Lecture 16: October 24, 2001

Logic with Complementary State Devices

A) Discovering a Pull-Up Device

B) Designing a Pull-Up Device

C) EE 42 Pull-Up Device Model (42PU)

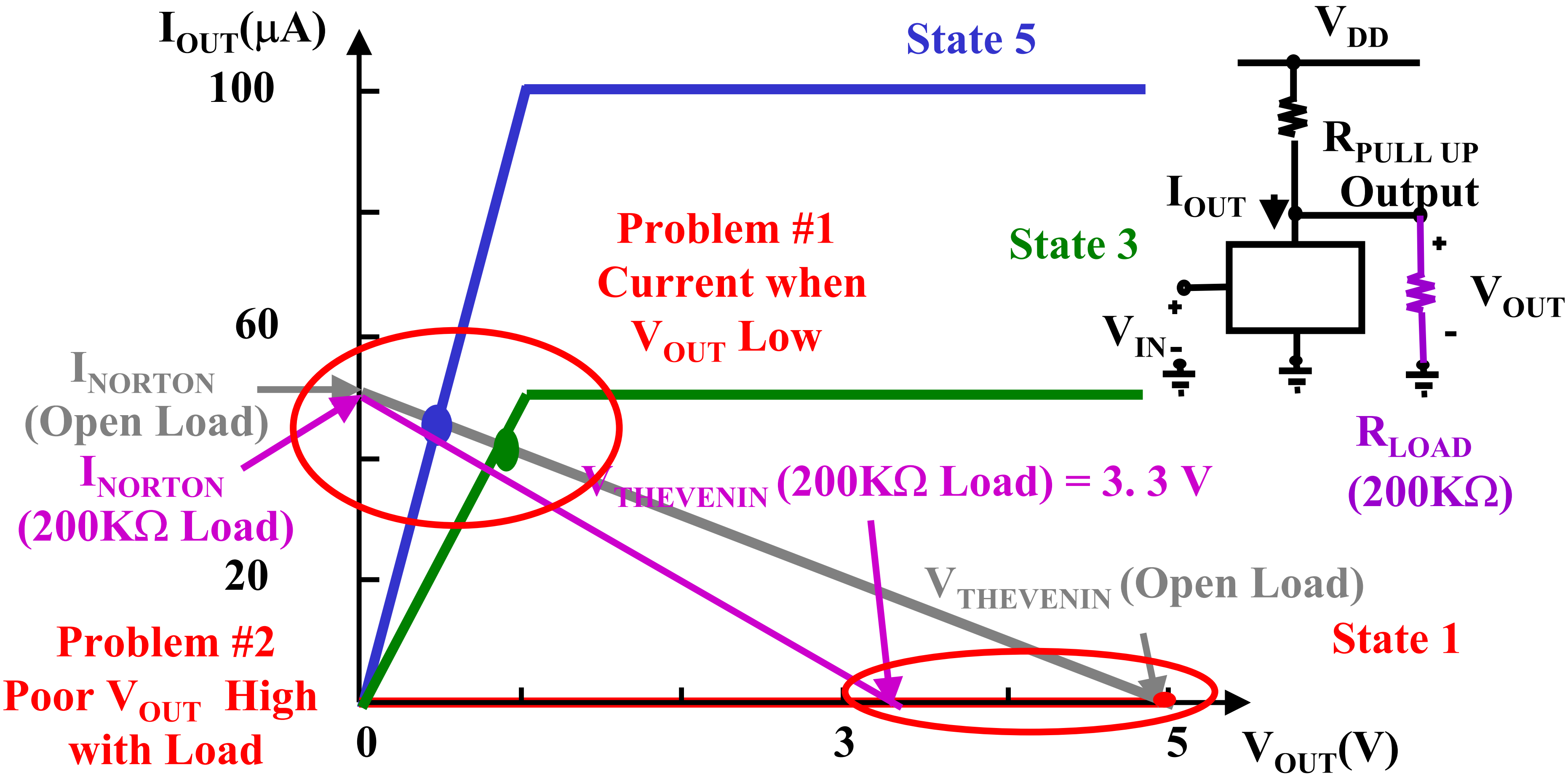
D) Composite I_{OUT} vs. V_{OUT}

E) Voltage Transfer Function and V_M

Reading:

Schwarz and Oldham pp. 607-611 (read for graphs and not device equations) and lecture viewgraphs

Composite Current Plot for the 42PD Circuit with 200kΩ Load to Ground



Problems and Opportunities in Logic Circuit Design

Problem #1: Significant wasted current and power when V_{OUT} is low.

