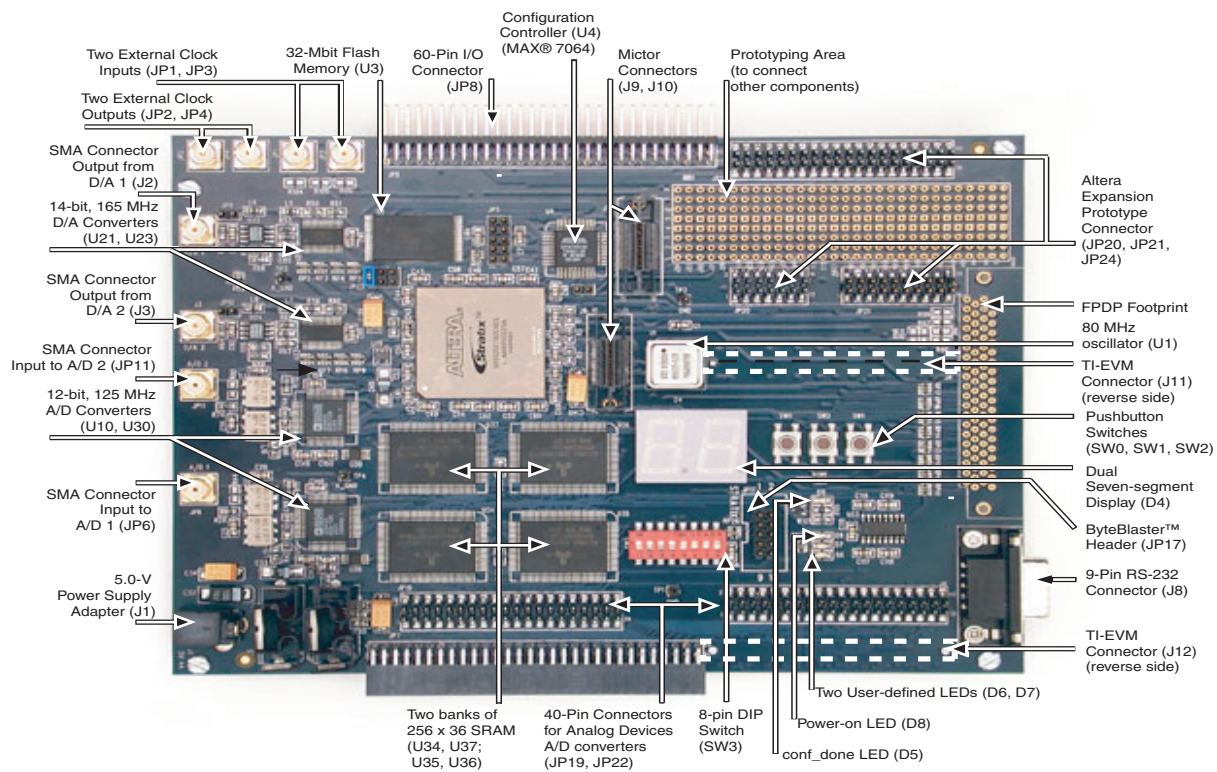
- The other data path goes through the Reed-Solomon encoder, through the channel, through the Reed-Solomon decoder, and then the picture is displayed in the GUI.

The MegaCore functions in this demonstration are configured with the following parameters:

- Half, standard, streaming Reed-Solomon decoder (204, 188)
  - 8-bit symbol width
  - 204 symbols per codeword ( $N = 204$ )
  - 16 check symbols ( $R = 16$ )

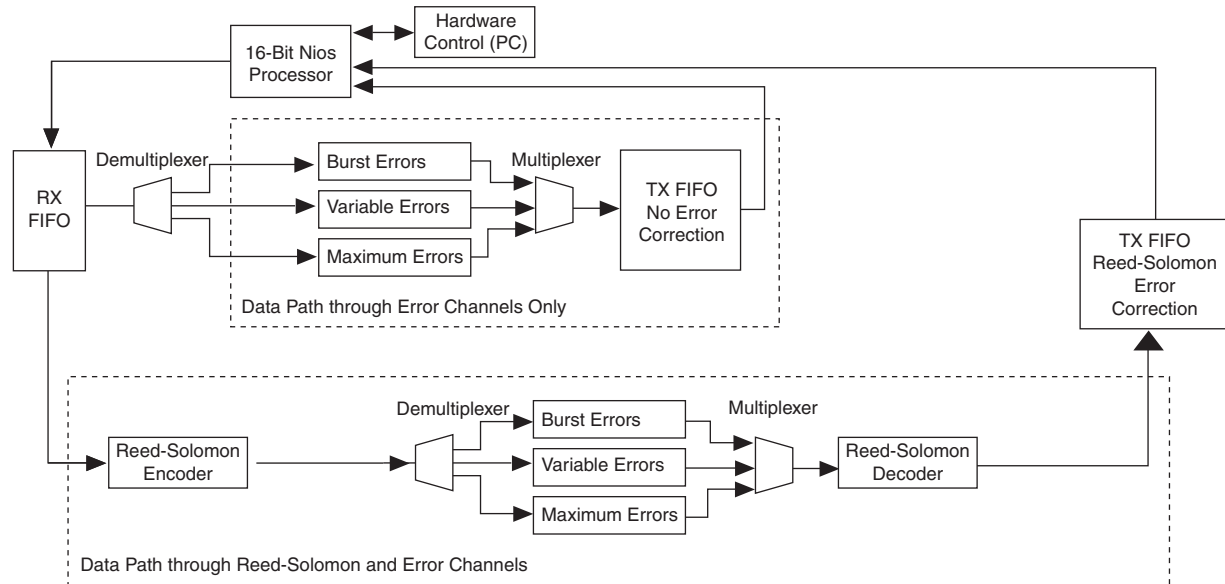
The demonstration runs at 33 MHz, generated by the DSP development board from the 80-MHz clock. [Figure 9](#) shows an overview of the demonstration setup using the Stratix EP1S25 DSP development board. The setup for the Stratix EP1S80 DSP development board is similar.

