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RF.Spice A/D

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



Mixed-Signal Tutorial Lesson 5

Exploring a 3-Bit A/D Converter Circuit

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5.1 What You Will Learn

In this tutorial you will use SPICE's standard voltage-controlled switch to sample signals and will build and test sample-and-hold (S/H) circuits.

5.2 Testing a Voltage Comparator Integrated Circuit

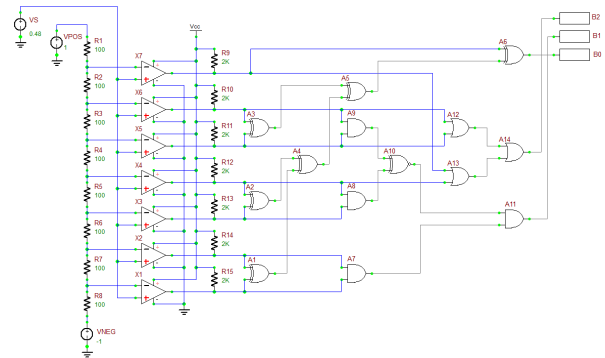
The following is a list of parts needed for this part of the tutorial lesson:

Part Name	Part Type	Part Value
V1	Voltage Source	2
V2	Voltage Source	1
VCC	DC Bias Voltage Source	5
R1	Resistor	2k
X1	LM393 Differential Voltage Comparator	Defaults
VOUT	Voltage Probe Marker	N/A

In Analog Tutorial Lesson 12, you analyzed the operation of an analog voltage comparator integrated circuit. In this project, you will use a commercial voltage comparator IC called LM393 manufactured by Texas Instruments. The DC bias voltage source Vcc determines the comparator's high output voltage. We choose +5V high state voltage for this project. You can access the IC either from **Part Bin** or using the menu item **menu > Parts > Active Devices > Integrated Circuits > LM393 Differential Voltage Comparator**. Each LM393 IC package contains two devices. When you place the part, a dialog opens up and asks you whether you want "Section A" or "Section B". If one has been used up earlier, only the other available section will show up in the list. The dialog also gives you options or buttons for **New Device** and **Next Device**.

The Device & Section dialog.

