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RF.Spice A/D

Visual Software Environment For
Analog/Digital/RF/Mixed-Signal
Circuit & System Simulation



Digital Tutorial Lesson 5

Building a Ripple-Carry Adder Using Reusable Digital Adder Devices

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5.1 What You Will Learn

In this tutorial you will first build and analyze binary half adder and full adder circuits made up of logic gates. Then, you will create a new reusable digital device out of the full adder circuit and will store it in the RF.Spice A/D parts database for later use. Next, you will use your reusable digital full adder device to build a four-bit ripple-carry adder circuit.

You can use multiple full adders to build an N-bit adder circuit. Each full adder inputs a C_{in} , which is the C_{out} of the previous adder. This kind of adder is called a ripple-carry adder since each carry bit "ripples" to the next full adder. Note that the first (and only the first) full adder may be replaced by a half adder (under the assumption that $C_{in} = 0$).

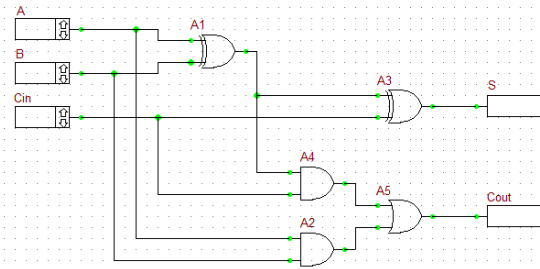
5.2 Building a Binary Half Adder

The following is a list of parts needed for this part of the tutorial lesson:

Part Name	Part Type	Part Value
A	Digital Input	1-bit
B	Digital Input	1-bit
Out1	Digital Output	N/A
S	Digital Output	N/A
C	Digital Output	N/A
A1	Generic XOR Gate	Defaults
A2	Generic AND Gate	Defaults

The binary half adder is a digital circuit that adds two single binary bits A and B. It has two outputs, sum (S) and carry (C). The carry signal represents an overflow into the next significant bit of a multi-bit addition. The equivalent decimal value of the binary sum is $2C + S$. The half adder can be built using an XOR gate and an AND gate as shown in the figure below.

Tutorial Project: Creating Reusable Digital Devices - Binary Half & Full Adders

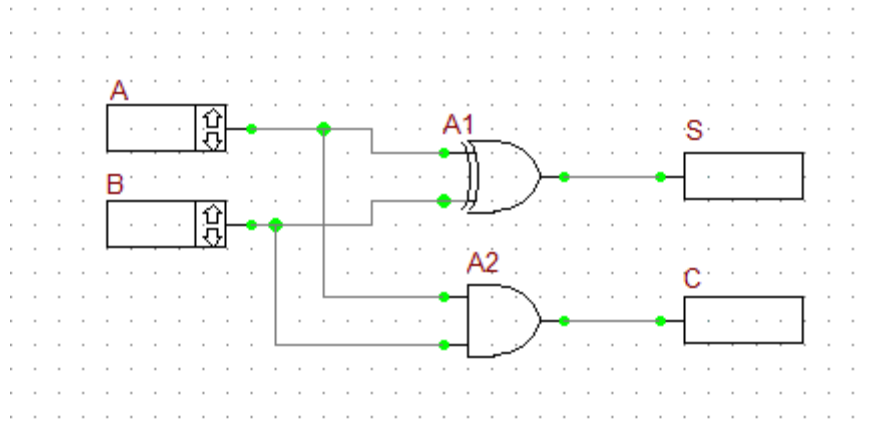


Objective: In this project, you will build binary adder circuits using logic gates and will store them as reusable digital devices in the parts database.

Concepts/Features:

- Half Adder
- Full Adder
- XOR Gate
- Carry Bit
- Reusable Device
- Parts Database
- Binary Counter
- Least Significant Bit
- Most Significant Bit