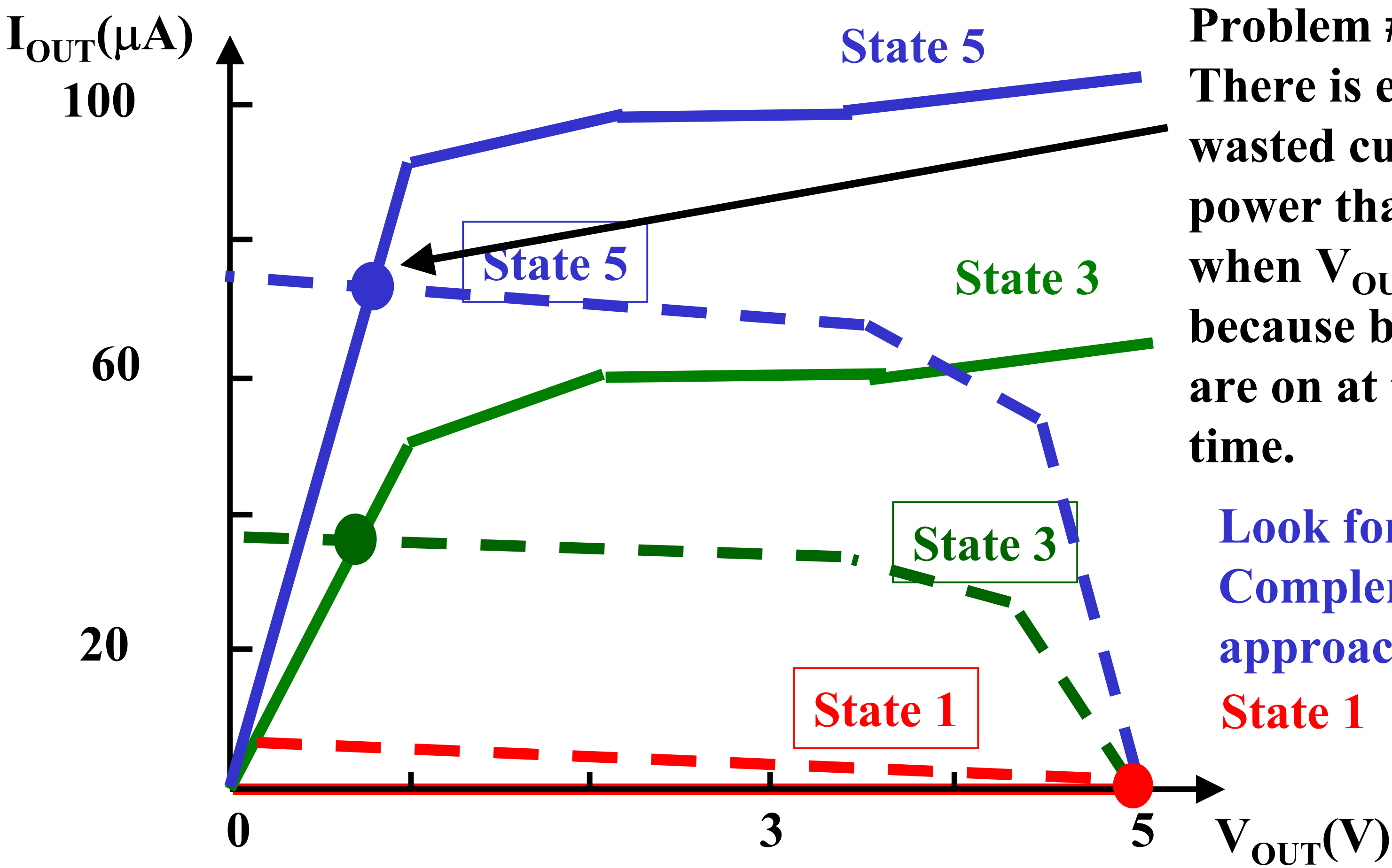
Problem #2: High value of V_{OUT} is adversely affected by a load resistor.

Missed Opportunity: The value of the input control signal is not used to adjust the state of the pull-up device.

What if : If the pull-up device could be a state-dependent device what kind of device would we want?