Tutorial Project: Exploring a 3-Bit A/D Converter Circuit

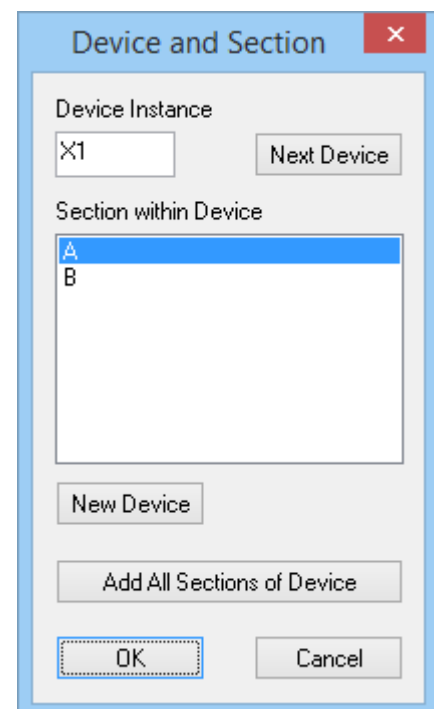


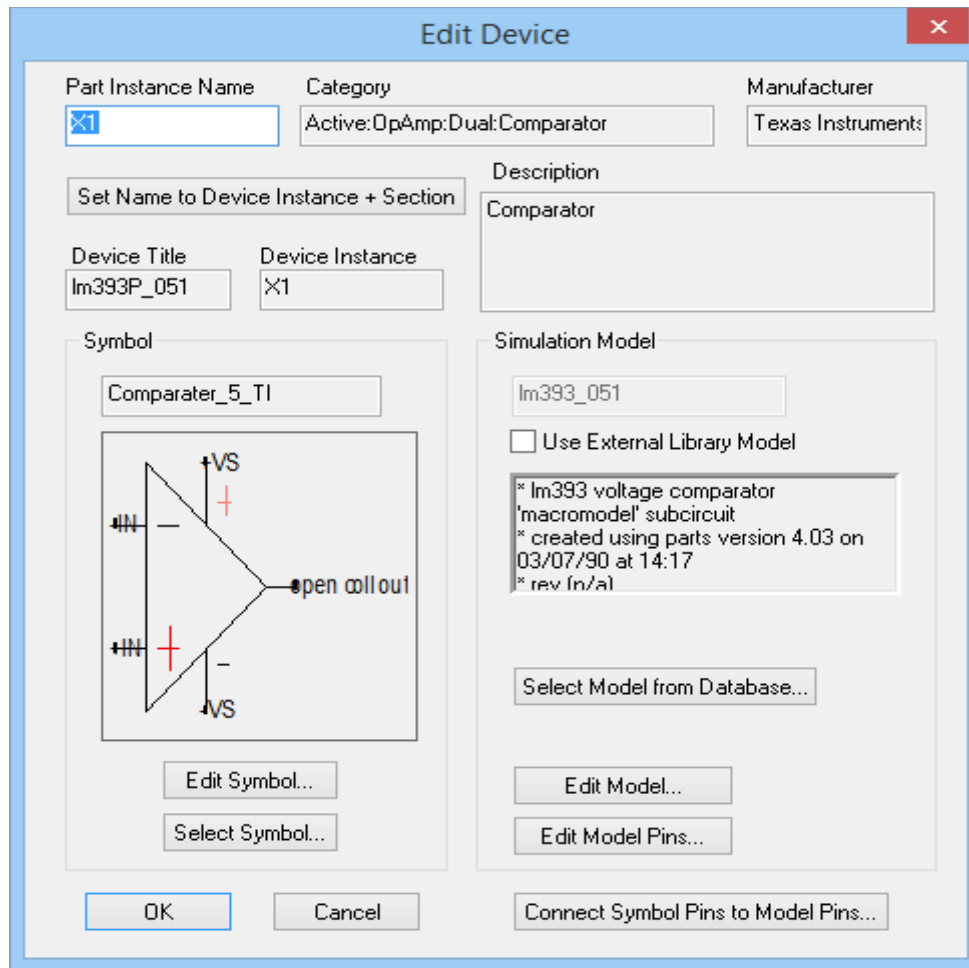
Objective: In this project, you will build and test an A/D converter using commercial integrated circuits.

Concepts/Features:

- Analog-to-Digital Converter
- Voltage Comparator
- Ladder Resistive Network
- Logic Decoder

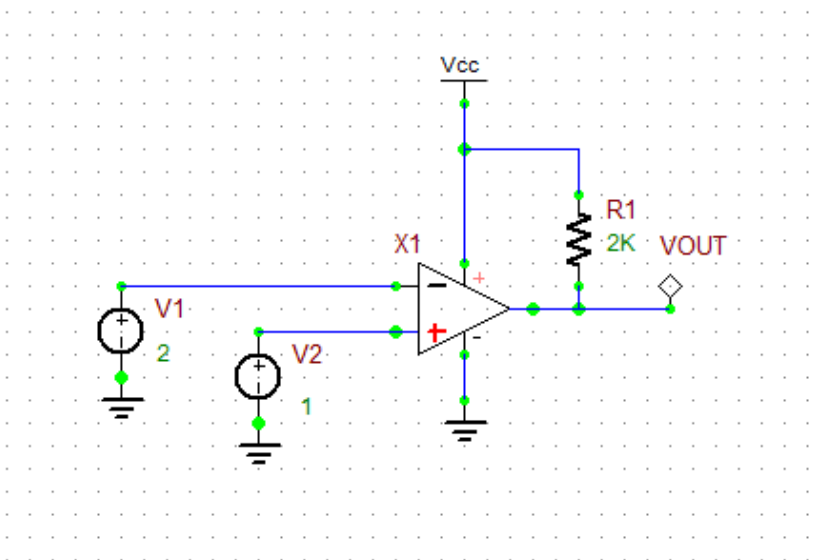
Minimum Version Required: All versions





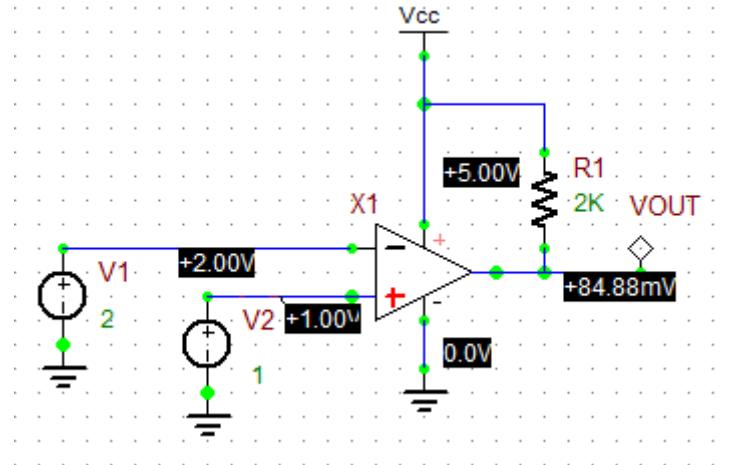
The property dialog of the voltage comparator IC LM393.

