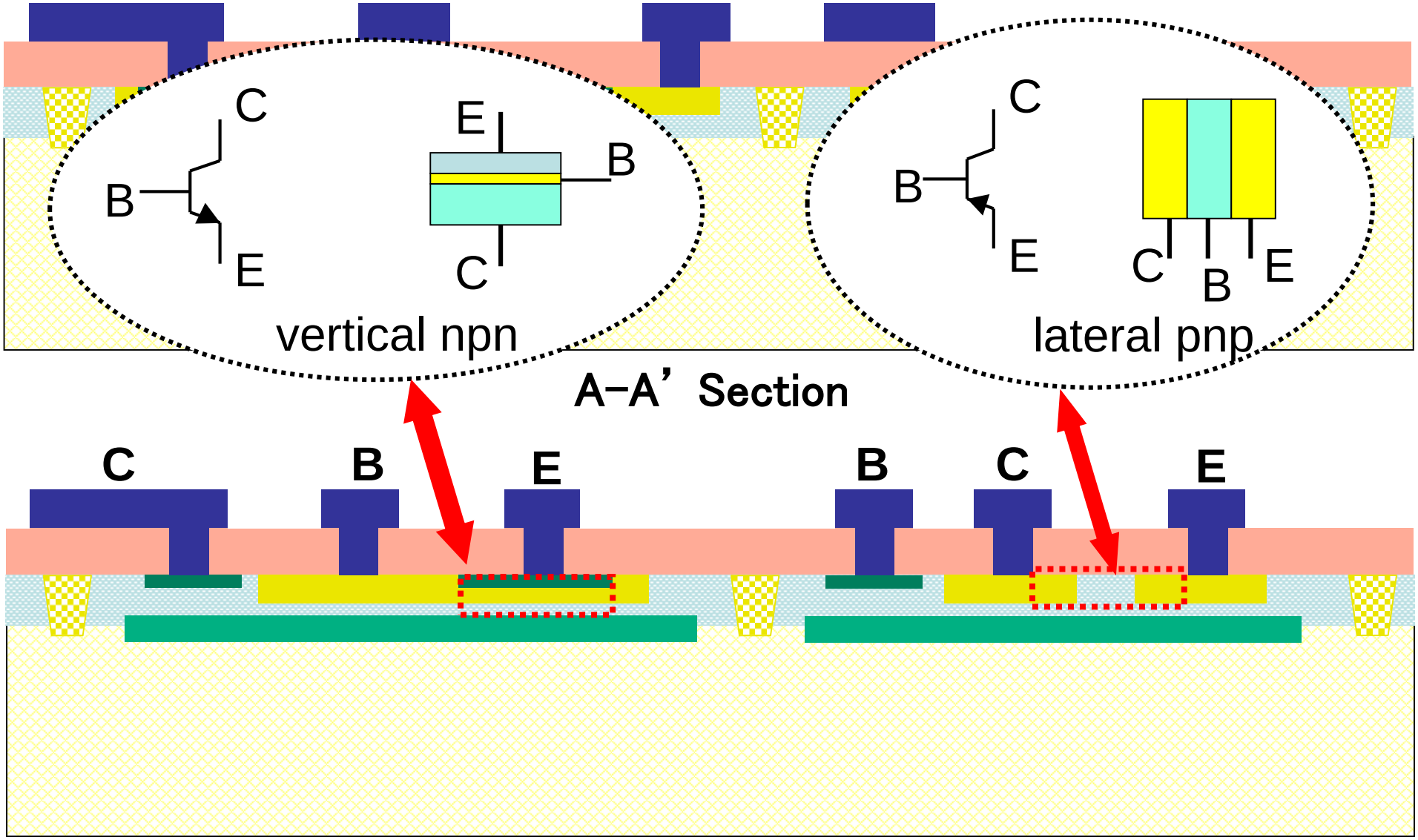
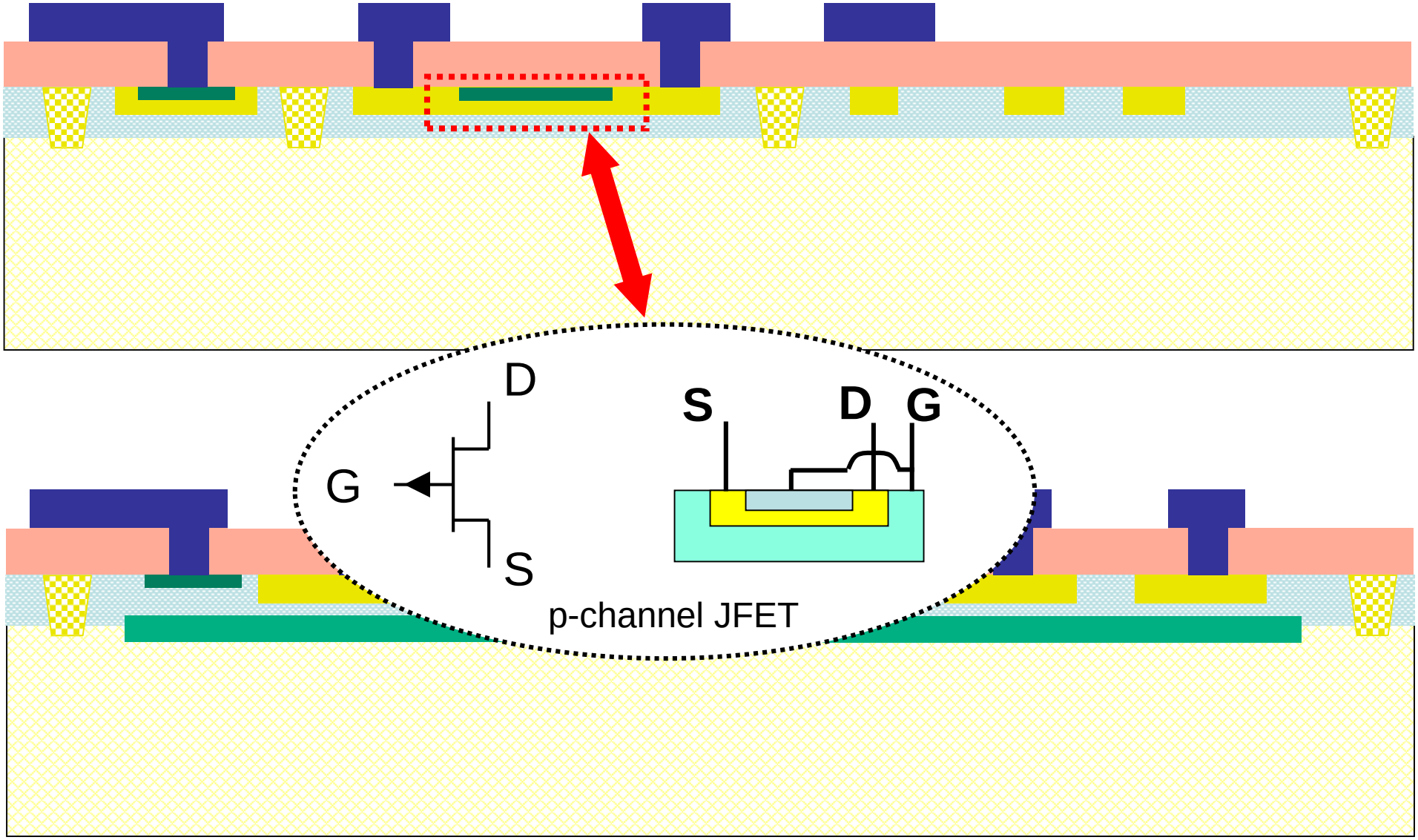
EE 330
Lecture 22