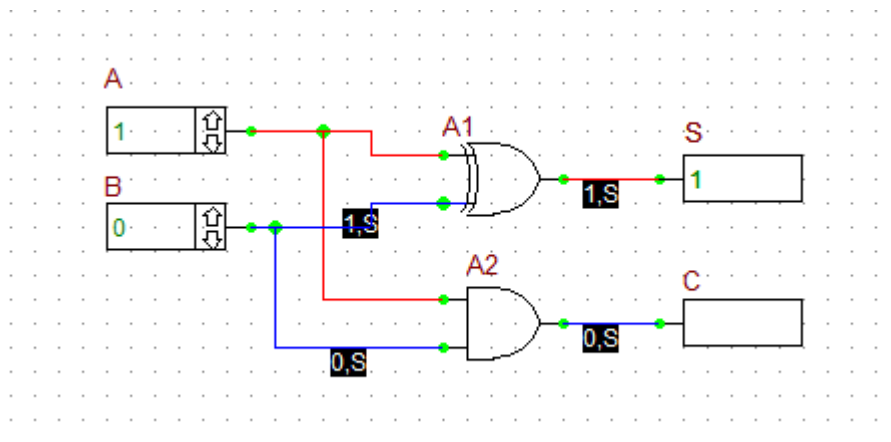
Minimum Version Required: All versions



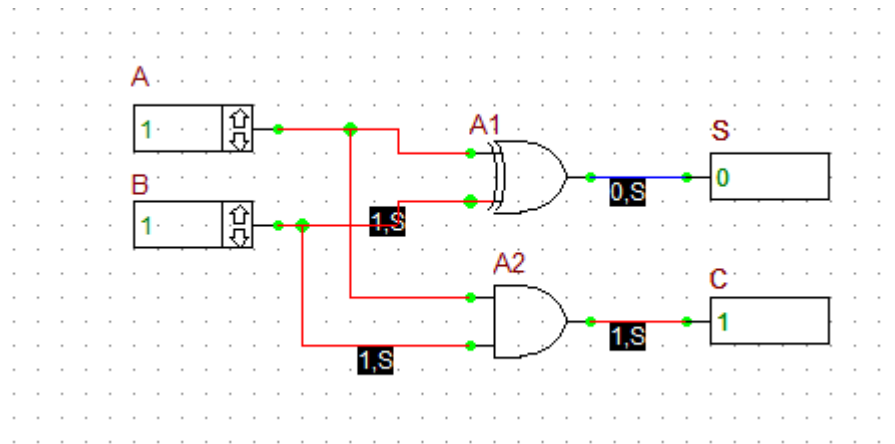
The binary half adder digital circuit.

Connect the parts as shown in the figure. Run a live digital simulation by stepping in time. Use the same time step of 20ns as in the previous tutorial lessons. To generate the truth table of the half adder, set the values of the inputs A and B using their up and down arrow buttons to (0,0), (1,0), (0,1) and (1,1) at each time step, consecutively. Note that when you change the input values, the output does not change instantaneously until you increment the time step. The truth table of the binary half adder and two simulation scenarios are shown in the figures below. In a live digital simulation, RF.Spice's Circuit Animation feature is always enabled by default. You can see the binary state of all the wires. Also note how all the wires of the circuit are color-coded in red and blue for 1 (High) and 0 (Low) states, respectively.

Inputs		Outputs	
A	B	C	S
0	0	0	0
1	0	0	1
0	1	0	1
1	1	1	0



The outputs of the Binary Half Adder when A = 1 and B = 0.

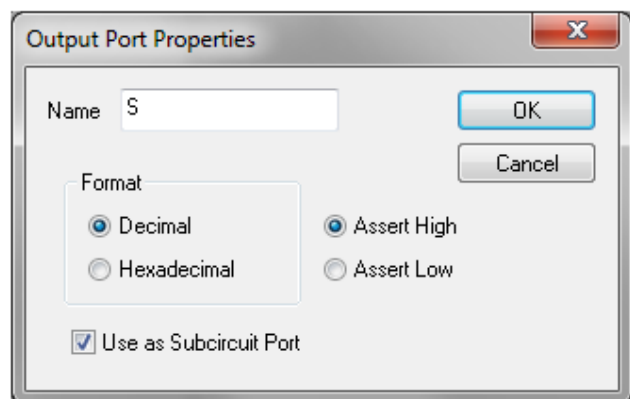
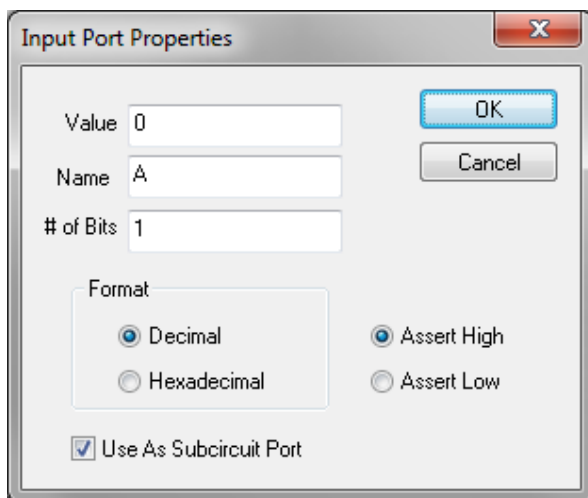


The outputs of the Binary Half Adder when $A = B = 1$.

5.3 Creating a Reusable Digital Device from Your Half Adder Circuit

In this part of the tutorial lesson, you will create a reusable digital device out of your binary half adder circuit. This procedure is very similar but much simpler than the case of analog circuits you carried out in Analog Tutorial Lesson 5. If you open the property dialog of your digital inputs or outputs, you will notice that a checkbox labeled **Use As Subcircuit Port** has been already been checked by default. This means that RF.Spice A/D takes your digital circuit with all the designated input and output ports and packages it as a digital device "As Is".

Go the File Menu and select **Create Part from Circuit...** or simply use the keyboard shortcut **Ctrl+M**. A dialog pops up asking you to enter a name for your new device. Enter "MyHA" (My Half Adder) for the name of your half adder circuit. Then, the program asks you if you want it to create a symbol for your new device. Answer "Yes" and proceed. The device will be generated and added to your Parts Database. Keep in mind that you can create your own symbols or modify the program-generated symbol using RF.Spice's Symbol Editor.



The property dialogs of Digital Input and Digital Output parts.