**Figure 9. Reed-Solomon Demonstration Setup (Stratix EP1S25 DSP Development Board)**



[Figure 10](#) shows a block diagram of the design implemented in the Stratix device on the board.

Figure 10. Block Diagram of Design Implemented in Stratix Device on the Board

**Note:**

- (1) The interleaver/deinterleaver is added if you select the **Burst Errors** option and turn on **Add Interleaver/Deinterleaver** in the application.

**Definitions**

The following definitions apply to this demonstration only:

- **Symbol**—An 8-bit piece of data
- **Codeword**—204 bytes consisting of 188 data symbols and 16 Reed-Solomon check symbols
- **Check symbol**—A symbol that the Reed-Solomon encoder adds to the data so the decoder can correct any errors that occur during the data transmission
- **Data packet**—A 940-byte piece of data
- **BER**—Bit error rate

**1. Connect the Cables to the Board**

Before running the demonstration, you must connect cables to the DSP development board. Refer to the getting started user guide for detailed instructions on how to connect the cables to the board. Perform the following steps to connect the cables:

- 1-1. Connect the power adapter cable to the board and plug it into a power outlet.
- 1-2. Connect the ByteBlaster II cable to your PC and to the board's 10-pin JTAG header for Stratix configuration.
- 1-3. Connect an RS-232 cable to your PC and to the board.

**2. Configure the Stratix Device**

Perform the following steps to configure the device:

- 2-1. Choose **Programs > Altera > Quartus II 2.2 Limited Edition** (Windows Start Menu) or **Programs > Altera > Quartus II 2.2** (Windows Start Menu).
- 2-2. Choose **Programmer** (Tools menu).

2-3. Click **Add File**.

2-4. Browse to the `c:\MegaCore\stratix_dsp_kit-v1.0.0\Labs\Error_Correction\Exercise3\sof` directory.

2-5. Select the file **Reed-Solomon\_Demo\_v3\_stratix.sof**.

2-6. Click **Open**.

2-7. Turn on the **Program/Configure** option.

2-8. Click **Start** to configure the Stratix device.

### 3. Run the Demonstration

This section describes how to run the demonstration. The application does not display properly on systems that use large fonts. To change your font settings, perform the following steps. If you are already using small fonts, skip to step 7.

3-1. Choose **Settings > Control Panel** (Windows Start menu).

3-2. Double-click the **Display** icon.

3-3. Click the **Settings** tab.

3-4. Choose **Small Fonts** under **Font Size**.

3-5. Click **OK**.


3-6. Reboot your system for the changes to take effect.

3-7. Execute the file


`c:\MegaCore\stratix_dsp_kit-v1.0.0\Labs\Error_Correction\Exercise3\Reed-Solomon_Demo_v3.exe` to start the demonstration software.

3-8. Click the **PC Options** button, indicate which COM port you are using, and click **OK**.

3-9. Select the picture to transmit in the **Picture Selection** box.