- Small Signal Analysis
- Small Signal Modelling

Review from Last Lecture

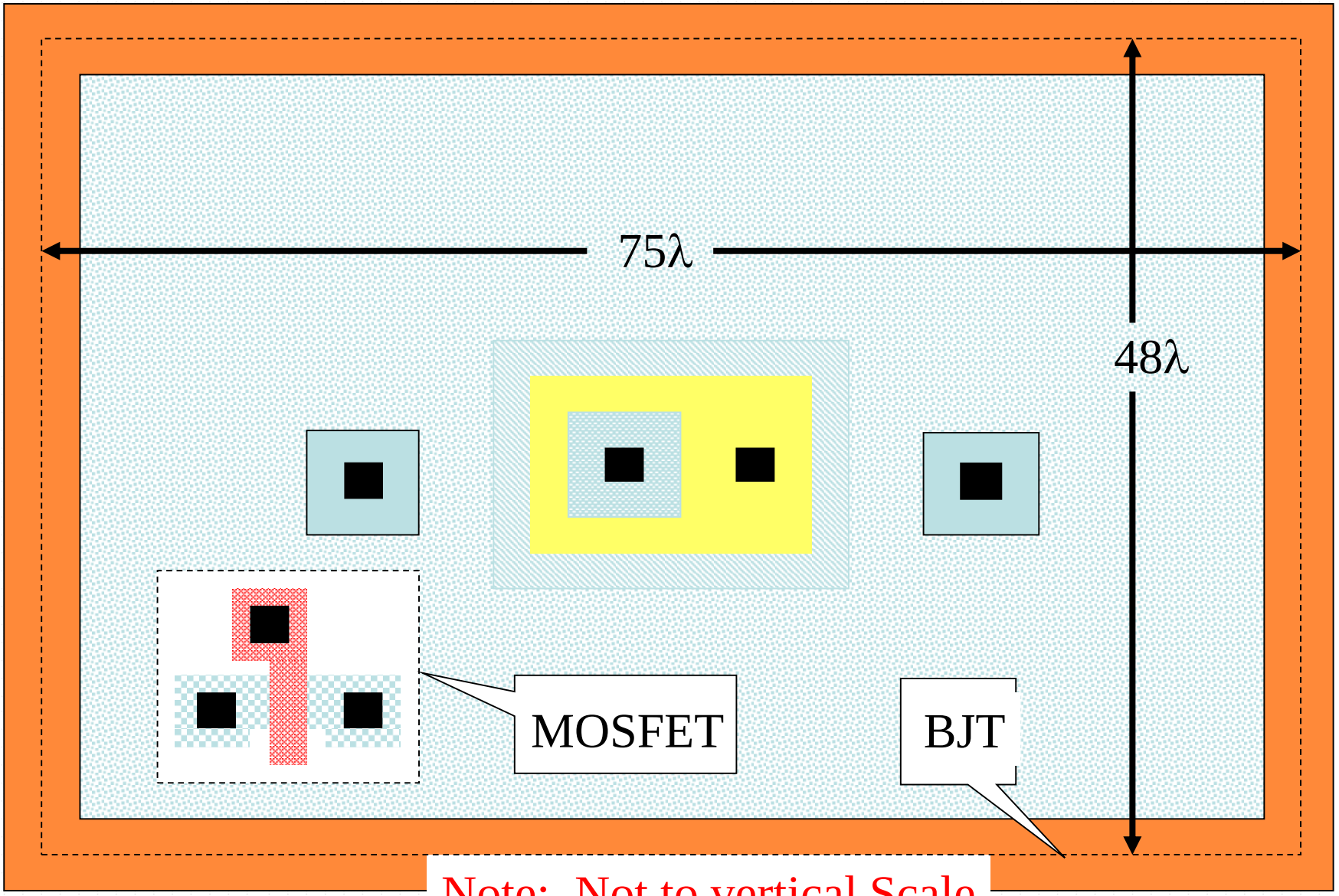


Review from Last Lecture



B–B’ Section

Review from Last Lecture



Note: Not to vertical Scale

Area Comparison between BJT and MOSFET

- BJT Area = 3600 λ^2
- n-channel MOSFET Area = 168 λ^2
- Area Ratio = 21:1

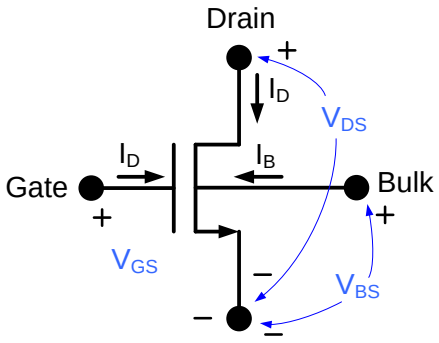
Small-Signal Models

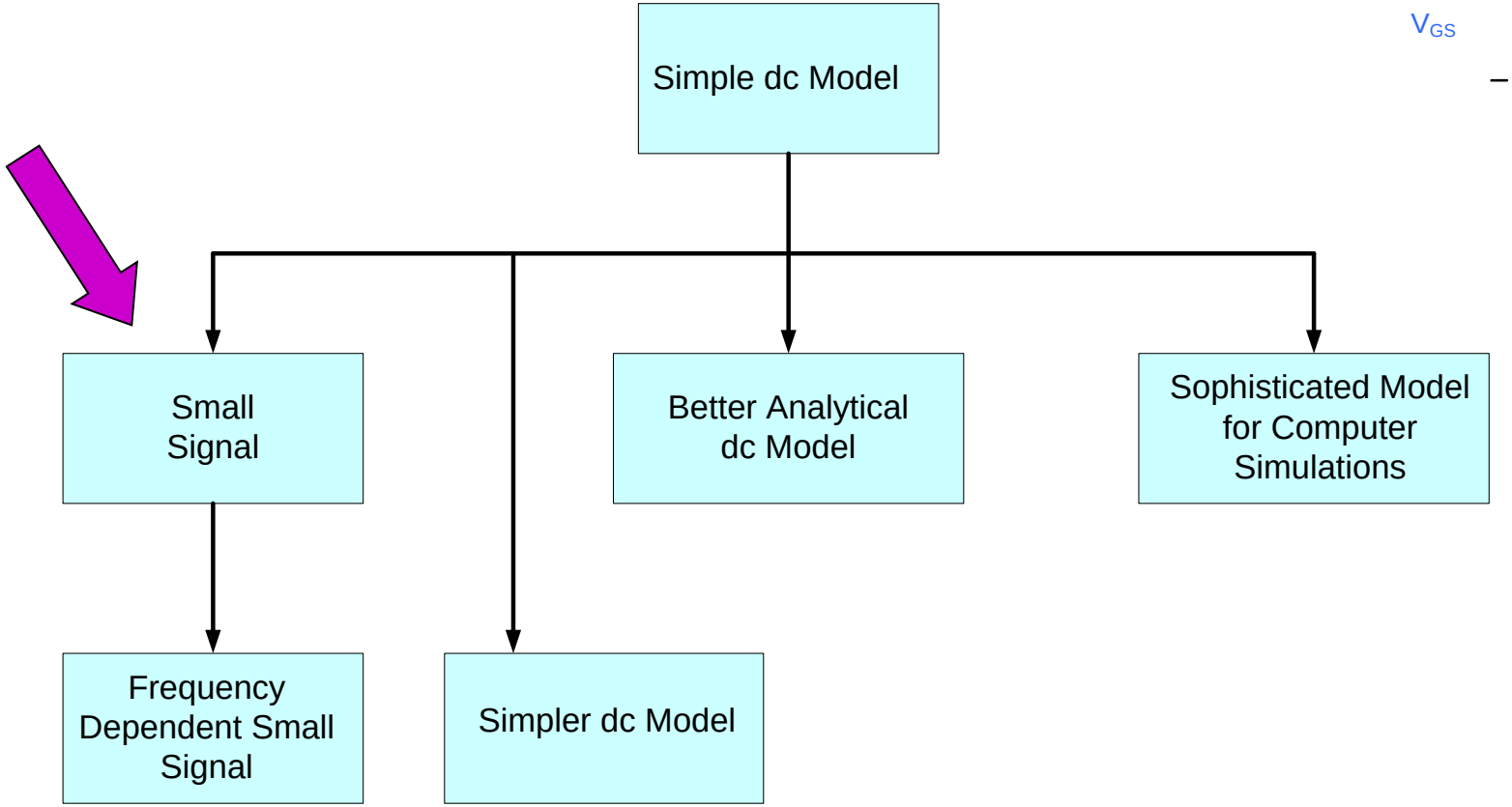
- MOSFET
- BJT
- Diode (of limited use)