5.4 Building a Binary Full Adder

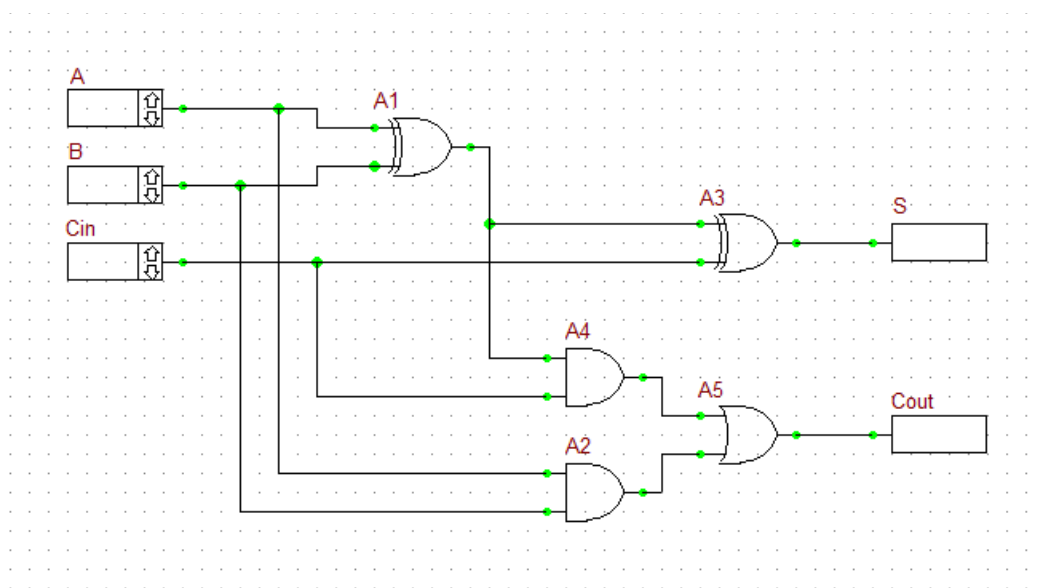
The following is a list of parts needed for this part of the tutorial lesson:

Part Name	Part Type	Part Value
A	Digital Input	1-bit
B	Digital Input	1-bit
Cin	Digital Input	1-bit
Out1	Digital Output	N/A
S	Digital Output	N/A
Cout	Digital Output	N/A
A1	Generic XOR Gate	Defaults
A2	Generic AND Gate	Defaults
A3	Generic XOR Gate	Defaults
A4	Generic AND Gate	Defaults
A5	Generic OR Gate	Defaults

A binary full adder is a digital circuit that adds two single binary bits A and B and accounts for values carried in as well as out. It adds three bits: A, B, and Cin, a bit carried in from the previous less significant stage. The circuit produces a two-bit output, sum (S), and output carry (C). The equivalent decimal value of the binary sum is $2C_{out} + S$. A full adder can be constructed from two half adders by feeding the inputs A and B to the first half adder, connecting the sum from the first half adder to an input to the second half adder, connecting Cin to the other input of the second half adder and passing the two carry outputs of the two half adders through an OR gate.

Connect the parts as shown in the opposite figure.

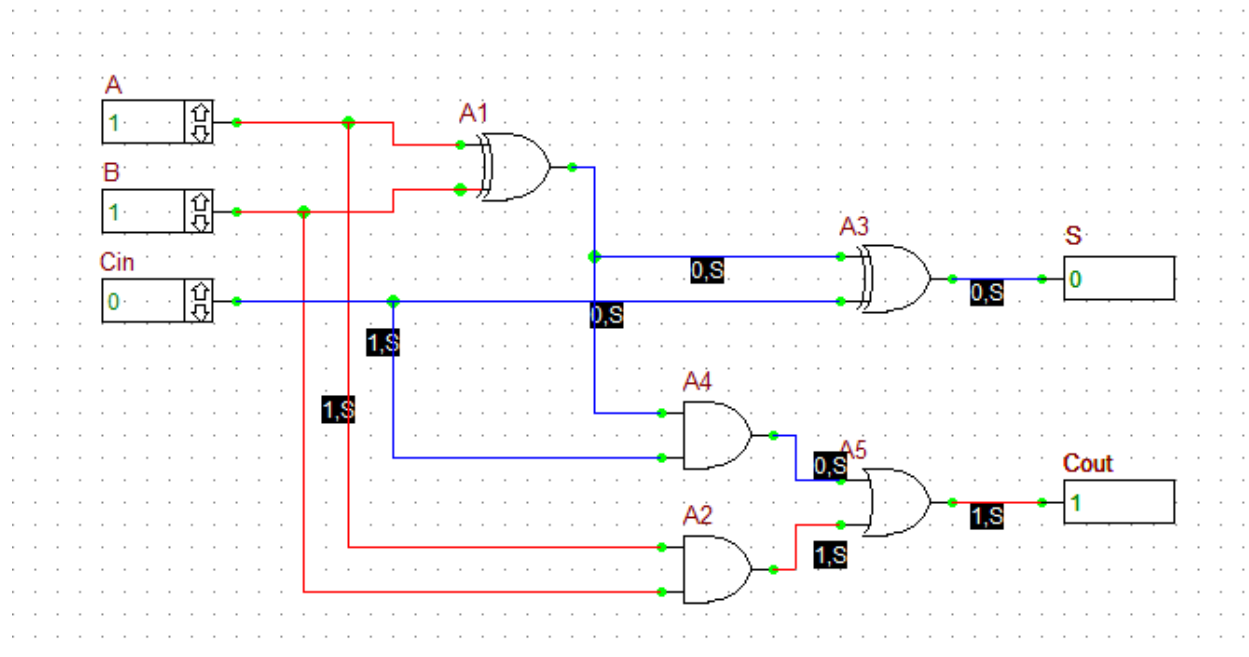
Run a live digital simulation of your circuit using manual stepping. Generate the truth table of the full



