Voltage & Current Controlled Switches

Presented by Thomas Mosteller
Voltage Controlled Switch – Model

- A voltage controlled switch must have a model defined.
  - Typically done as a SPICE directive placed directly on the schematic

- The V-switch .model syntax:

  .model <ModelName> SW(Ron=<Ω> Roff=<Ω> Vt=<V> Vh=<V> Lser=<H> Vser=<V> Ilimit=<A>)

  where

  - **Vt**: Threshold voltage
  - **Vh**: Hysteresis voltage
  - **Ron**: On resistance
  - **Roff**: Off resistance
  - **Lser**: Series inductance
  - **Vser**: Series voltage
  - **Ilimit**: Current limit.
Voltage Controlled Switch – Model

- As for other intrinsic Spice models, the device name of the schematic component must be changed to correspond to the switch model name.
- Schematic example of a voltage controlled switch:
Voltage Controlled Switch – Modes of Operation

The switch has three distinct modes of voltage control depending on the value of the hysteresis voltage, Vh:

- Vh = 0V: Switch is always completely on or off depending upon whether the input voltage is above the threshold.
- Vh > 0V: it shows hysteresis, as if it was controlled by a Schmitt trigger with trip points at Vt - Vh and Vt + Vh.
  - Note that Vh is half the voltage between trip points which is different than the common laboratory nomenclature.
- Vh < 0V: it will smoothly transition between the on and off impedances. The transition occurs between the control voltages of Vt - Vh and Vt + Vh. The smooth transition follows a low order polynomial fit to the logarithm of the switch's conduction.
Voltage Controlled Switch

Hands-on Exercise:

- Define and use voltage controlled switches.
- Learn to differentiate the different modes of operation of the V-switch.

```
With Vh = 0
   SW1
   R1 1
   V2 3.3
   S1
   CTRL

With Vh > 0
   SW2
   R2 1
   V1 3.3

With Vh < 0
   SW3
   R3 1
   V4 3.3

Control Source
   V3
   CTRL
   PULSE(0 0.5m 0.5m 0 1m)

.tran 1m
```

VswitchLab.asc
Current Controlled Switch – Model

- Like the V-switch, the current controlled switch must have a model defined.
  - Typically done as a SPICE directive placed directly on the schematic
- The C-switch .model syntax:
  - `.model <ModelName> CSW(Ron=<Ω> Roff=<Ω> It=<A> Ih=<A>)`
  - The parameters are:
    - *It*: Threshold current
    - *Ih*: Hysteresis current
    - *Ron*: On resistance
    - *Roff*: Off resistance
Current Controlled Switch – Model

- The name of the schematic component must be changed to correspond to the switch model name.
- Contrary to the V-switch, the stimulus is not wired to the switch symbol:
  - The C-switch symbol has only two terminals: the switch’s input and output terminals. No control terminal.
  - The control source is defined by setting the content of the Value attribute to read <Vcontrol> <ModelName> where
    - <Vcontrol> : name of the voltage source whose current controls the switch. **Important: Must be a voltage source.**
    - <ModelName> : name given to the controlled switch (model name)

- As an example:
Current Controlled Switch – Model

- Schematic example of a current controlled switch:

```
.model MySwitch  CSW(Ron=1m Roff=1Meg It=.5 Ih=0)
```

Value attribute: $V_{\text{control}} + \text{ModelName}$

Control source

C-switch model definition
Current Controlled Switch – Modes of Operation

- Like the voltage switch, the CC-switch has three distinct modes of current control depending on the value of the hysteresis current, $I_h$:
  - $I_h = 0A$: Switch is always completely on or off depending upon whether the control current is above the threshold.
  - $I_h > 0A$: it shows hysteresis with trip points at $I_t - I_h$ and $I_t + I_h$.
  - $I_h < 0A$: it will smoothly transition between the on and off impedances. The transition occurs between the control currents of $I_t - I_h$ and $I_t + I_h$. The smooth transition follows a low order polynomial fit to the logarithm of the switch's conduction.
Current Controlled Switch

Hands-on Exercise:

- Define and use current controlled switches including their control source.
- Learn to differentiate the different modes of operation of the C-switch.

With $I_h = 0$

With $I_h > 0$

With $I_h < 0$

Control Source

`PULSE(-1 0 0 .5m .5m 0 1m)`

`.tran 1m`
Switches - Application Circuit Examples

- LT3081 - Linear Regulator current limit
  - Test the circuit current limiter
- LTC2954 - Push-Button controller
  - Replicate the push-button function
  - Implement a kill switch function
- LT3954 - LED driver
  - Open LED circuit response
  - Emulate a LED cathode short to GND (no dimming)
- LTC4227 - Dual ideal diode and hot-swap
  - Check the Ideal diode response to input disconnect
  - Verify the hot-swap current limiting function
ADVANCED TOPICS

To consult at your leisure.
Voltage Controlled Switch – Level 2 Model

- The level 2 V-switch model is an advanced version of the level 1 switch with negative hysteresis.
  - The level 2 switch is never completely on or off.
- The conduction as a function of control voltage $V_c$ is
  \[ g(V_c) = \exp(A \cdot \arctan((V_c - V_t)/|V_h|)) + B \]
  where
  - $A = \log(R_{off} / R_{on}) / \pi$
  - $B = \log(1 / (R_{off} \cdot R_{on})) / 2$
- The transition of the level 2 switch to current limit is gradual instead of abrupt. At a fixed control voltage, the I-V curve is given by the equation
  \[ I(V) = I_{limit} \cdot \tanh(g(V_c) \cdot V) \]
  where $I_{limit}$ defaults to 10 amperes for the level 2 switch.
Voltage Controlled Switch – Level 2 Model

- The level 2 switch supports the option to conduct in only one direction by specifying either the flag "oneway" or a voltage drop with parameter Vser.
  - The transition between forward conduction and reverse open circuit can be specified to be a smooth transition by specifying the parameter epsilon to be non-zero.

- Syntax

  `.model <ModelName> SW(level=2 Ron=<Ω> Roff=<Ω> Vt=<V> Vh=<V> Lser=<H> Vser=<V> Ilimit=<A> oneway)`

  - Vh is always negative

- The C-Switch does not have a level 2 model.
Voltage Controlled Switch – Level 2 Model

Lab to consult at your leisure:

- Shows how to define and use level 2 voltage controlled switches.
- Demonstrates the differences between a level 2 and a level 1 with negative hysteresis V-switch.

.model MySW2 SW(Level=2 Ron=1m Roff=1Meg Vt=1 Vh=-0.5)