Modeling of the MOSFET

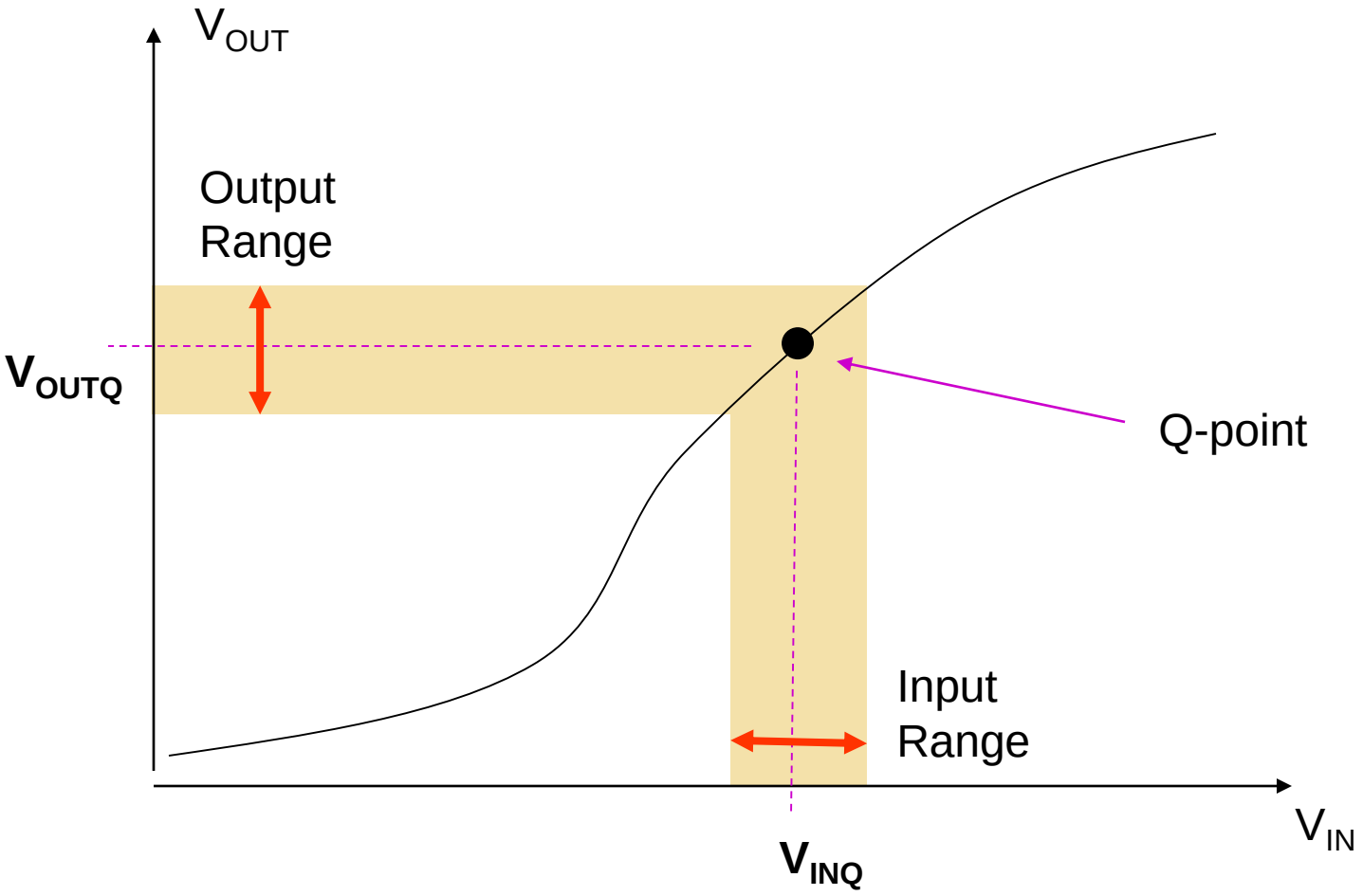
Goal: Obtain a mathematical relationship between the port variables of a device.