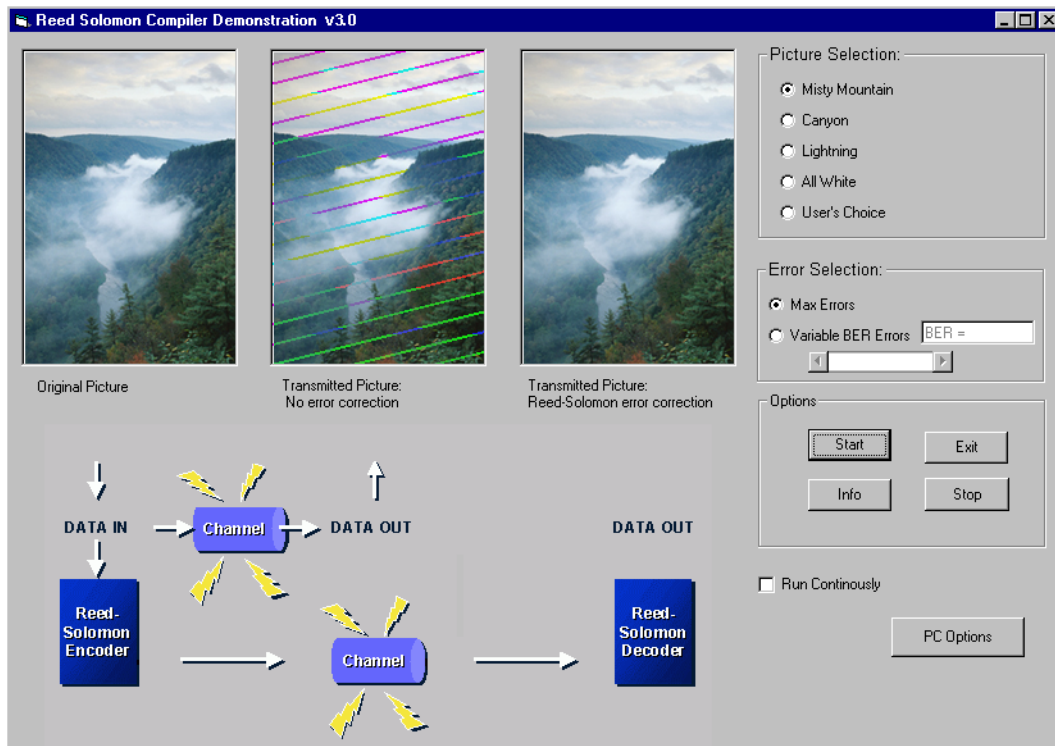
 If you prefer, you can use a picture of your choice instead of the ones provided with the demonstration. See "6. Adding a Custom Picture" on page 19 for more details.

3-10. Select the error type in the **Error Selection** box (The demonstration provides several types of errors that can be injected into the channel. See "5. Error Channels" on page 18. for more details, and click **Start**.

 The flashing LED flashes twice as fast while the data is being processed.

The data paths are shown in the block diagram in the demonstration software GUI. The transmitted pictures are displayed as the data bits are processed. See [Figure 11](#).

Figure 11. Reed-Solomon Demonstration User Interface



#### 4. Transmission Details

Each bitmap image transmitted in this demonstration has three data bytes representing each pixel. Data is transmitted in blocks of 5 Reed-Solomon codewords (188 bytes each for a total data packet of 940 bytes). After a block is transmitted to the board and processed, it is sent back to the demonstration software and displayed in the appropriate window before another data packet is sent. A 16-bit Nios embedded processor receives the data using a UART peripheral from the Nios peripheral library. The Nios processor writes the data into a memory-mapped FIFO buffer, where it is read out and passed to the appropriate data path. Then, the data is written to a pair of memory-mapped FIFO buffers from which the Nios processor reads the data and sends it back to the PC.

#### 5. Error Channels

You can choose from three provided error channels. The **Max Errors** channel deterministically injects 8 errors into each Reed-Solomon codeword. The Reed-Solomon encoder used in this implementation has 16 check symbols, which supports the detection and correction of up to 8 errors per codeword. Therefore, the **Max Errors** channel option injects the maximum number of errors into the data path that the Reed-Solomon decoder can correct.

The **Variable BER** channel lets you select one of several different bit error rates (BERs). This channel injects errors routinely into each codeword, spreading the errors farther apart as lower BERs are selected. The highest BER setting adds 12 symbol errors to each codeword, which is more than this implementation of the Reed-Solomon core can correct. Therefore, this setting causes the Reed-Solomon decoder to fail, and both of the transmitted pictures return with errors.

## 6. Adding a Custom Picture

All bitmaps of the same size have the same structure, therefore you can create a custom picture to transmit. Save your image as **my\_file.bmp** in the **c:\MegaCore\stratix\_dsp\_kit-v1.0.0\Labs\Error\_Correction\Exercise3\application\bmps** directory. The image must be 183 pixels wide by 260 pixels tall.

For example, you can create an image using the Microsoft Paint software by performing the following steps:

- 6-1. View the image on your PC, for example in a web browser or other viewer.
- 6-2. Press the **Print Screen** button on your keyboard to copy the image to the clipboard.
- 6-3. Open Paint and paste the clipboard contents into a new file.
- 6-4. Choose the **Attributes** command (Image menu), set the height to 260 pixels and the width to 183 pixels, and click **OK**. If your current picture is bigger than the new size, it is cut from the right side and bottom to fit within the smaller area. If the current picture is smaller than the new size, the extra area is filled with the selected background color.



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