Place and connect all the parts as shown in the figure below:

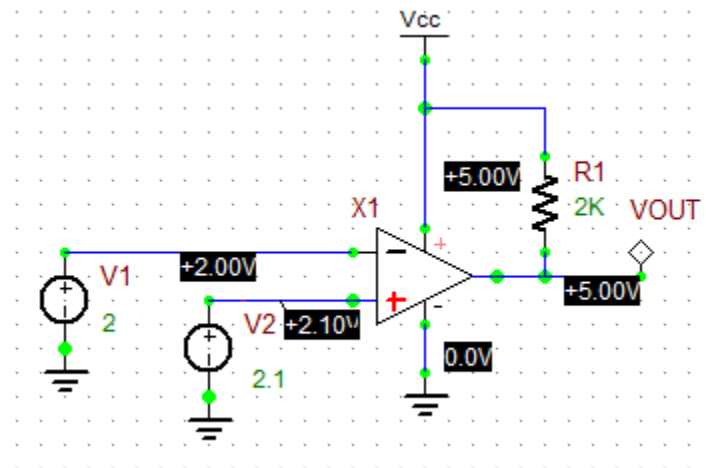


A simple circuit for testing the voltage comparator IC LM393.

With $V_2 = 1V$ and $V_1 = 2V$, run a live simulation of this circuit and enable **Show Voltage Text**. From the figures below, you can see that the output voltage is less than 0.1V or at "low state", because $V_2 < V_1$. Next, change the source voltage of V_2 to 2.1V. This time, you will see the output voltage jump to +5V, which is the voltage of V_{cc} .



The output voltage of LM393 when $V_2 < V_1$.



The output voltage of LM393 when $V_2 > V_1$.