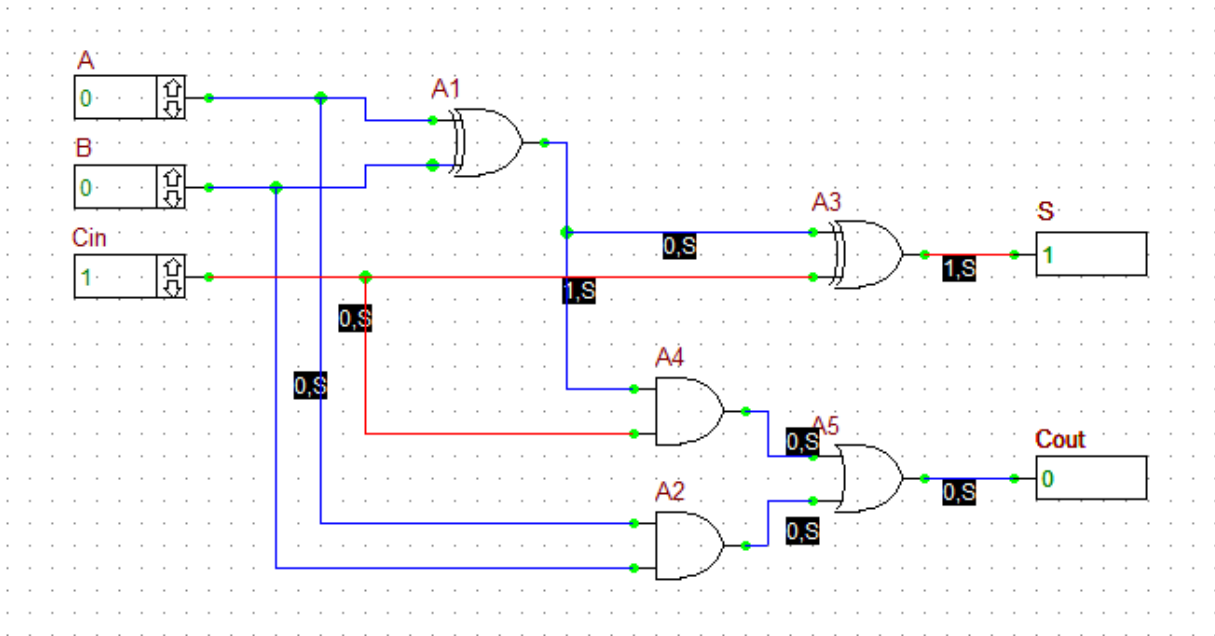
The Binary Full Adder digital circuit.

adder circuit in a similar manner as in the previous case. However, in this case, first you set $C_{in} = 0$, change the values of A and B, and then you set $C_{in} = 1$, and repeat the procedure. The truth table of the binary full adder and four different simulation scenarios are shown in the figures below. As you can see from the figures, RF.Spice's color coding of the digital wires comes in very handy.