Pull-Up Device Design: Trial 1

Similar pull-up and pull-down states



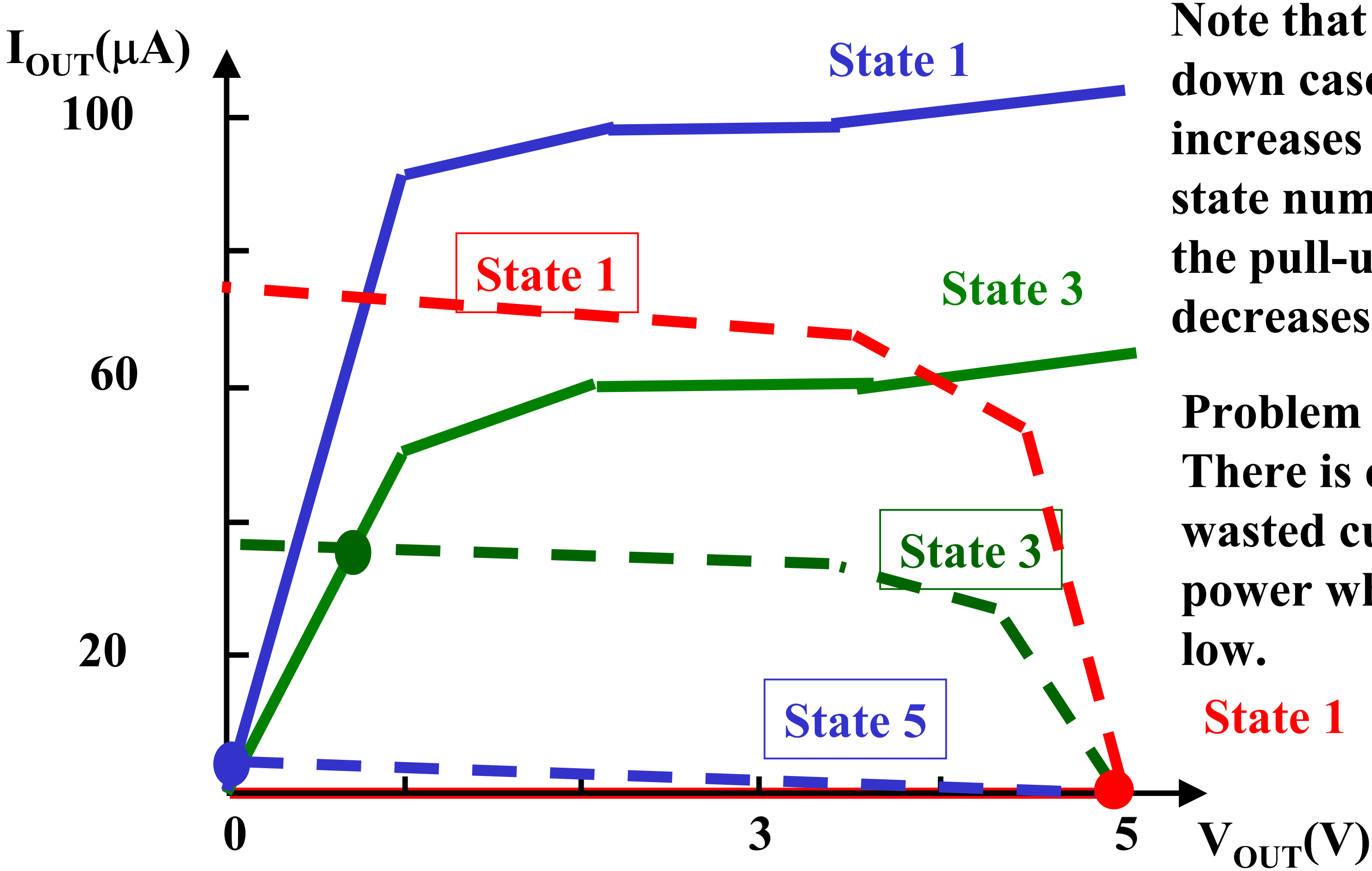
Problem #1 is worse! There is even more wasted current and power than before when V_{OUT} is low because both devices are on at the same time.

Look for a more Complementary approach.

State 1

Pull-Up Device Design: Trial 2

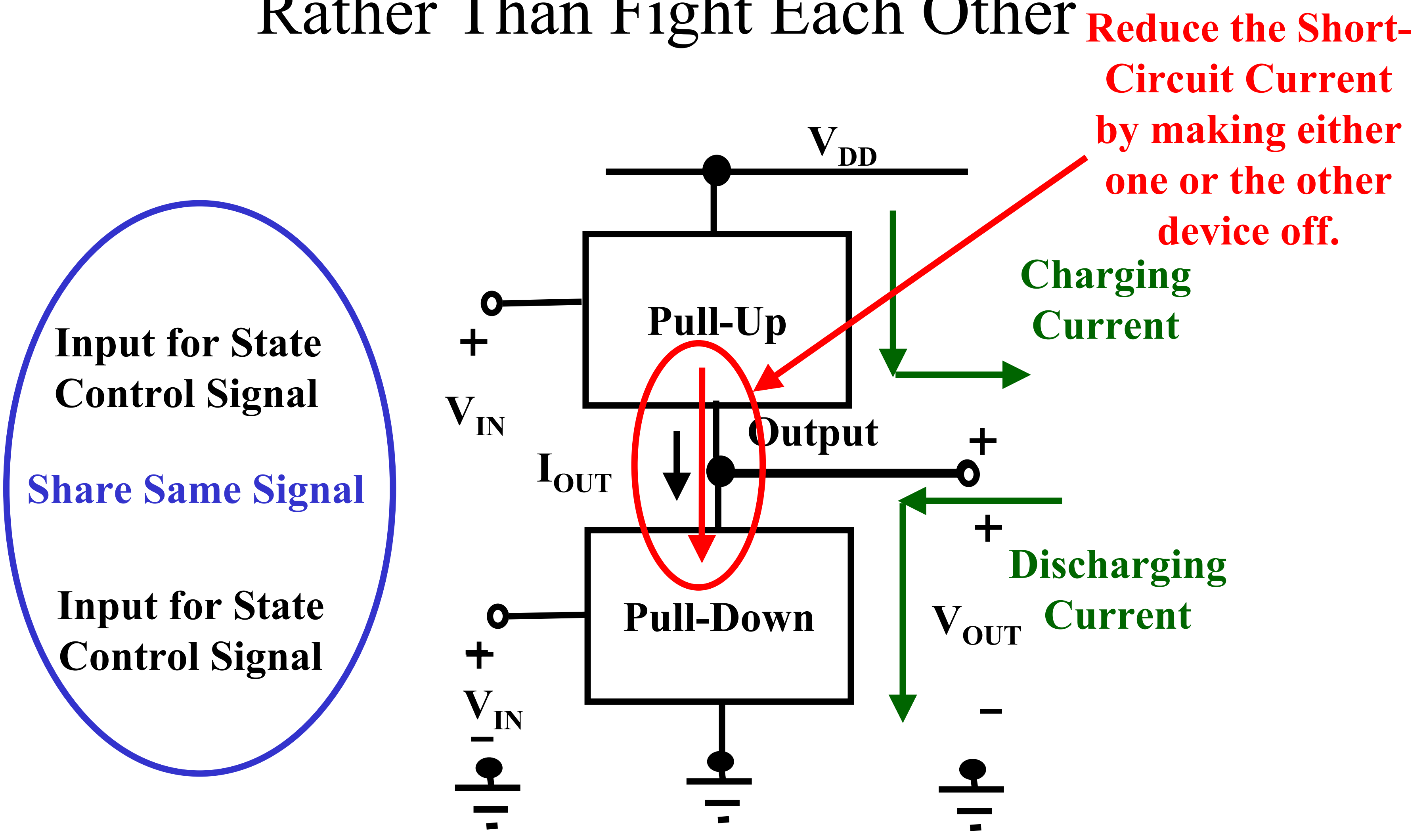
Complementary pull-up and pull-down states