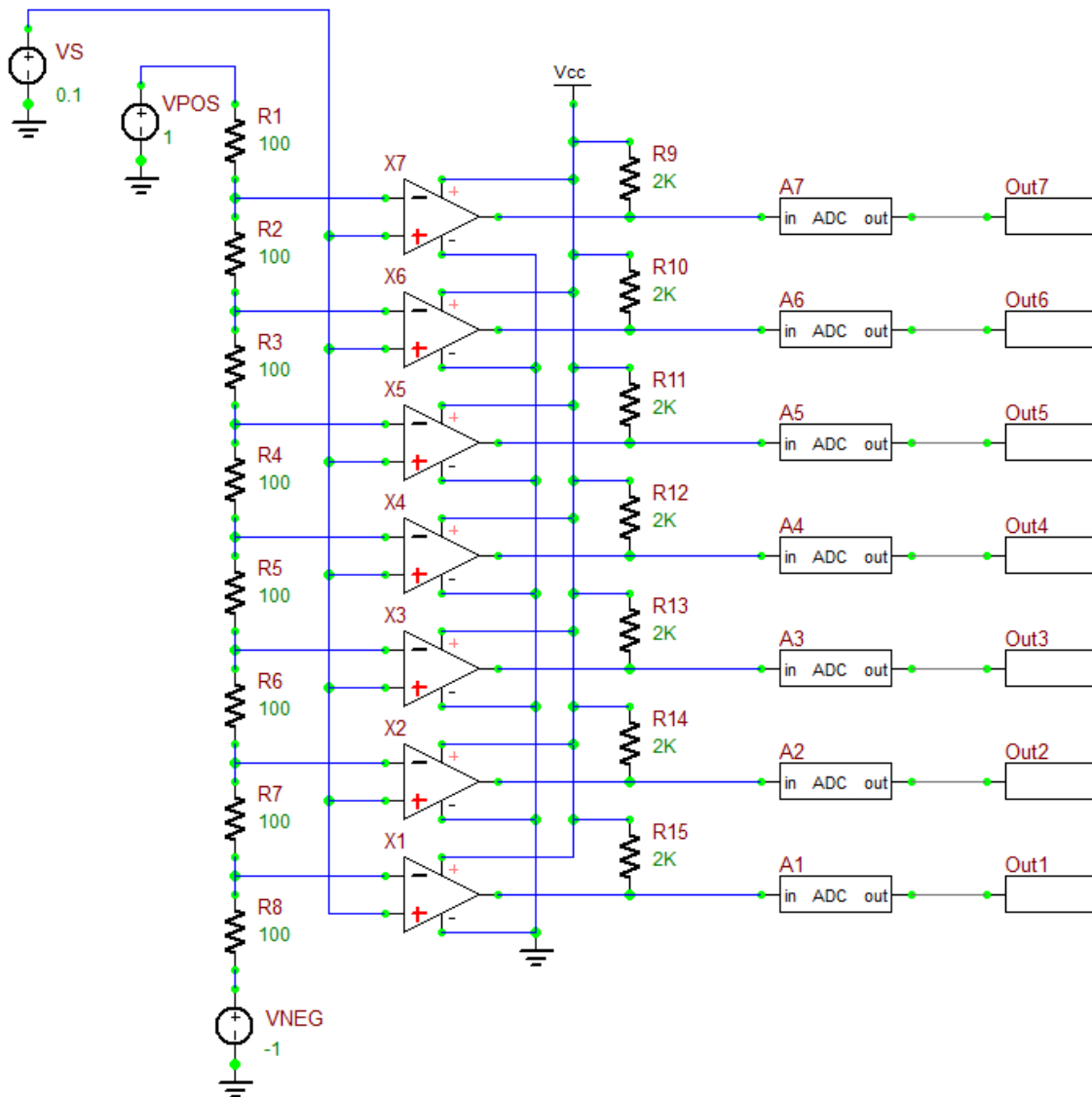
5.3 Building a Ladder A/D Converter

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

Part Name	Part Type	Part Value
VS	Voltage Source	Value TBD
VPOS	Voltage Source	+1
VNEG	Voltage Source	-1
VCC	DC Bias Voltage Source	5
R1 - R8	Resistor	100
R9 - R15	Resistor	2 k
X1 - X7	LM393 Differential Voltage Comparator	Defaults
A1 - A7	1-Bit A/D Conversion Bridge	Defaults, in_high = 4.5
Out1 - Out7	Digital Output	N/A

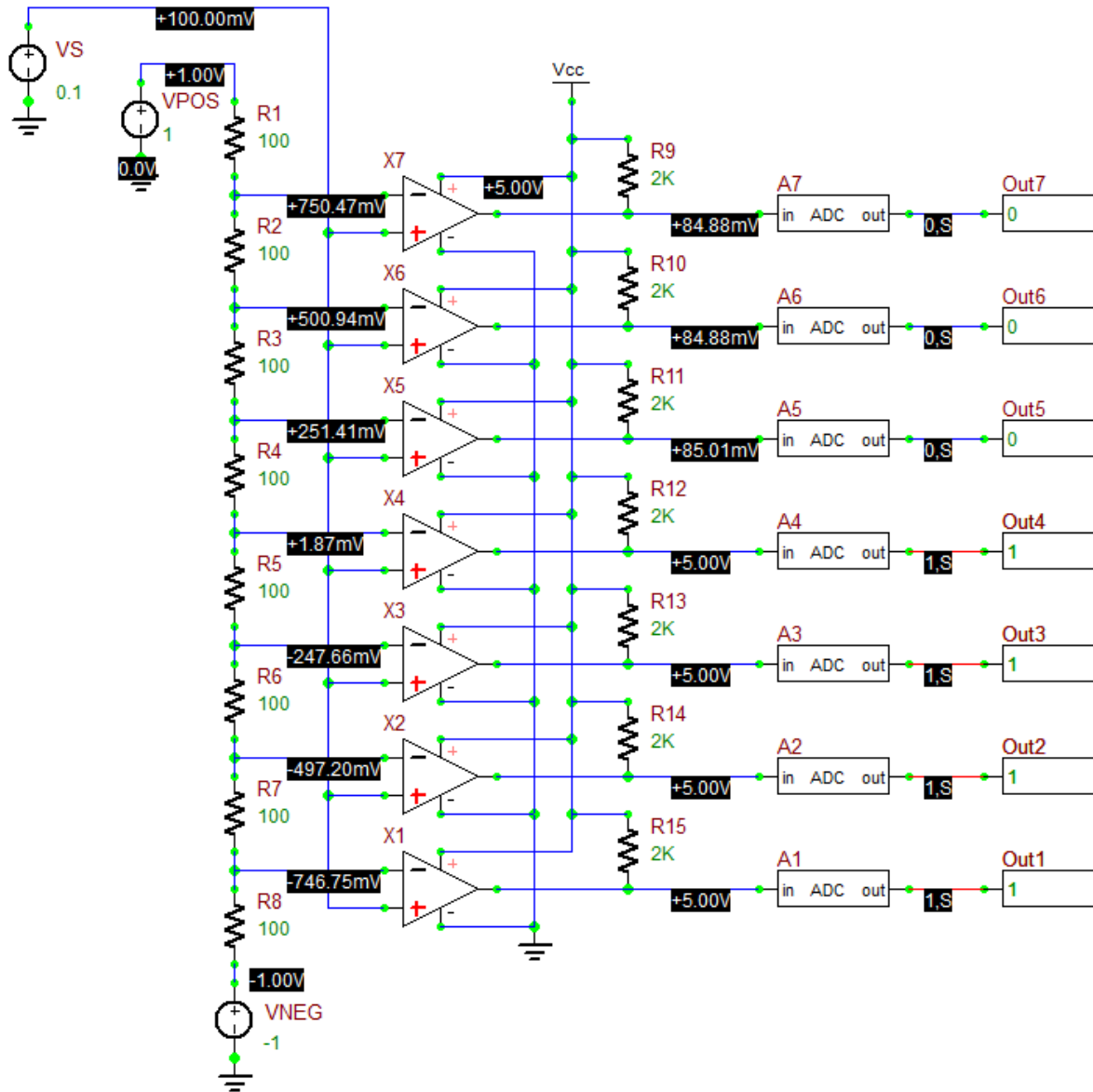
The voltage source VPOS and VNEG are set to the highest and lowest values of your analog signal, which are +1V and -1V, respectively. The resistive ladder network made up of R1 to R8 provides incremental voltages from -1V to +1V with successive steps of 0.25V. Therefore, you have $8 = 2^3$ distinct voltage levels corresponding to 3 binary bits. VS is your analog signal source, whose voltage is compared to all these 8 distinct voltage levels. The outputs of the comparators are then converted to binary values using the 7 A/D bridges.