$$I_D = f_1(V_{GS}, V_{DS}, V_{BS})$$
$$I_G = f_2(V_{GS}, V_{DS}, V_{BS})$$
$$I_B = f_3(V_{GS}, V_{DS}, V_{BS})$$



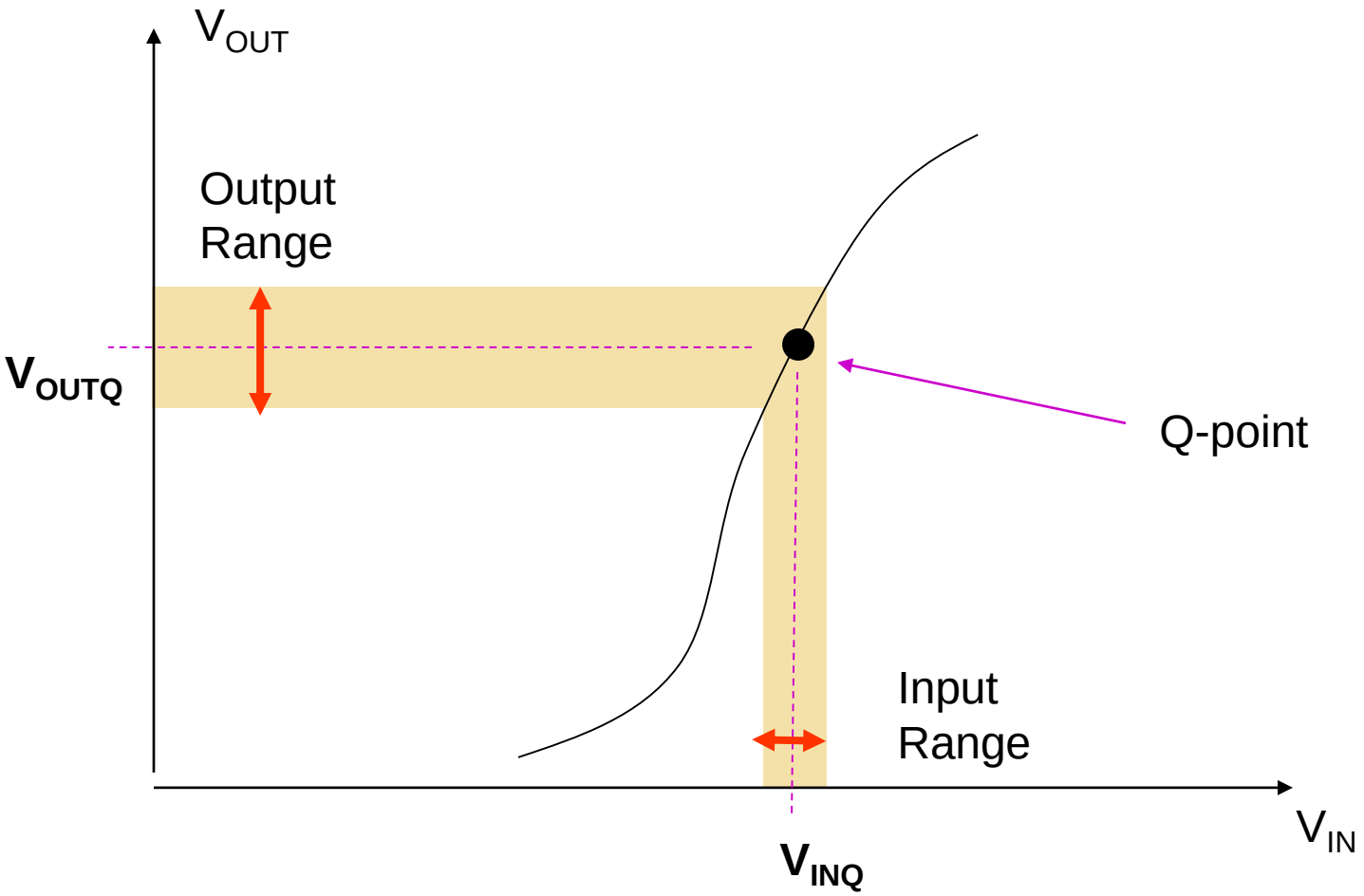


Small-Signal Operation



Throughout the small input range, the “distant” nonlinearities do not affect performance

Small-Signal Operation

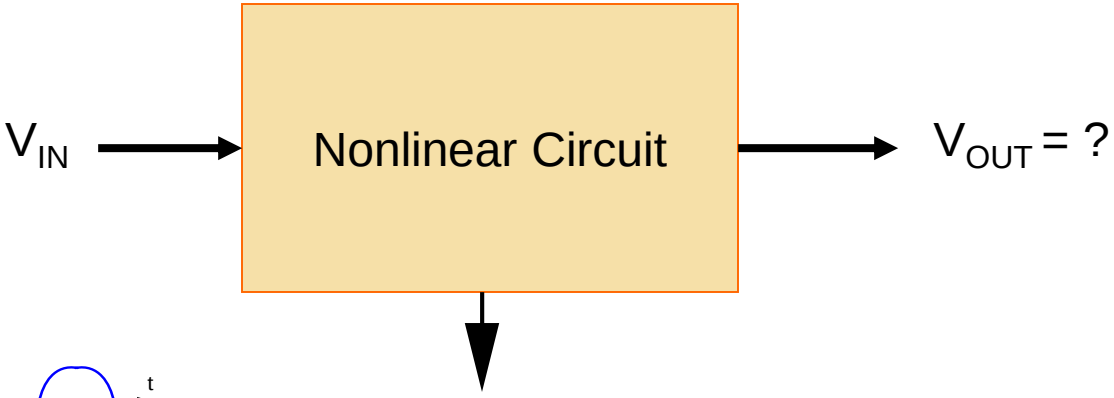


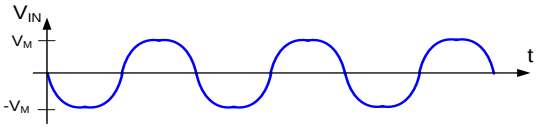
- If slope is steep, output range can be much larger than input range
- The slope can be viewed as the voltage gain of the circuit
- Nonlinear circuit behaves as a linear circuit near Q-point with small-signal inputs

Small signal operation of nonlinear circuits

$V_{IN}=V_m \sin\omega t + V_{INQ}$

V_M is small





- **Small signal concepts often apply when building amplifiers**
- **If small signal concepts do not apply, usually the amplifier will not perform well**
- **Small signal operation is usually synonymous with “locally linear”**
- **Small signal operation is relative to an “operating point”**

Operating Point of Electronic Circuits

Often interested in circuits where a small signal input is to be amplified (e.g. V_M in previous slide is small)

The electrical port variables where the small signals goes to 0 are termed the Operating Points, the Bias Points, the Quiescent Points, or simply the Q-Points

By setting the small signal inputs to 0, it means replacing small voltage inputs with short circuits and small current inputs with open circuits

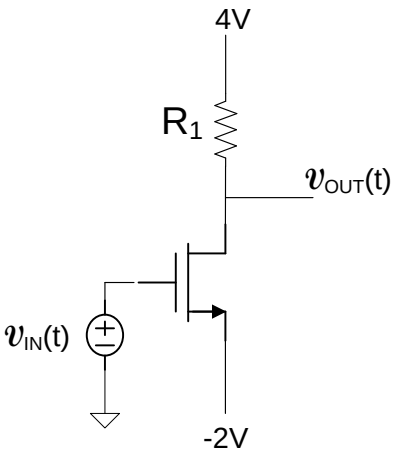
When analyzing small-signal amplifiers, it is necessary to obtain the Q-point

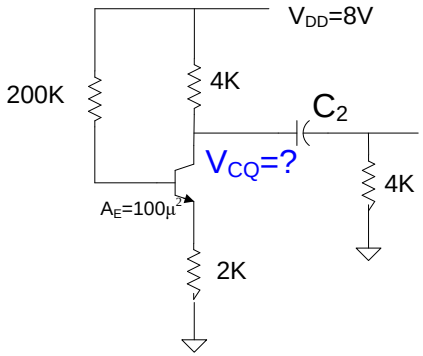
When designing small-signal amplifiers, establishing of the desired Q-point is termed "biasing"

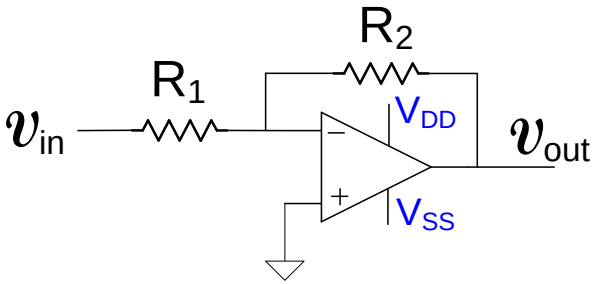
- Capacitors become open circuits (and inductors short circuits) when determining Q-points
- Simplified dc models of the MOSFET (saturation region) or BJT (forward active region) are usually adequate for determining the Q-point in practical amplifier circuits
- DC voltage and current sources remain when determining Q-points
- Small-signal voltage and current sources are set to 0 when determining Q-points

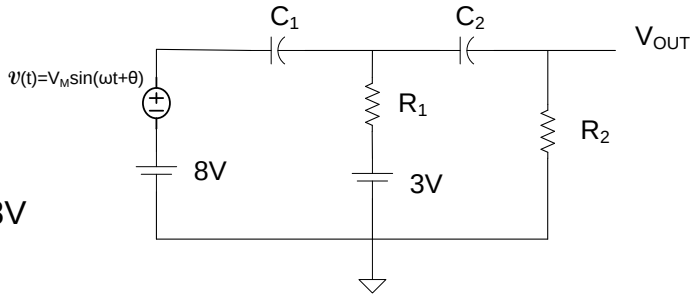
Operating Point of Electronic Circuits

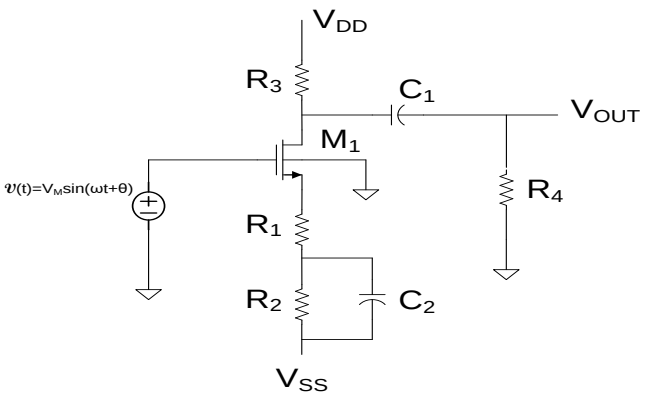
(small signal inputs, if there are any, are set to 0)