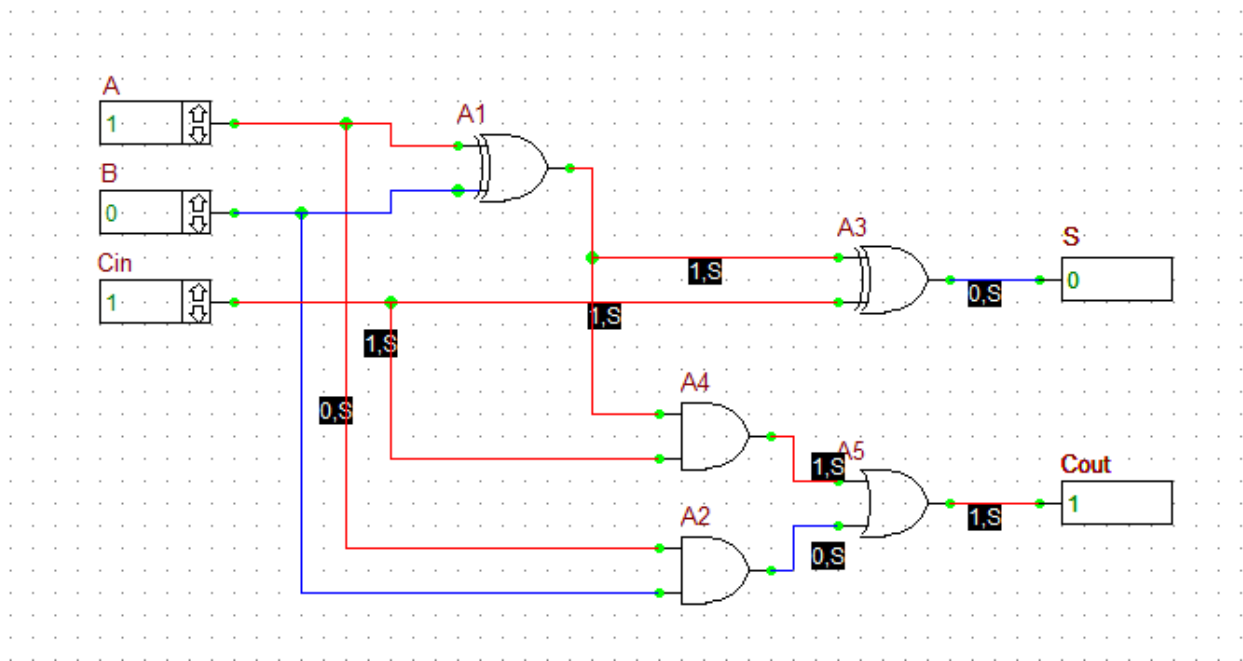
Inputs			Outputs	
A	B	C_{in}	C_{out}	S
0	0	0	0	0
1	0	0	0	1
0	1	0	0	1
1	1	0	1	0
0	0	1	0	1
1	0	1	1	0
0	1	1	1	0
1	1	1	1	1



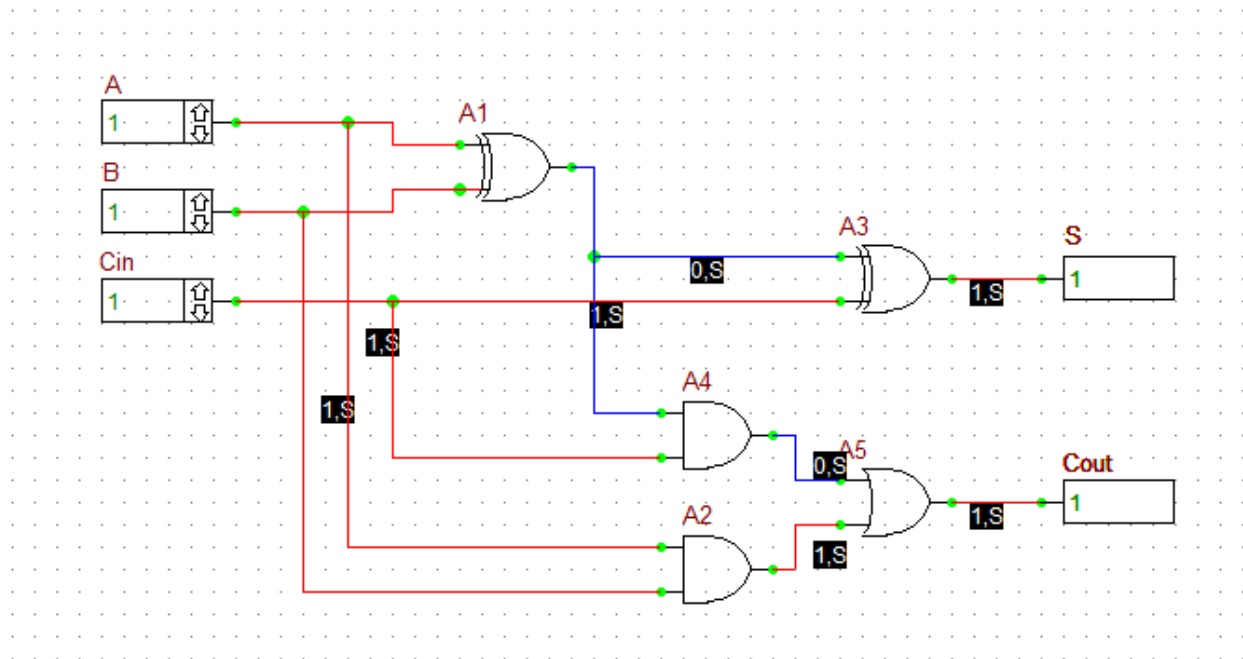
The outputs of the Binary Full Adder when $C_{in} = 0$ and $A = B = 1$.



The outputs of the Binary Full Adder when $Cin = 1$ and $A = B = 0$.



The outputs of the Binary Full Adder when $Cin = 1$ and $A = 1$ and $B = 0$.



The outputs of the Binary Full Adder when $Cin = 1$ and $A = B = 1$.