Place and connect all the part as shown in the figure below. When placing the LM393 parts, do not use the half-package devices and place all new devices.

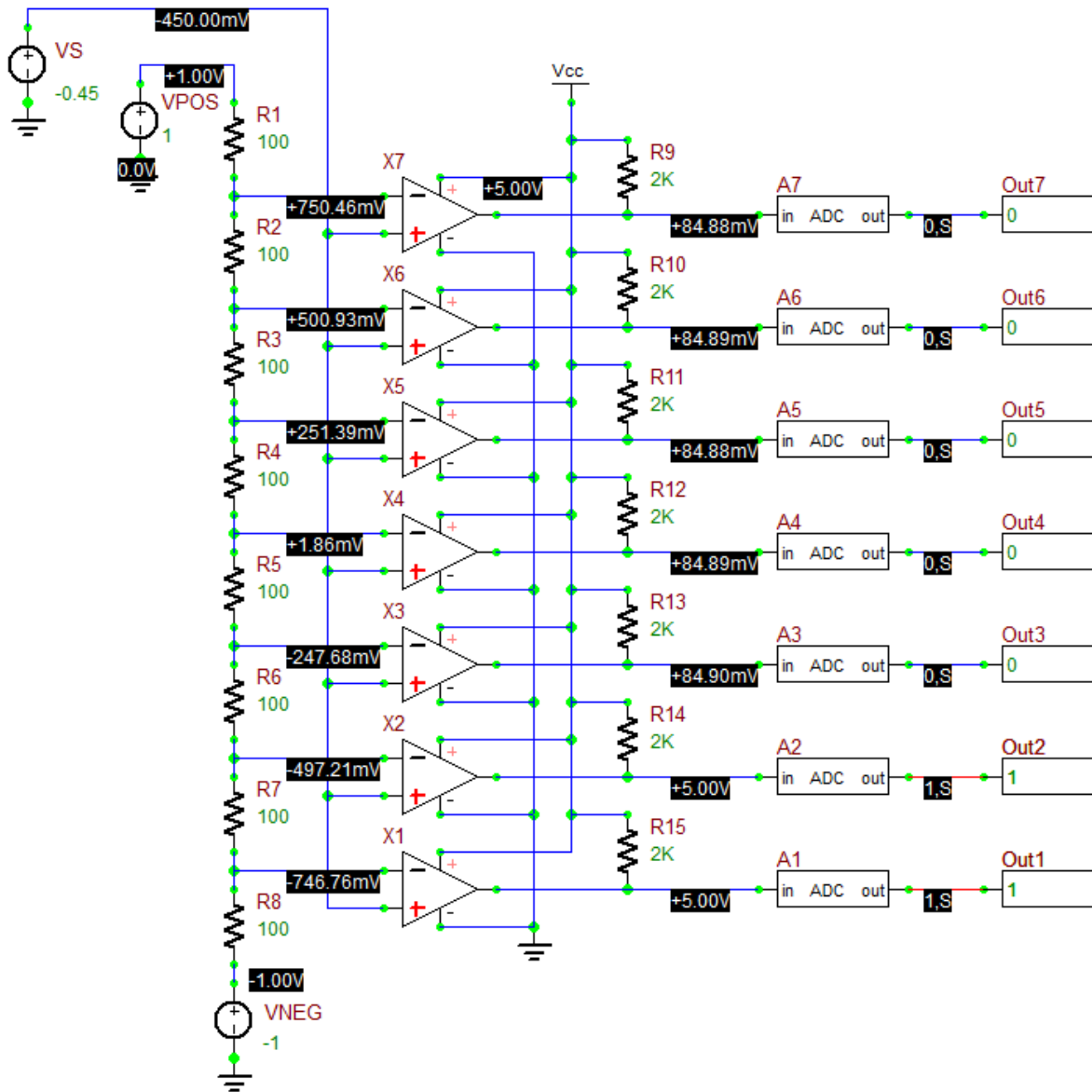


The ladder A/D circuit with seven voltage comparators.

Set the voltage of the signal source VS to +0.45V and then -0.45V. Run live simulations of each case and observe the state of digital outputs:



The digital outputs of the ladder A/D circuit with $V_S = +0.45V$.