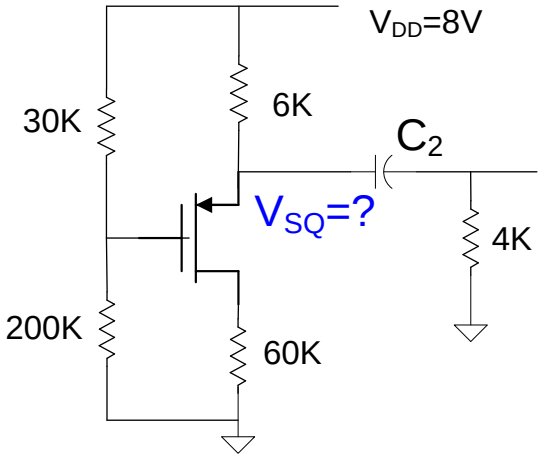








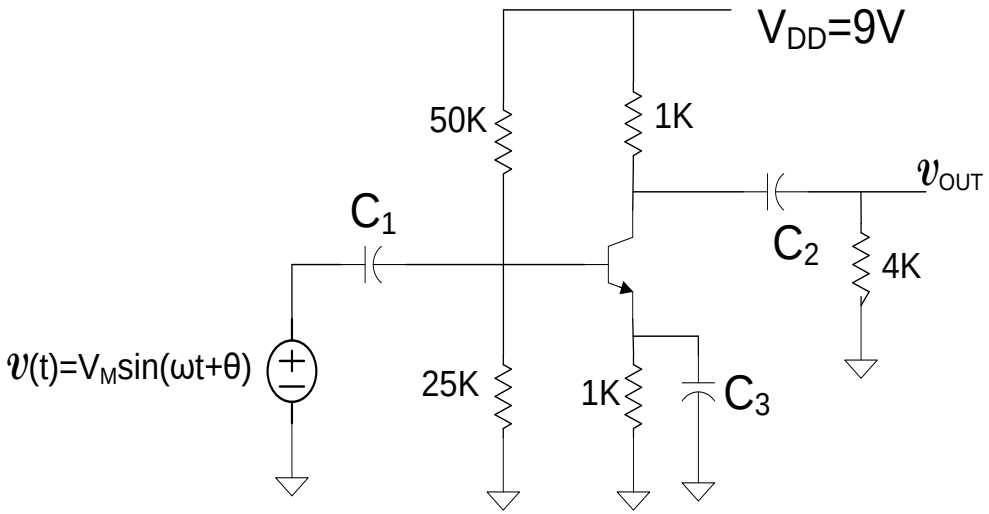




Operating Point Analysis of MOS and Bipolar Devices

Example:

Determine V_{OUTQ} and V_{CQ}

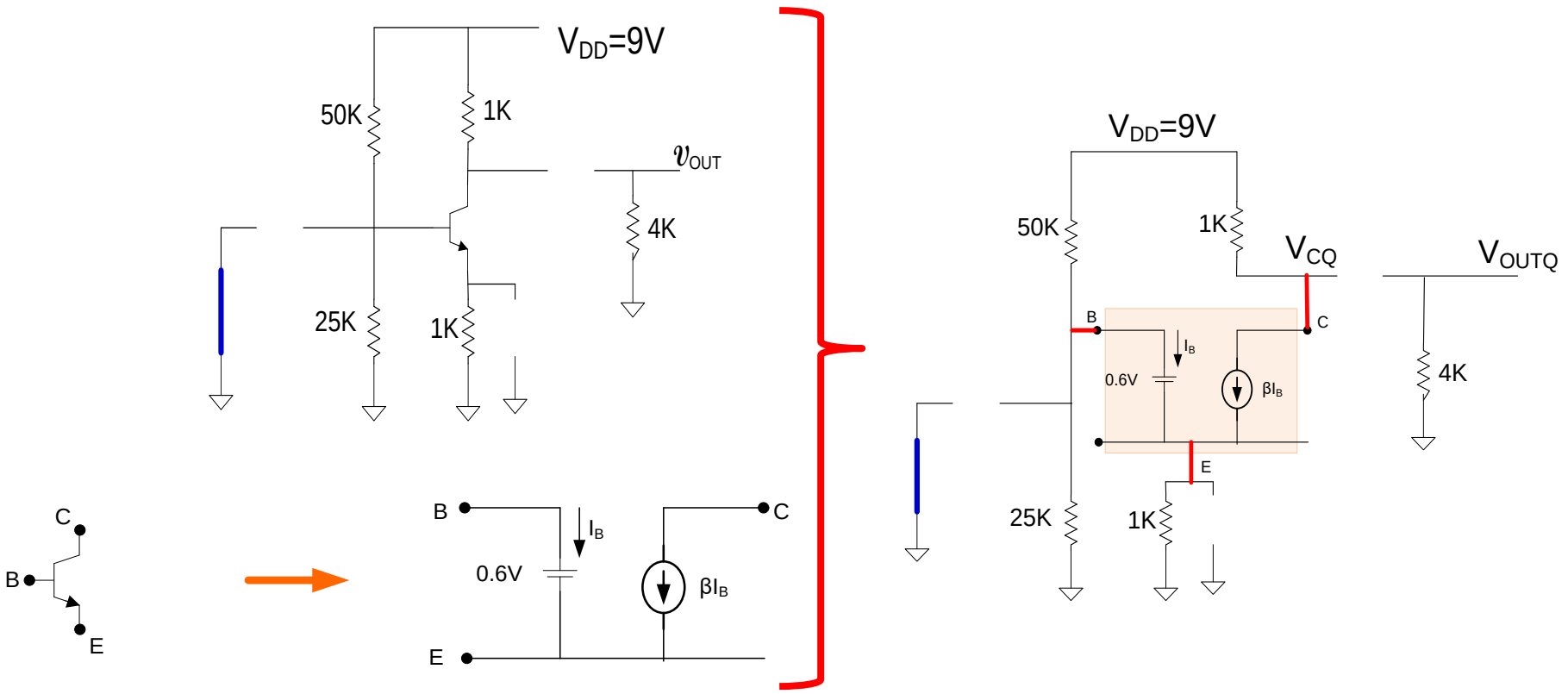


Will formally go through the process in this example, will go into more detail about finding the operating point later

Operating Point Analysis of MOS and Bipolar Devices

Example:

Determine V_{OUTQ} and V_{CQ}



Operating Point Analysis of MOS and Bipolar Devices

Example:

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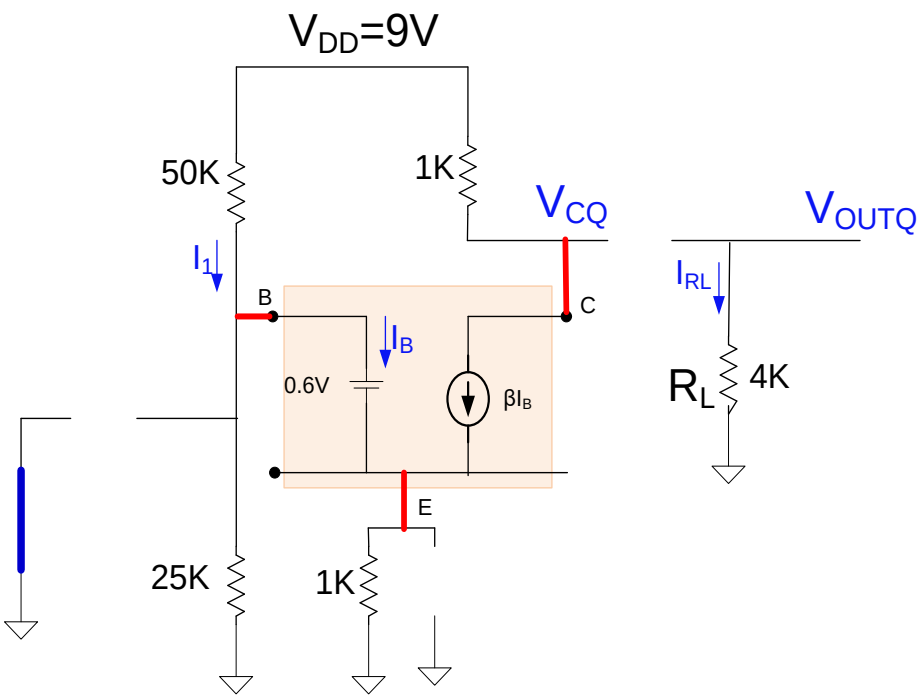


Assume β=100

Assume $I_B << I_1$ (must verify)

$$V_{BQ} = \frac{9V}{3} = 3V$$

$$V_{EQ} = 3V - 0.6V = 2.4V$$

$$I_{EQ} = I_{CQ} = \frac{2.4V}{1K} = 2.4mA$$

$$V_{CQ} = 9V - I_{CQ} \bullet 1K = 9V - 2.4V = 6.6V$$

$V_{OUTQ} = I_{RL} \bullet 4K = 0V$

V_{CQ}=6.6V

V_{OUTQ}=0V

Amplification with Transistors

From Wikipedia: (Oct. 2019)

> An **amplifier**, **electronic amplifier** or (informally) **amp** is an electronic device that can increase the power of a signal (a time-varying voltage or current).

What is the “power” of a signal?

Can an amplifier make decisions?

Does Wikipedia have such a basic concept right?

Amplification with Transistors

From Wikipedia: (Feb. 2017)

An **amplifier**, **electronic amplifier** or (informally) **amp** is an electronic device that increases the power of a signal (a time varying voltage or current.

From Wikipedia: (Oct. 2015)

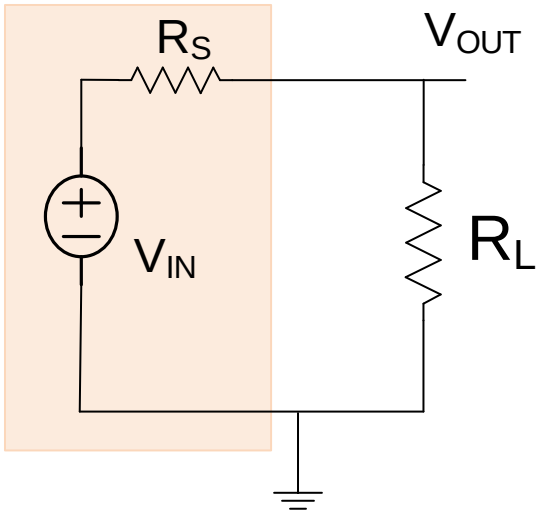
An **amplifier**, **electronic amplifier** or (informally) **amp** is an electronic device that increases the power of a signal.

From Wikipedia: (approx. 2010)

Generally, an **amplifier** or simply **amp**, is any device that changes, usually increases, the amplitude of a signal. The "signal" is usually voltage or current.

These “minor” differences in definition are not trivial !

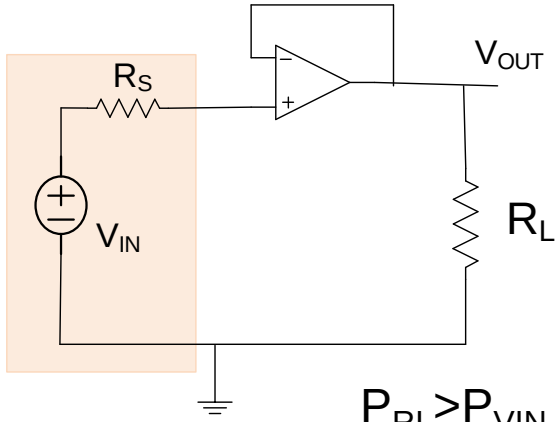
Signal and Power Levels



$P_{RL}<P_{VIN}$

$V_{OUT}<V_{IN}$

P_{RL} will be maximum when load impedance matches source impedance



$P_{RL}>P_{VIN}$

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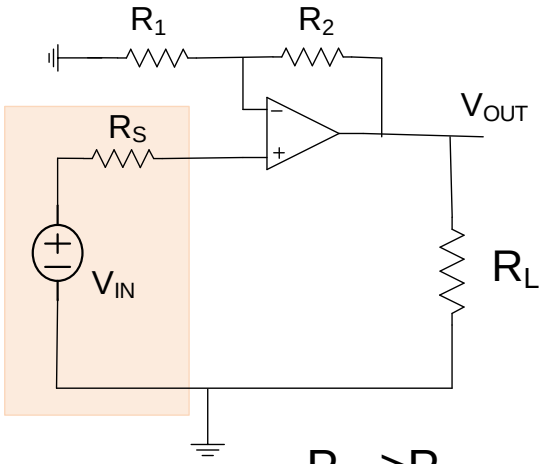
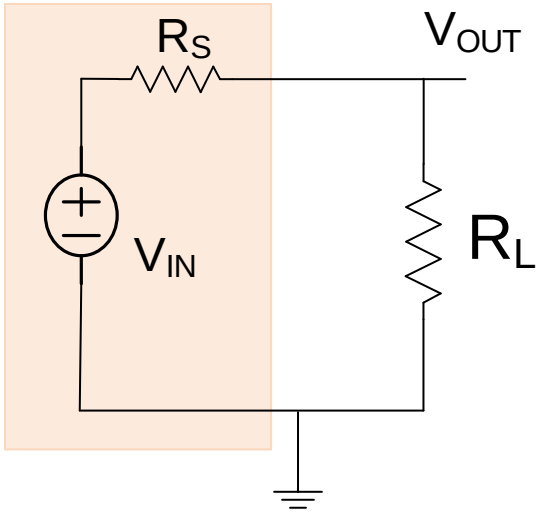