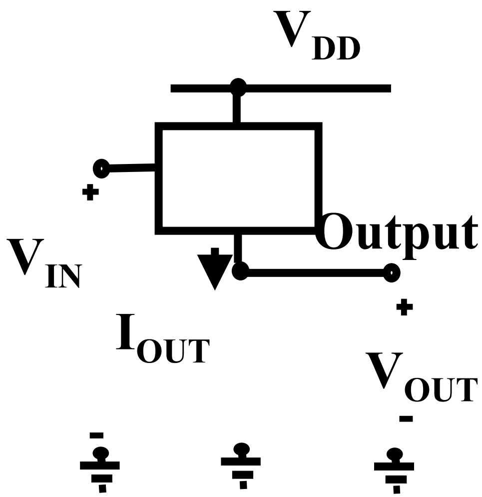
Note that in the pull-down case the current increases with the state number and in the pull-up case it decreases.

Problem #1 is solved. There is essentially no wasted current or power when V_{OUT} is low.

Pull-Down and Pull-Up Must Complement Rather Than Fight Each Other



Desirable Complementary Device Characteristics

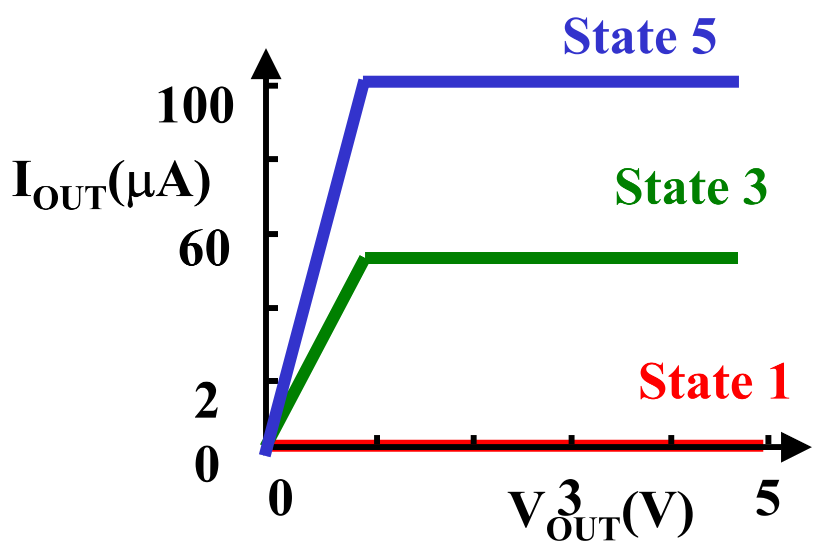


We desire characteristics that are complementary for the pull-down and pull-up state-dependent devices.

V_{IN}	Low	High
Pull-Down Current	Low not leak	High Discharge Output
Pull-Up Current	High Charge Output	Low not leak

Designing the Complementary Device

Make This



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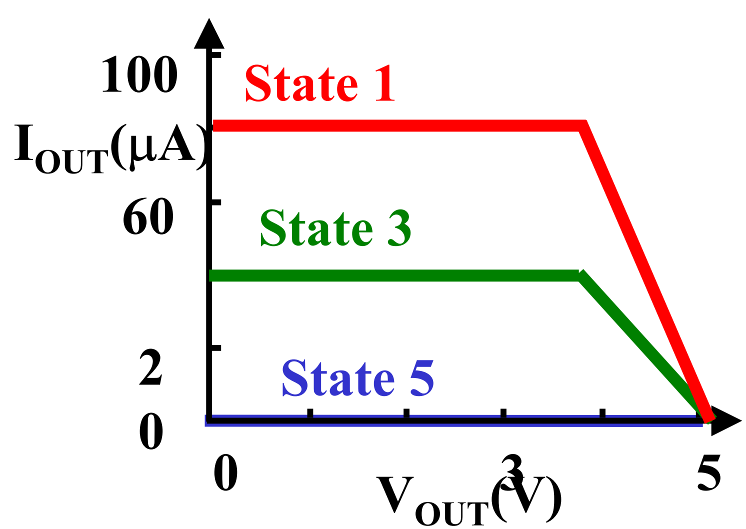


The curve sets are very similar but have two key changes.

The creation of current with input State (V_{IN}) is reverse ordered (and also shifted).