The digital outputs of the ladder A/D circuit with VS = -0.45V.

5.4 Adding the Logic Decoder

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

Part Name	Part Type	Part Value
VS	Voltage Source	Value TBD
VPOS	Voltage Source	+1
VNEG	Voltage Source	-1
VCC	DC Bias Voltage Source	5
R1 - R8	Resistor	100
R9 - R15	Resistor	2 k
X1 - X7	LM393 Differential Voltage Comparator	Defaults
A1 - A6	Generic XOR Gate	Defaults
A7 - A9 , A11	Generic AND Gate	Defaults
A10	Generic XNOR Gate	Defaults
A12 - A14	Generic OR Gate	Defaults
B0 - B2	Digital Output	N/A

The outputs of the seven comparators are either +5V or less than 0.1V in all cases. In this section, you will add a logic decoder to convert the 7 digital outputs to a 3-bit digital word. The following table shows all the 8 distinct voltage levels, their corresponding signal voltage ranges, and their associated 3-bit digital words:

Signal Voltage Range	Voltage Level Index	B2	B1	B0
$-1V < VS < -0.75V$	0	0	0	0
$-0.75V < VS < -0.50V$	1	0	0	1
$-0.50V < VS < -0.25V$	2	0	1	0
$-0.25V < VS < 0V$	3	0	1	1
$0V < VS < 0.25V$	4	1	0	0
$0.25V < VS < 0.50V$	5	1	0	1
$0.50V < VS < 0.75V$	6	1	1	0
$0.75V < VS < 1V$	7	1	1	1

If we denote the outputs of the seven comparators X1 - X7 by c1 - c7, it is not difficult to verify the following relationships:

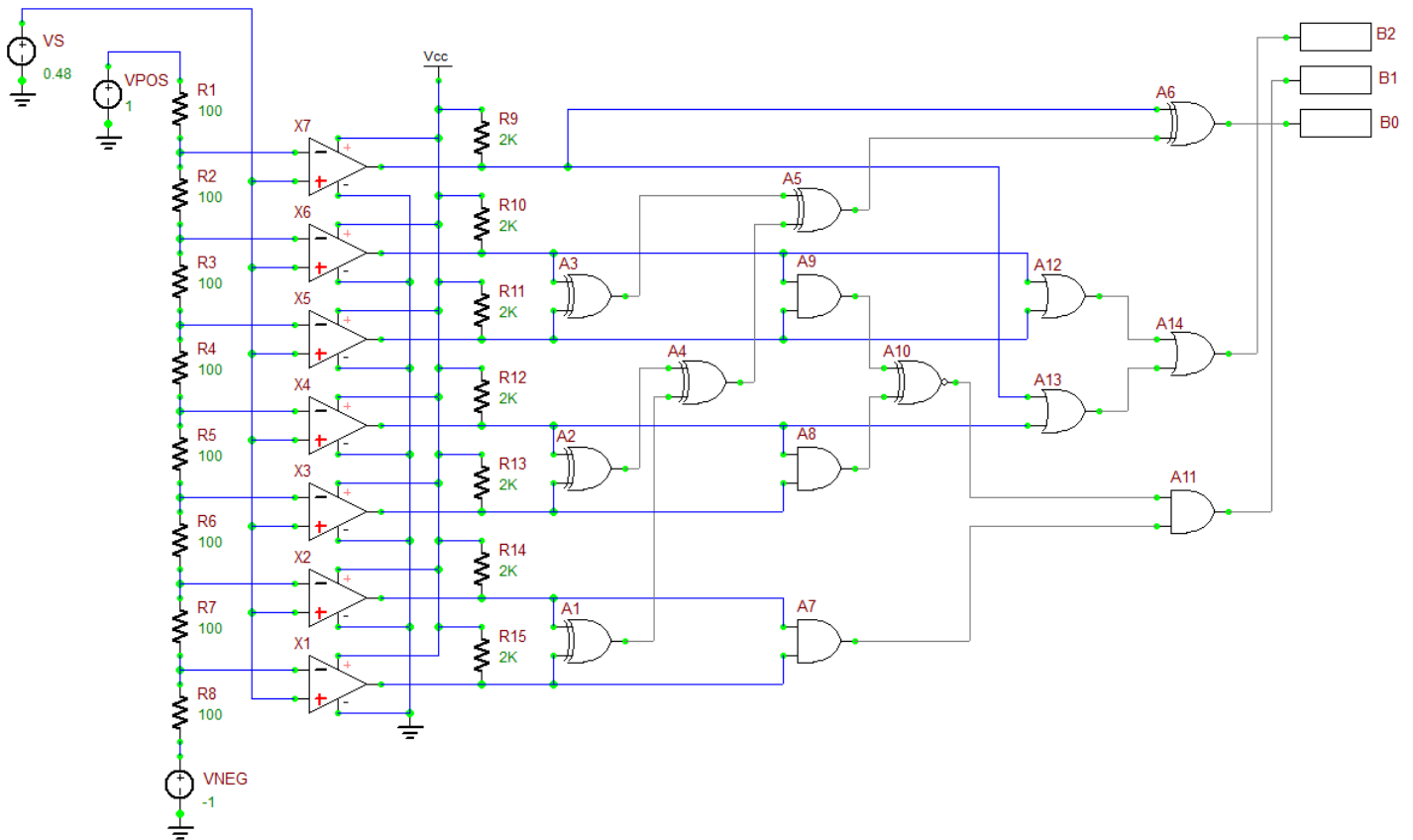
$$b0 = (((c1 \oplus c2) \oplus (c3 \oplus c4)) \oplus (c5 \oplus c6)) \oplus c7$$

