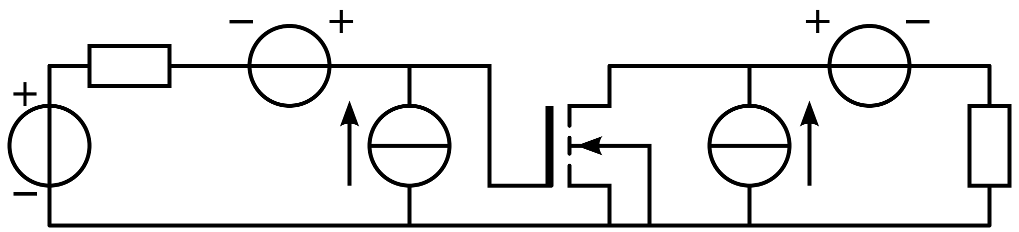
Structured Electronic Design

EE4109
Biasing

Anton J.M. Montagne

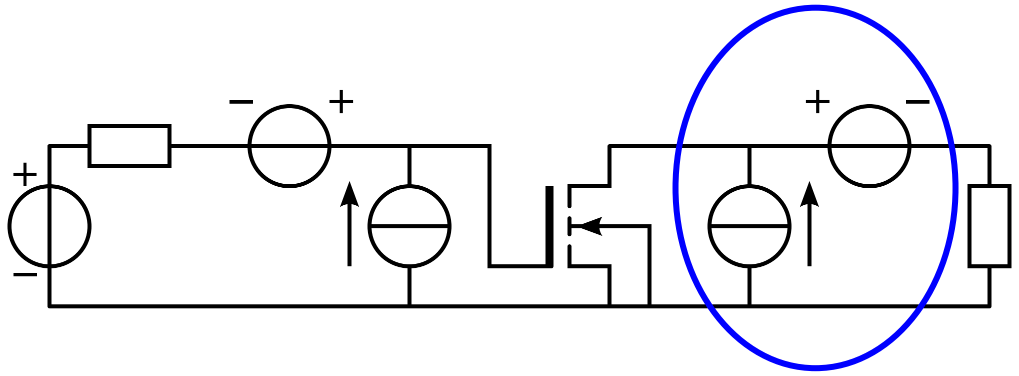
Introduction to biasing

Introduction to biasing



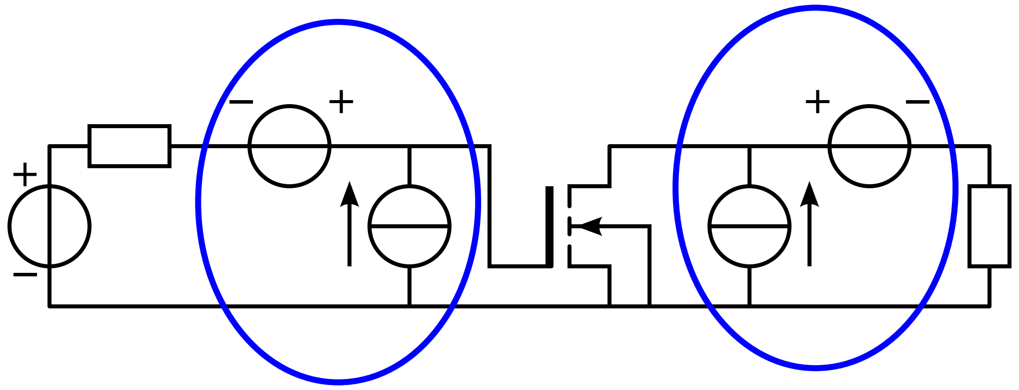
Introduction to biasing

Values assigned during design



Introduction to biasing

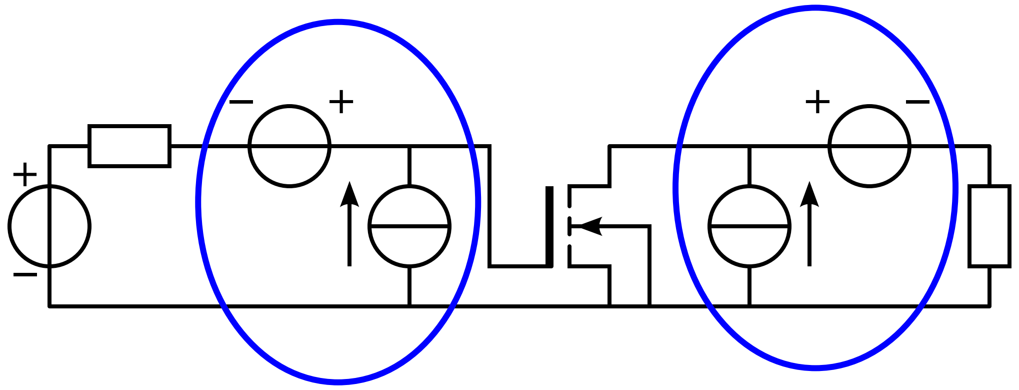
Values assigned
during design