5.5 Creating a Reusable Digital Device from Your Full Adder Circuit

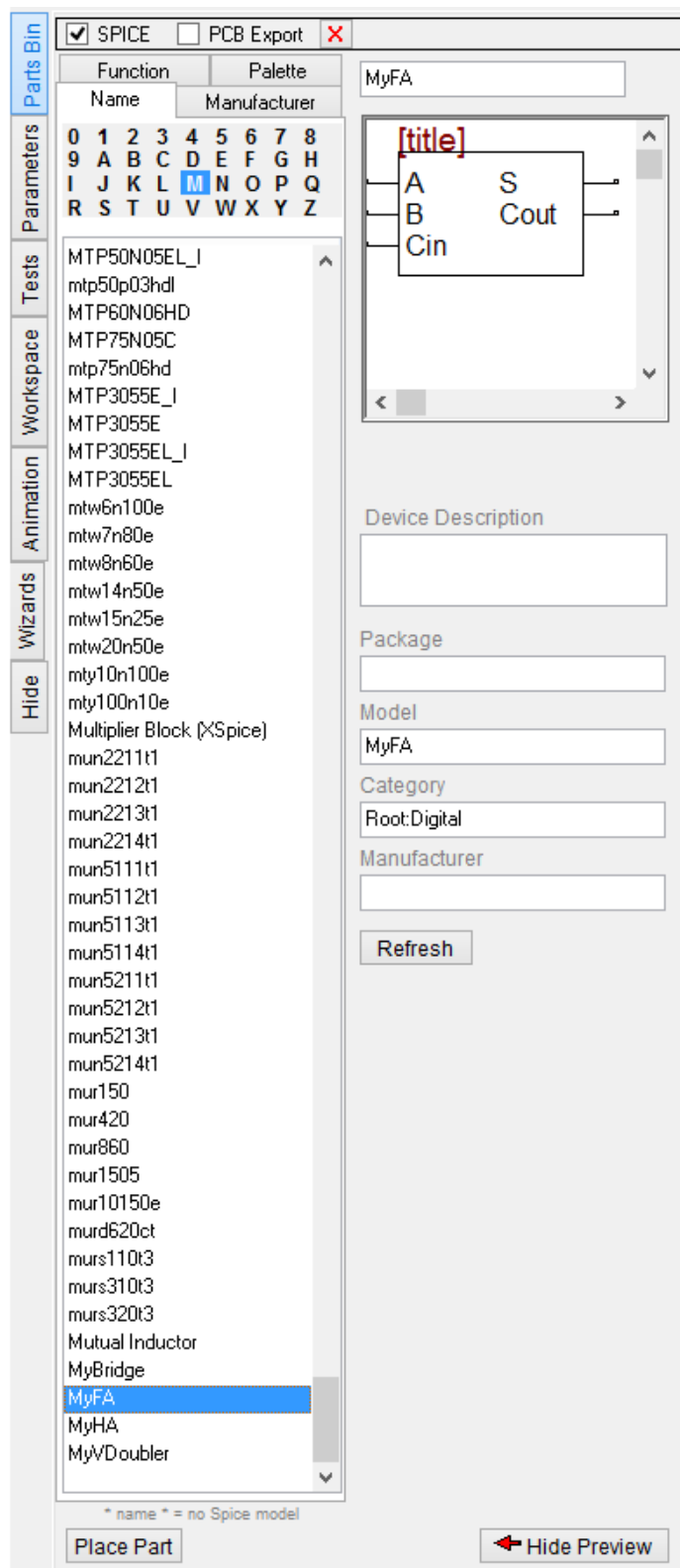
Using the same procedure you carried out earlier in this tutorial lesson, create a new reusable digital device out of your full adder circuit. Choose the name "MyFA" (My Full Adder) for your new device and let RF.Spice A/D create a default automatic symbol for the device. Note that "MyHA" was a 4-pin device with 2 input pins and 2 output pins, while "MyFA" is a 5-pin device with 3 input pins and 2 output pins. You will use both of your new reusable digital devices for the construction of the circuit in the next tutorial lesson.

5.6 Building a Ripple-Carry Adder

The following is a list of parts needed for this part of the tutorial lesson:

Part Name	Part Type	Part Value
A0 - A3	Digital Input	1-bit
B0 - B3	Digital Input	1-bit
S0 - S3	Digital Output	N/A
Cout	Digital Output	N/A
U1	Reusable Digital Device MyHA	Defaults
U2 - U4	Reusable Digital Device MyFA	Defaults

In this tutorial lesson, you will build a 4-bit ripple-carry binary adder using the half adder and full adder devices you created in the previous tutorial lesson. To find and place your new adder parts, you can go to the Parts Bin of the Toolbox and search for "MyHA" and "MyFA" alphabetically under the letter "M".