$$b1 = (c1 \cdot c2) \cdot ((c3 \cdot c4) \oplus (c5 \cdot c6))$$

$$b2 = (c4 + c5) + (c6 + c7)$$

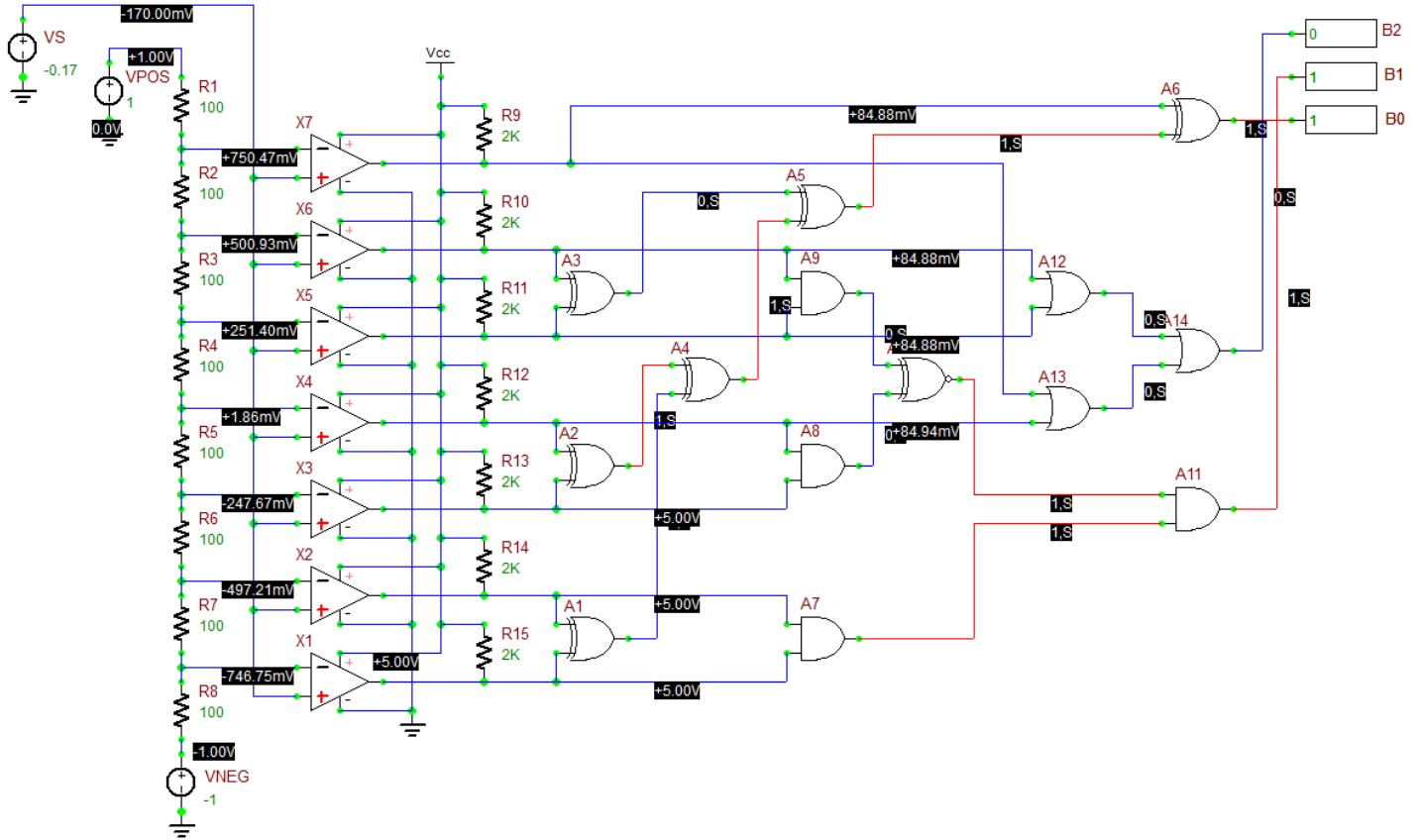
where b0, b1 and b2 are the three bits of the output digital word.