The dependence on V_{OUT} is reverse ordered and shifted by V_{DD}

42Pull-Down Device Equations

Describe I_{OUT} as function of V_{IN} and V_{OUT}

Cut-off $V_{IN} \leq V_{TD}$

$$I_{OUT-PD} = 0$$

Linear (with V_{OUT}) $V_{IN} \geq V_{TN}$ $V_{OUT} \leq V_{TD}$

$$I_{OUT-PD} = k_D\left(V_{IN} - V_{TD}\right)V_{OUT}$$

Saturation (with V_{OUT}) $V_{IN} \geq V_{TD}$ $V_{OUT} \geq V_{TD}$

$$I_{OUT-PD} = k_D\left(V_{IN} - V_{TD}\right)V_{TD}$$

Drawing I_{OUT} as function of V_{IN} and V_{OUT} for the 42Pull-Down Device Equations

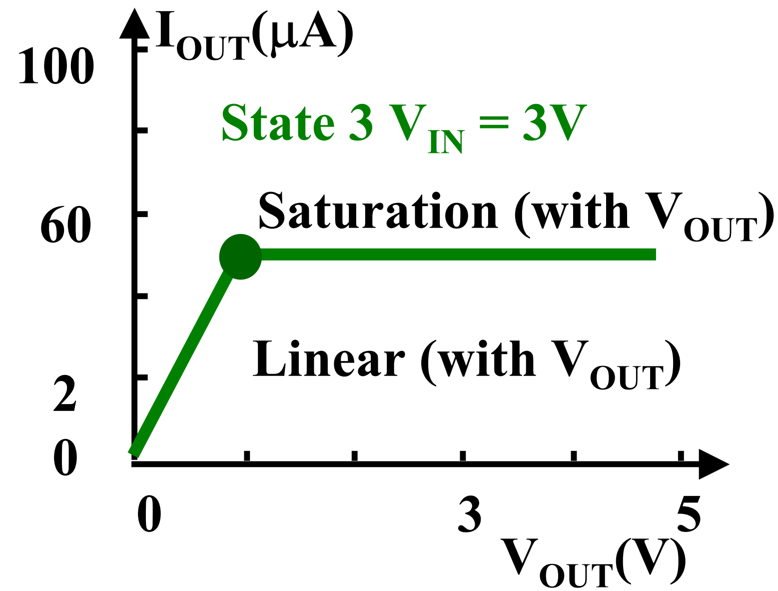
The equations are expressly designed for EE42 to make it very simple to draw I_{OUT} vs. V_{OUT}

1) For $V_{IN} < V_{TD}$, the current is zero.

2) For $V_{IN} > V_{TD}$, first evaluate the current I_{OUT} at $V_{OUT} = V_{TD}$ and plot the single point (I_{OUT}, V_{OUT})

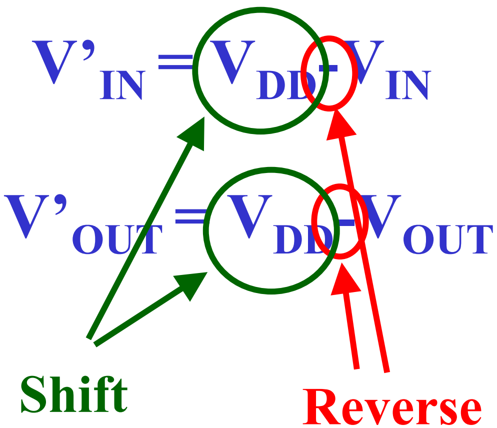
3) Draw a line from this point to the origin to create the linear region.

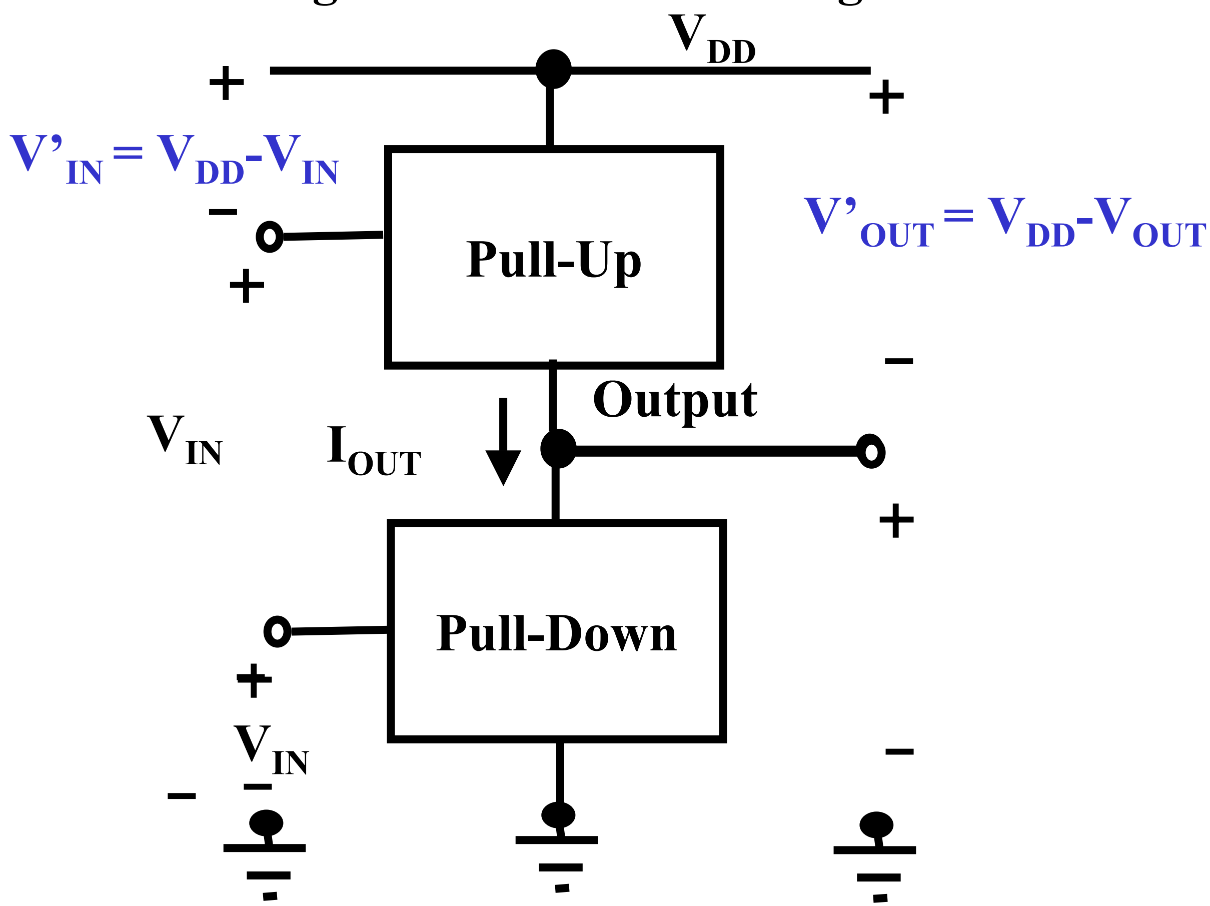
4) Draw a horizontal line from this point to create the saturation region