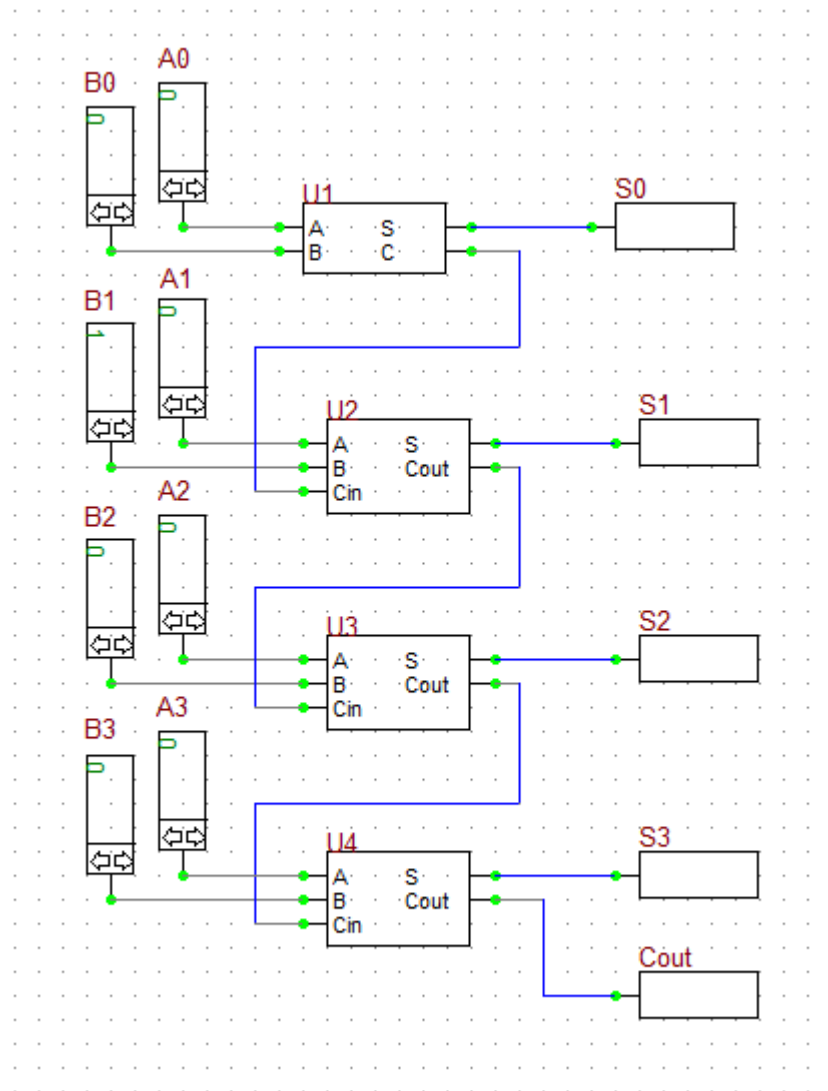


Finding a device in the Parts Bin of the Toolbox.

Alternatively, you can open the "Select Device Dialog" by choosing **Menu > Parts > Select Part....** If you know the device's name, you can type it in the box labeled **Name** and click the **Find** button. Or you can use the device database filter and type in a few letters, e.g. "My" to find both of your devices.

Finding a device using the "Select Device" dialog.

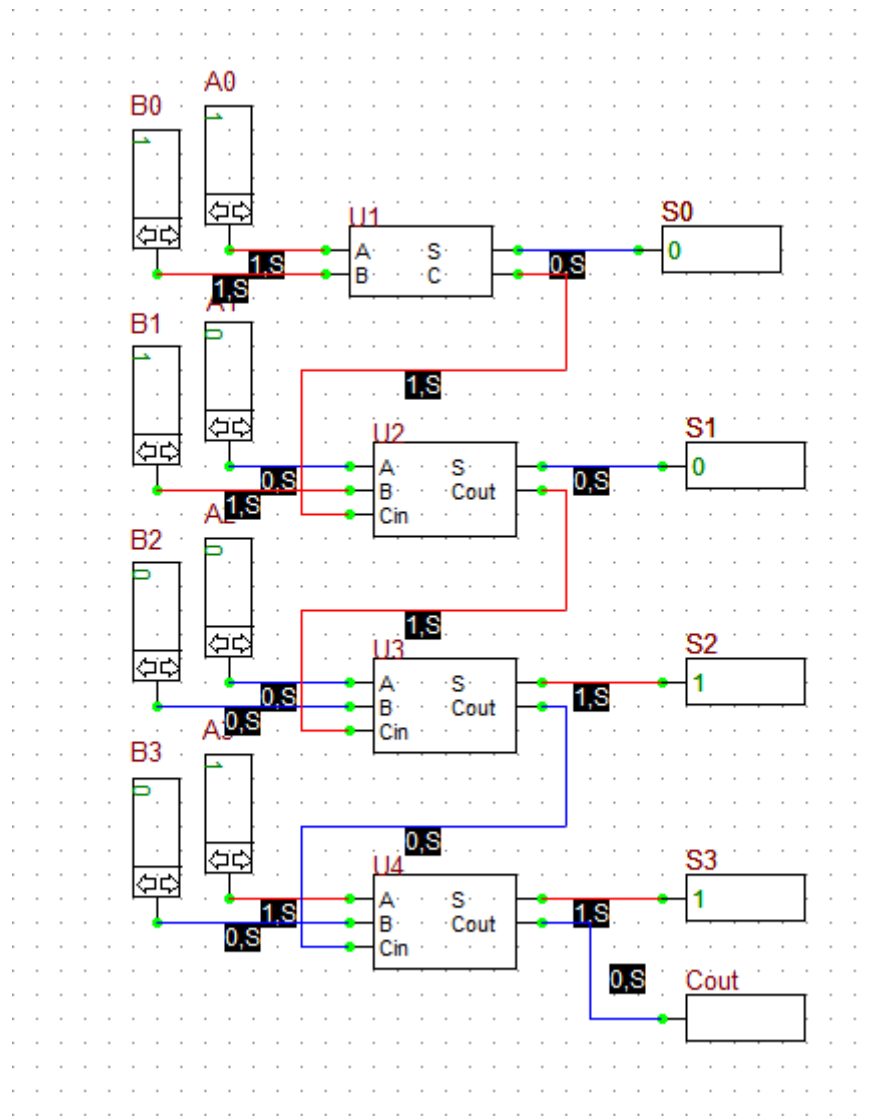
Place all the parts listed above in the schematic editor and connect them as shown in the figure below. Note that the half adder block U1 is used for the least significant bits A0 and B0, and the full adder block U2, U3 and U4 are used for the more significant bits. The "Cout" output of the last full adder block U4 summing the most significant bits A4 and B4 is taken out as the "Carry" output of the whole circuit.