$P_{RL}>P_{VIN}$

V_{OUT} can be larger of smaller than V_{IN}

Signal and Power Levels



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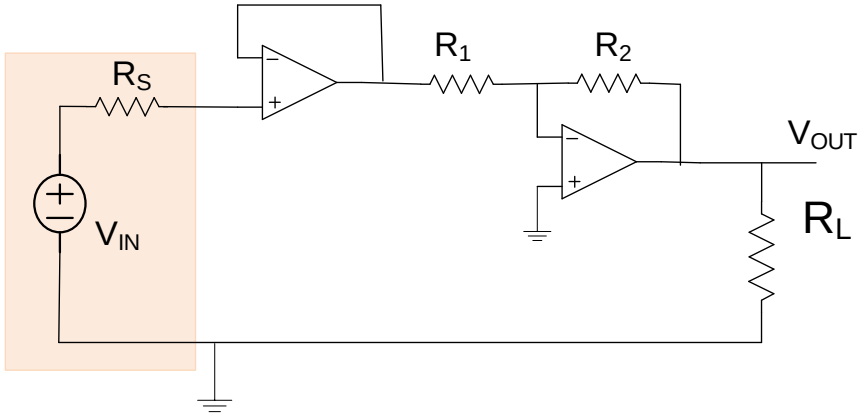
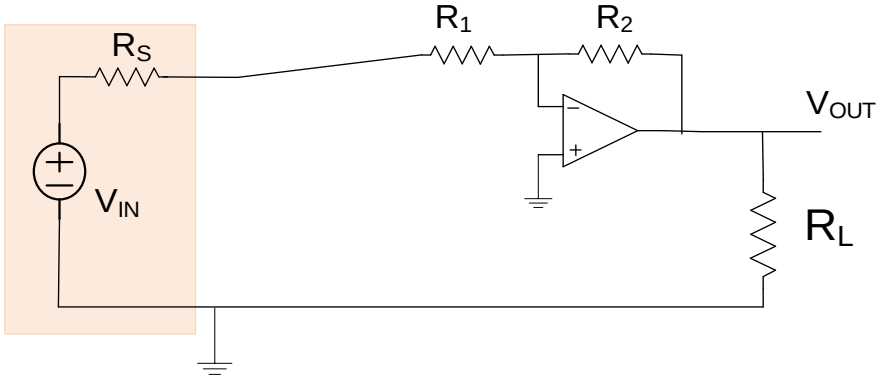


$P_{RL}>P_{VIN}$

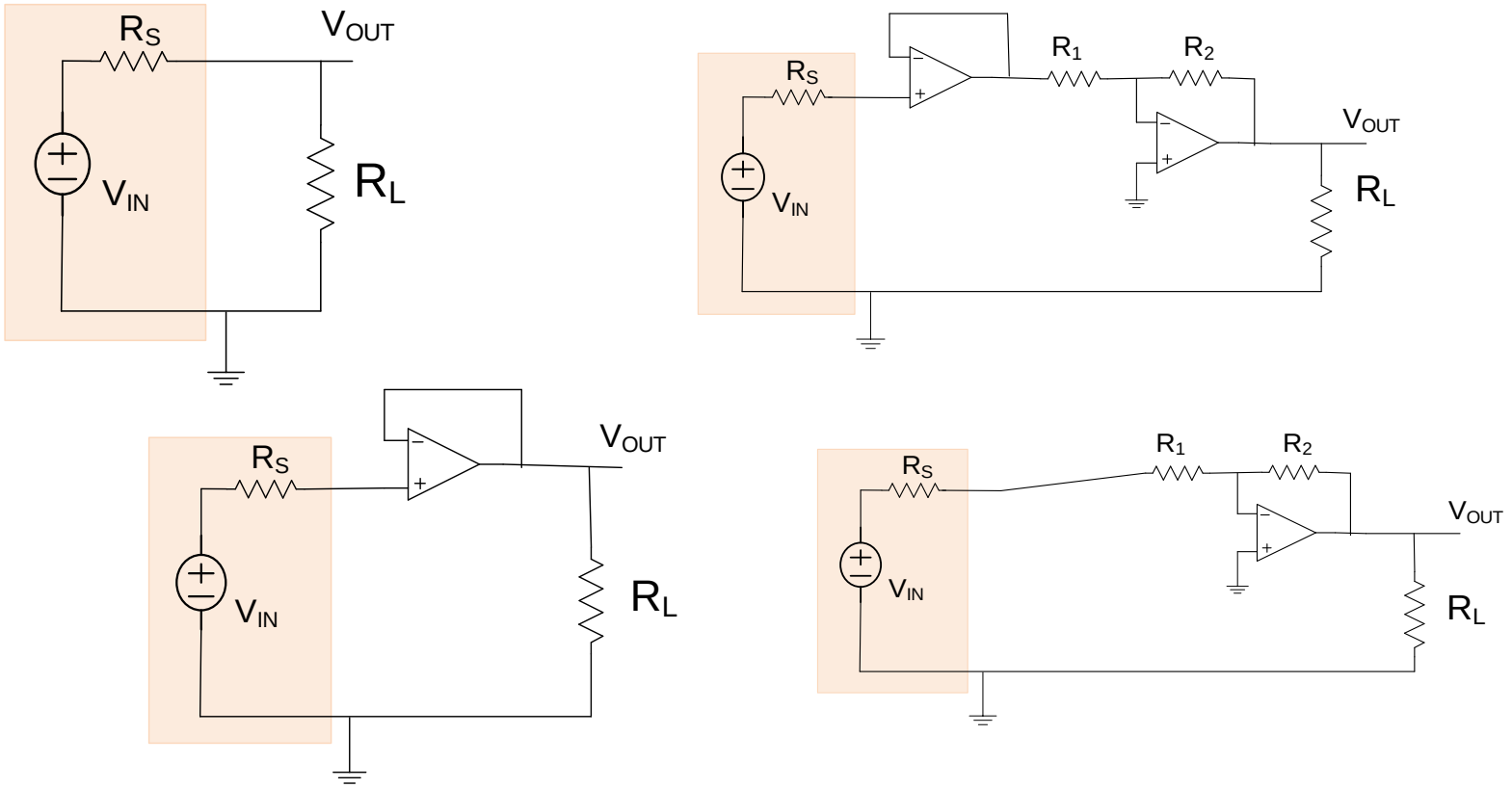
V_{OUT} can be larger of smaller than V_{IN}



V_{OUT} can be larger of smaller than V_{IN}

P_{RL} can be larger of smaller than P_{VIN}

Signal and Power Levels



In most electronic circuit “amplifier” applications, there is little concern about whether the power in the load is larger or smaller than the power supplied by the source

Impedance matching for the purpose of delivering power to a load is seldom of concern or even used in most electronic circuits

Amplification with Transistors

From Wikipedia: (Oct. 2019)

An **amplifier**, **electronic amplifier** or (informally) **amp** is an electronic device that can increase the power of a signal (a time-varying voltage or current).

- It is difficult to increase the voltage or current very much with passive RC circuits
- Voltage and current levels can be increased a lot with transformers but not practical in integrated circuits
- Power levels can not be increased with passive elements (R, L, C, and Transformers)

- Often an amplifier is defined to be a circuit that **can** increase power delivered to a resistive load (be careful with Wikipedia and WWW even when some of the most basic concepts are discussed)
- Transistors can be used to increase not only signal levels but power levels to a load
- In transistor circuits, power that is delivered in the signal path is supplied by a biasing network
- Signals that are amplified are often not time varying

In the electronic community, there is often little or no concern about the power delivered to a load and the term “amplifier” generally refers to a device that changes the level of a voltage or current or converts from one unit to another (V to I or I to V)

Amplification with Transistors

From Wikipedia: (Oct. 2019)

An **amplifier**, **electronic amplifier** or (informally) **amp** is an electronic device that can increase the power of a signal (a time-varying voltage or current).

From Wikipedia: (Oct. 2015)

It does this by taking energy from a power supply and controlling the output to match the input signal shape but with a larger amplitude. In this sense, an amplifier modulates the output of the power supply to make the output signal stronger than the input signal.