V_{DD}-V_X Gives Complementary Characteristics

Physical Interpretation as device related rather than logic circuit related voltages.





42Pull-Up Device Equations

I_{OUT} as function of V_{IN} and V_{OUT} in the Logic Circuit

Based on: V_{TU} and K_U

Note: $V'_{IN} = V_{DD} - V_{IN}$

$V'_{OUT} = V_{DD} - V_{OUT}$

Cut-off $V_{DD} - V_{IN} \leq V_{TU}$

$$I_{OUT-PU} = 0$$

Linear (with V_{OUT}) $V_{DD} - V_{IN} \geq V_{TU}$ $V_{DD} - V_{OUT} \leq V_{TU}$

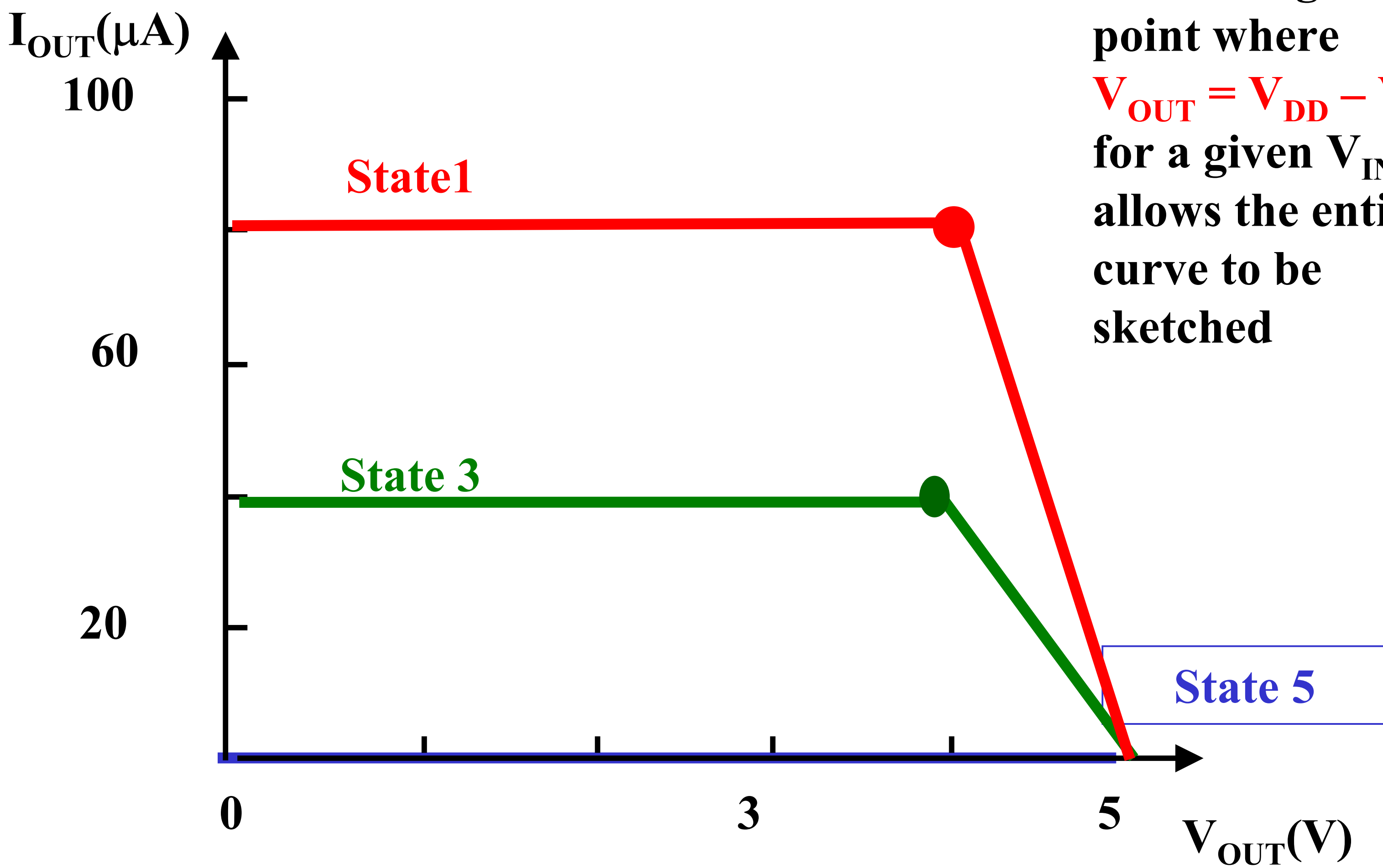
$$I_{OUT-PU} = k_U (V'_{IN} - V_{TU}) V'_{OUT} = k_U (V_{DD} - V_{IN} - V_{TU})(V_{DD} - V_{OUT})$$