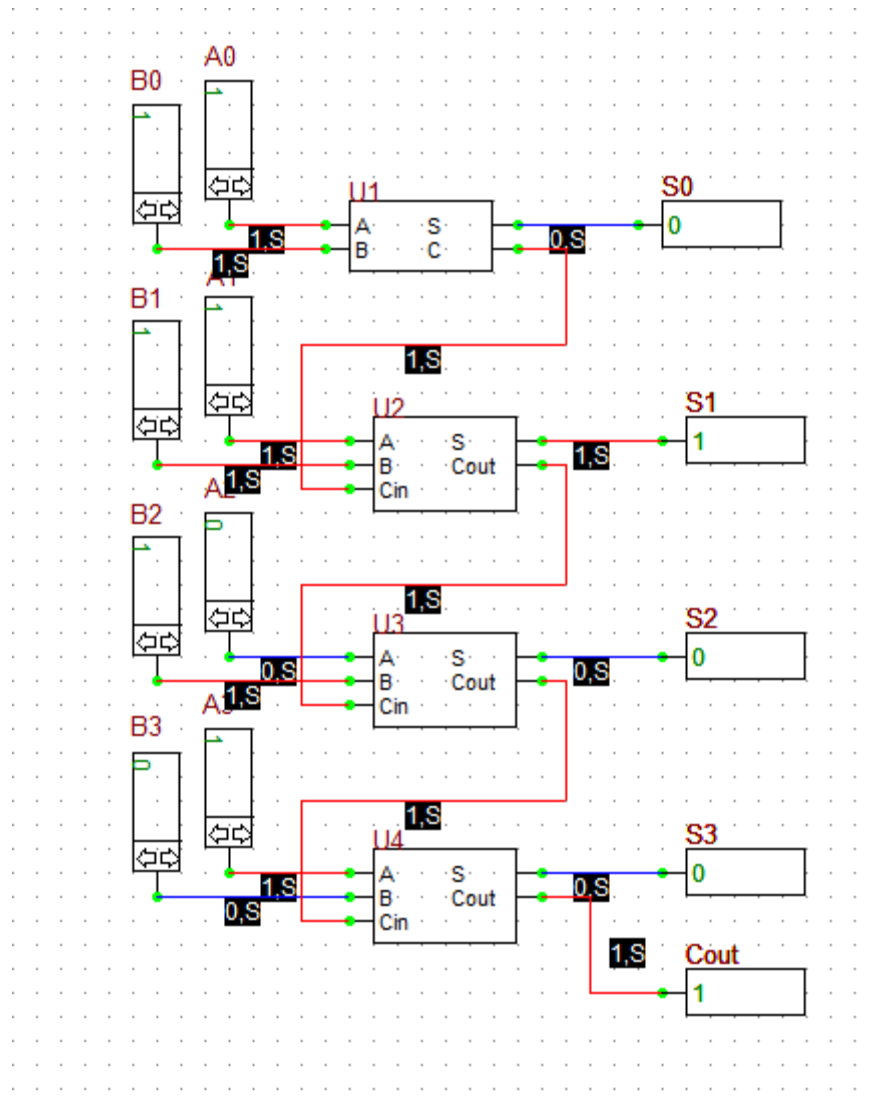
The 4-bit Ripple-Carry Binary Adder Circuit.

5.7 Testing Your Ripple-Carry Adder Circuit

You can run different simulation scenarios by inputting 4-bit binary numbers to A's and B's. The figures below show two of such scenarios. In the first figure, $A = 1001$ (9) and $B = 0011$ (3). The sum is 1100 representing the decimal number 12. In the second figure, $A = 1011$ (11) and $B = 0111$ (7). The sum of these inputs must be the decimal number 18, which is equivalent to 0010 with a carry of 1 in a 4-bit system (i.e., $2 + 16$), which can be seen in the figure.



The outputs of the 4-bit Ripple-Carry Binary Adder when $A = 1001$ and $B = 0011$ (adding $9 + 3$).



The outputs of the 4-bit Ripple-Carry Binary Adder when $A = 1011$ and $B = 0111$ (adding $11 + 7$).