Place and connect all the parts as shown in the figure below. Note that you do not need the ADC bridges for this part because RF.Spice A/D automatically takes care of A/D conversions due to the presence of the logic gates in combination with the analog parts. You can use the circuit from the previous part, remove the ADC bridges and add all the new gates listed above.

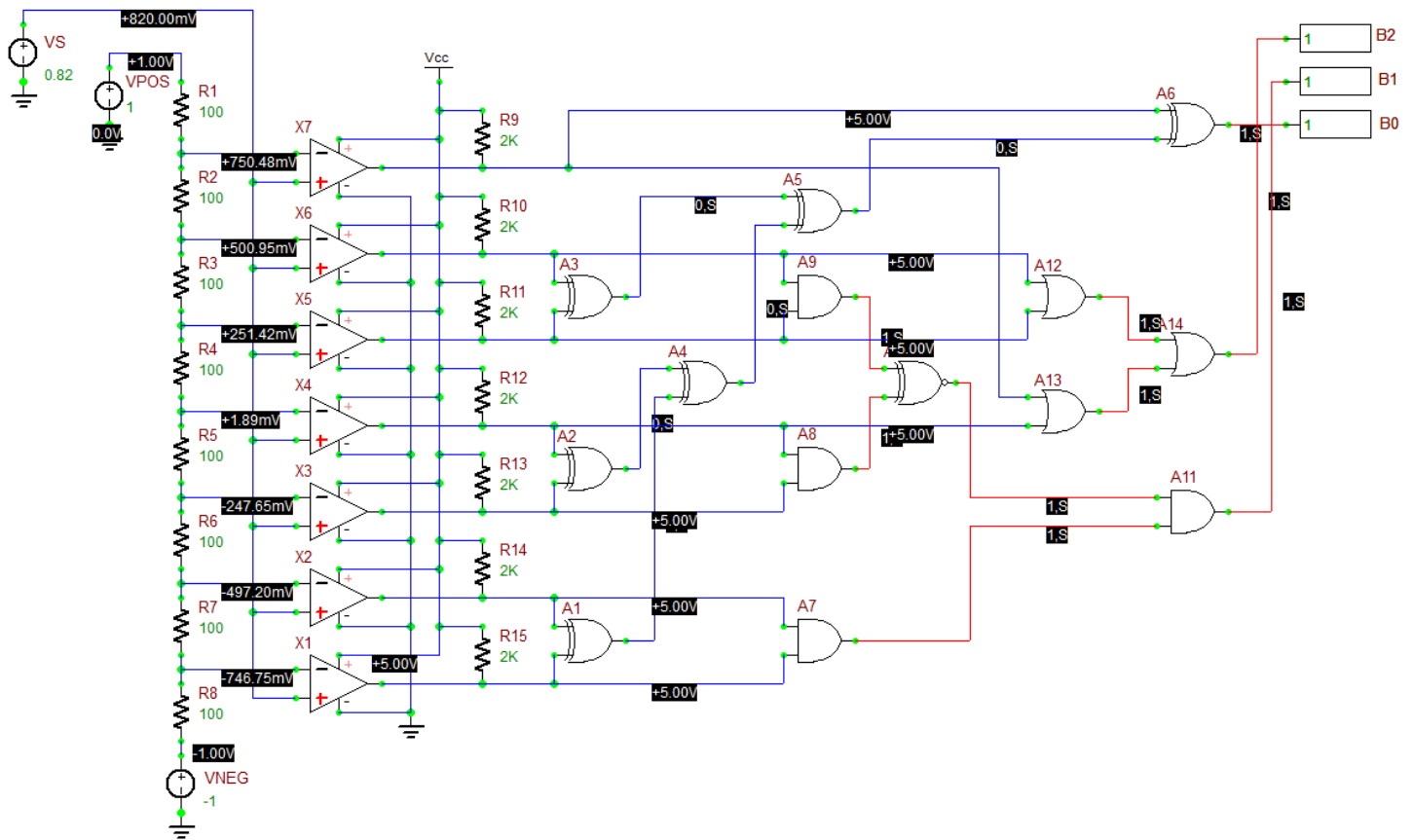


The ladder A/D circuit with logic decoder.

Set various values for the signal voltage and run live simulations of your circuit. In the figure below, the voltage animation is shown for the cases $V_S = -0.17V$ and $V_S = +0.82V$. Their corresponding digital words are 011 and 111, respectively.



The binary output of the ladder A/D circuit with logic decoder with $V_S = -0.17V$.



The binary output of the ladder A/D circuit with logic decoder with VS = +0.82V.