Saturation (with V_{OUT}) $V_{DD} - V_{IN} \geq V_{TU}$ $V_{DD} - V_{OUT} \geq V_{TU}$

$$I_{OUT-PU} = k_U (V'_{IN} - V_{TU}) V'_{TU} = k_U (V_{DD} - V_{IN} - V_{TU}) V_{TU}$$

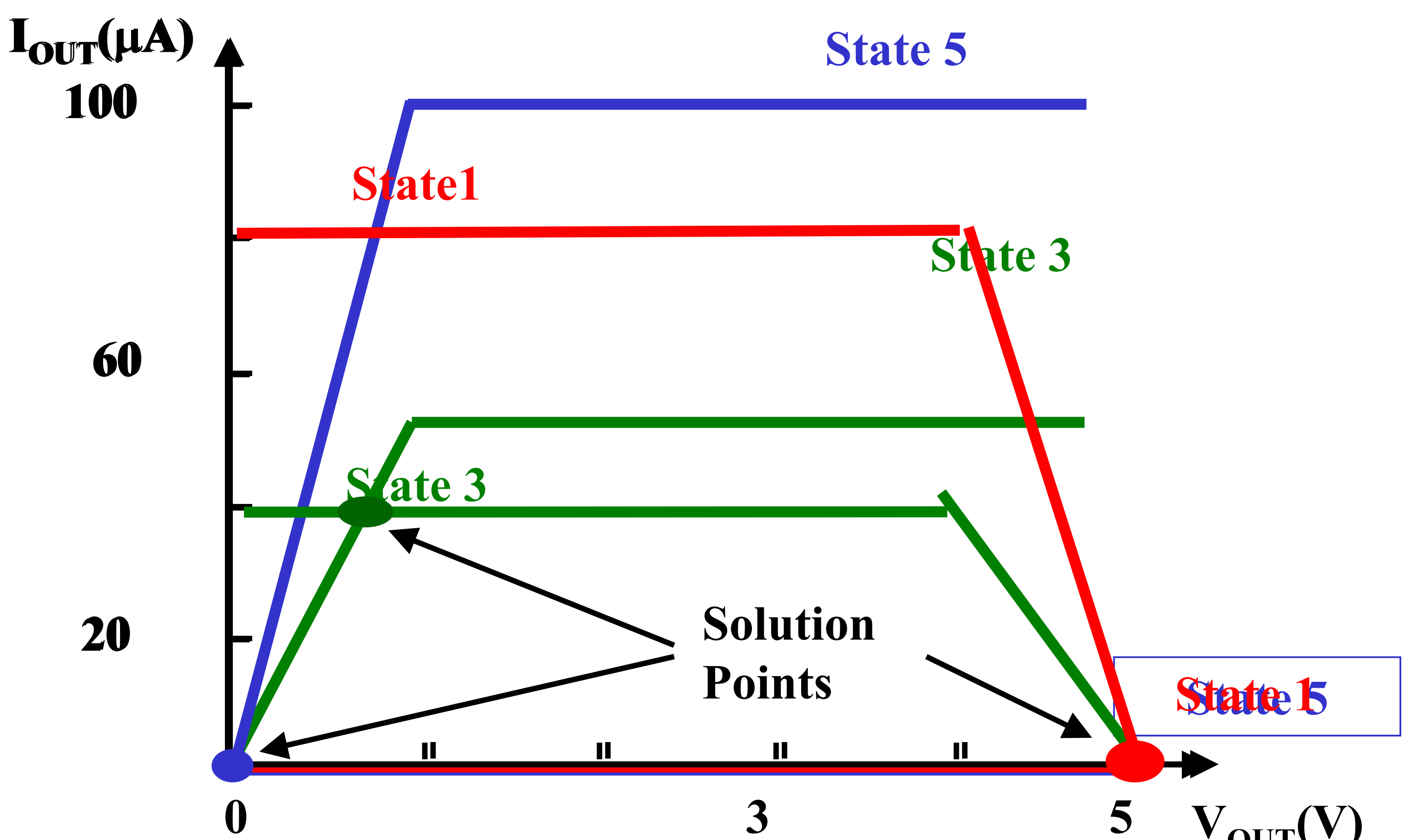
42Pull-UP Device Model

I_{OUT} vs. V_{OUT}

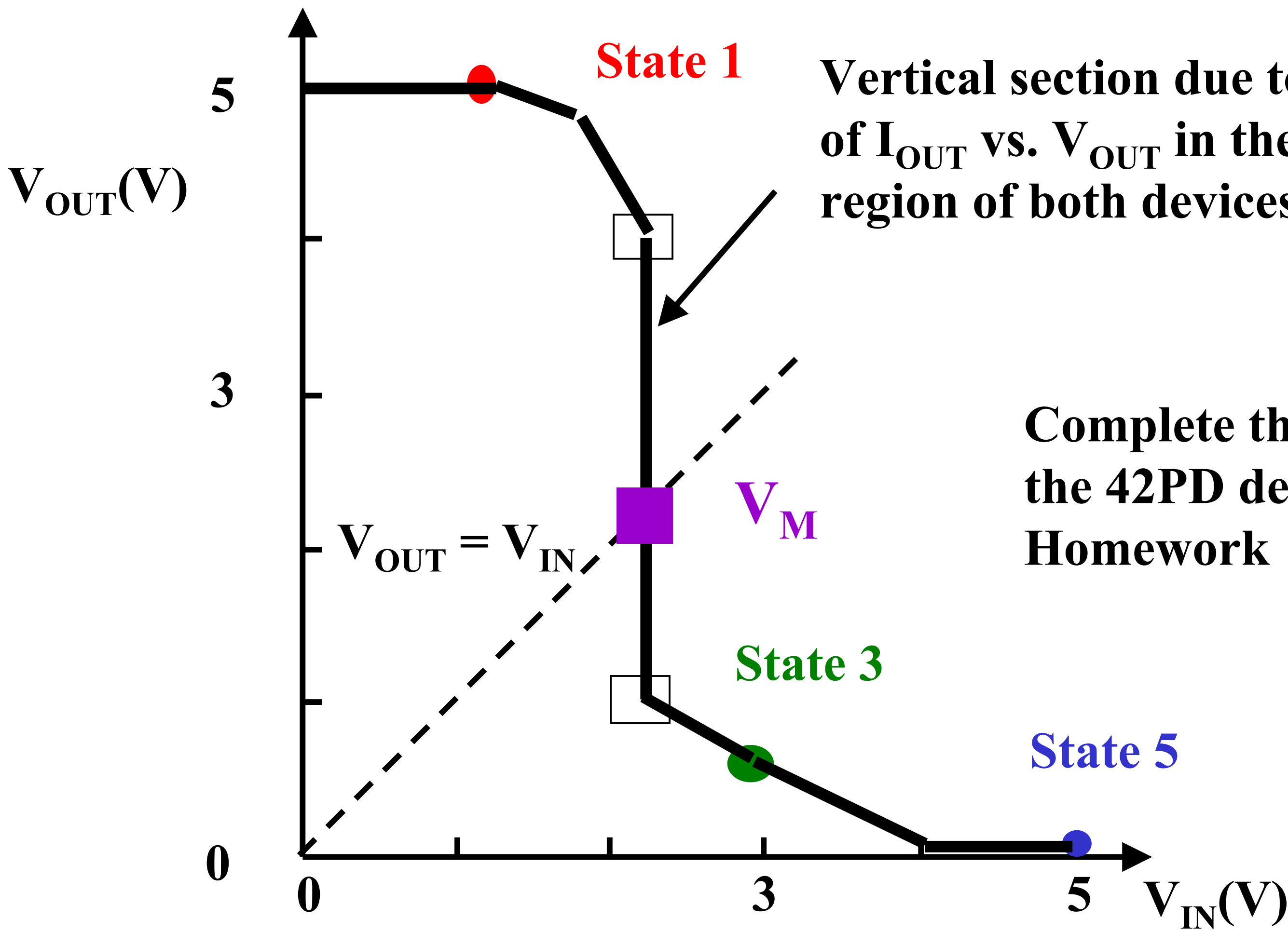


Evaluating the point where $V_{OUT} = V_{DD} - V_{TU}$ for a given V_{IN} allows the entire curve to be sketched

Composite I_{OUT} vs. V_{OUT} to Find Points That Satisfies Both Devices for Each V_{IN}



Voltage Transfer Function for the Complementary Logic Circuit



Vertical section due to zero slope of I_{OUT} vs. V_{OUT} in the saturation region of both devices.

Complete this VTC for the 42PD device in the Homework

Method for Finding V_M

At V_M,

1) $V_{OUT} = V_{IN} = V_M$

2) Both devices are in saturation

3) $I_{OUT\ PD} = I_{OUT\text{-}PU}$

$$I_{OUT-PD} = k_D \left(V_{IN} - V_{TD)}\right) V_{TD} = I_{OUT-PU} = k_U \left(V_{DD} - V_{IN} - V_{TU}\right) V_{TU}$$

Substitute V_M

Solve for V_M

Example Result: When $k_D = k_P$ and $V_{TD} = V_{TU}$, $V_M = V_{DD}/2$