Amplification with Transistors

Often the gain of an amplifier is larger than 1

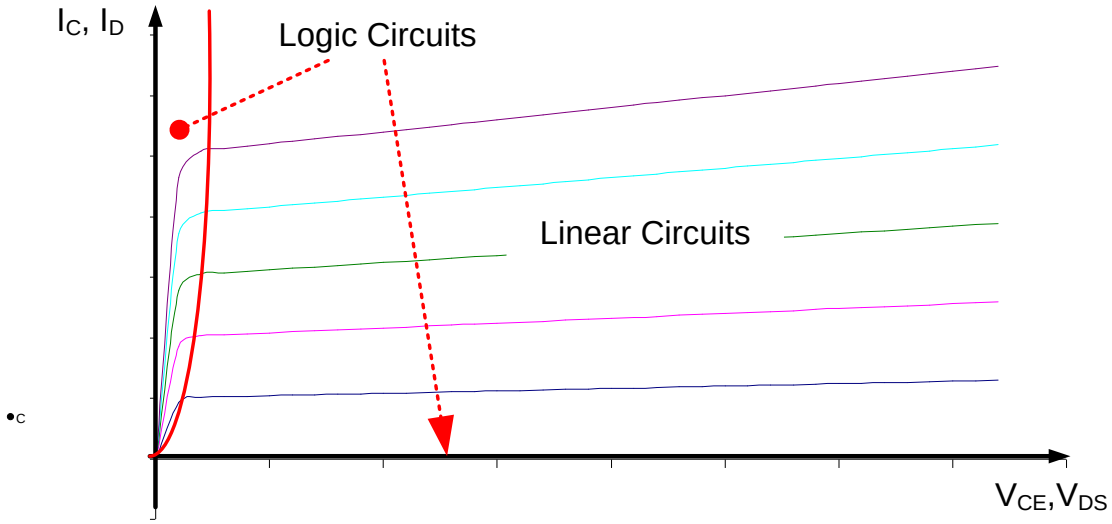
$$V_{OUT} = A_V V_{IN}$$

Often (but not always) the power dissipated by R_L is larger than the power supplied by V_{IN}

An amplifier can be thought of as a dependent source that was discussed in EE 201

Input and output variables can be either V or I or mixed

Applications of Devices as Amplifiers

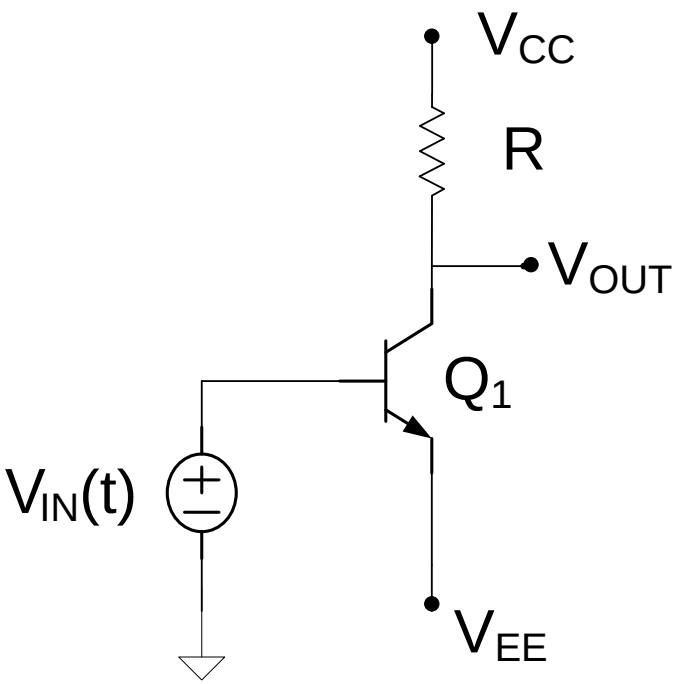


Typical Regions of Operation by Circuit Function

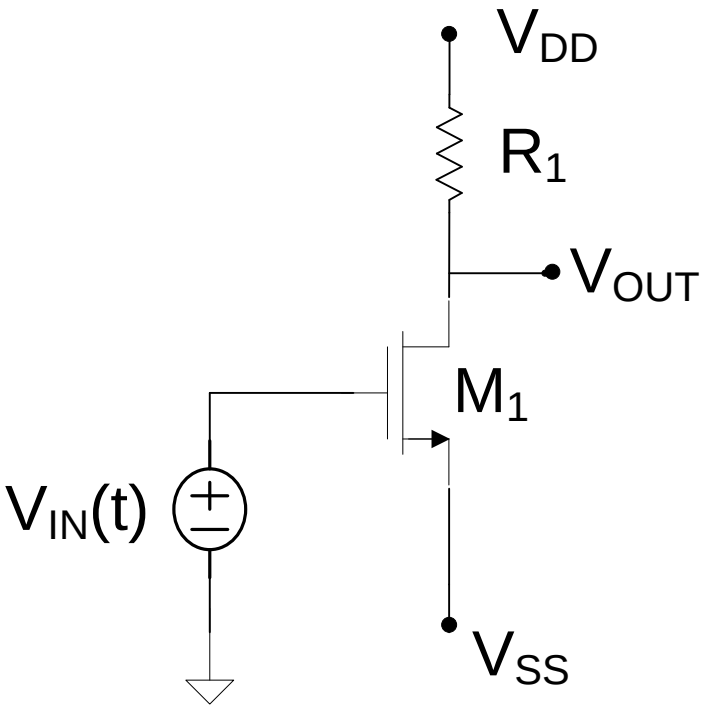
	MOS	Bipolar
Logic Circuits	Triode and Cutoff	Saturation and Cutoff
Linear Circuits	Saturation	Forward Active

Consider the following MOSFET and BJT Circuits

BJT



MOSFET



Assume BJT operating in FA region, MOSFET operating in Saturation

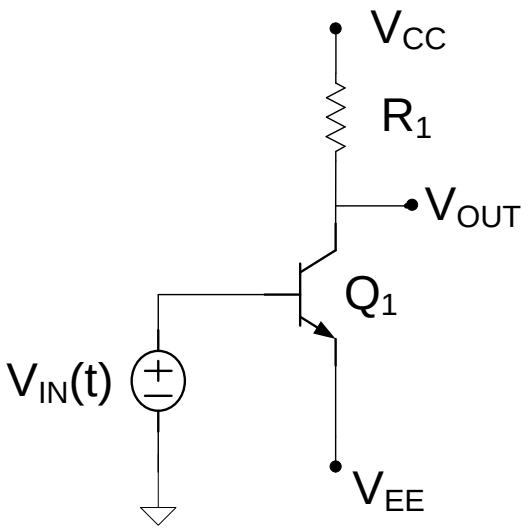
Assume same quiescent output voltage and same resistor R_1

Note architecture is same for BJT and MOSFET circuits

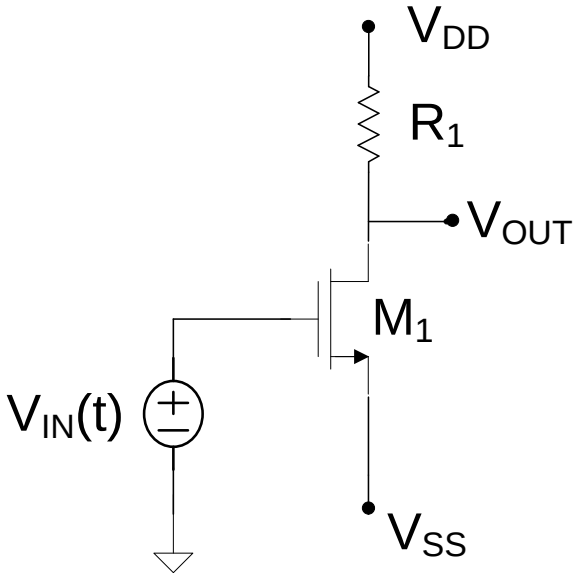
One of the most widely used amplifier architectures

Consider the following MOSFET and BJT Circuits

BJT



MOSFET



- MOS and BJT Architectures often Identical
- Circuit are Highly Nonlinear
- Nonlinear Analysis Methods Must be used to analyze these and almost any other nonlinear circuit

End of Lecture 22