Values depend on

Introduction to biasing

Values assigned
during design

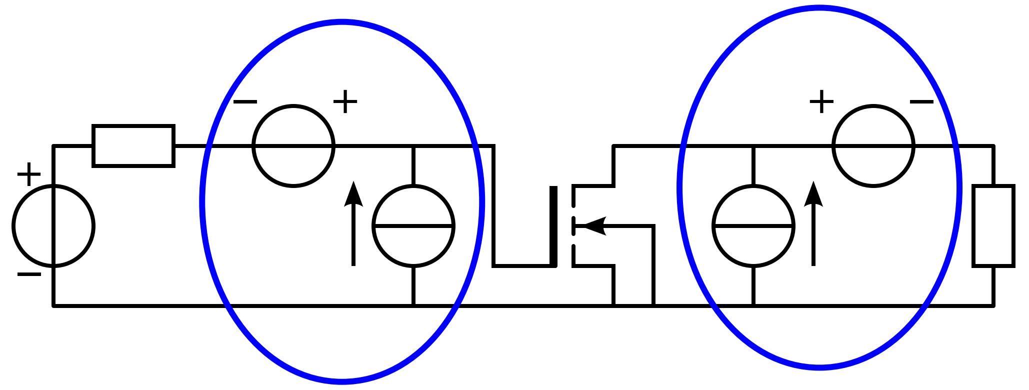


Values depend on

Bias sources at output port

Introduction to biasing

Values assigned
during design

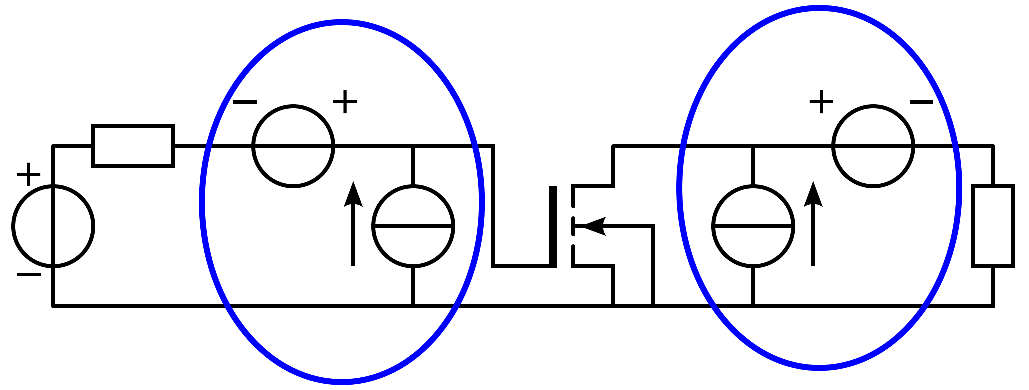


Values depend on

Bias sources at output port
Device characteristics

Introduction to biasing

Values assigned
during design

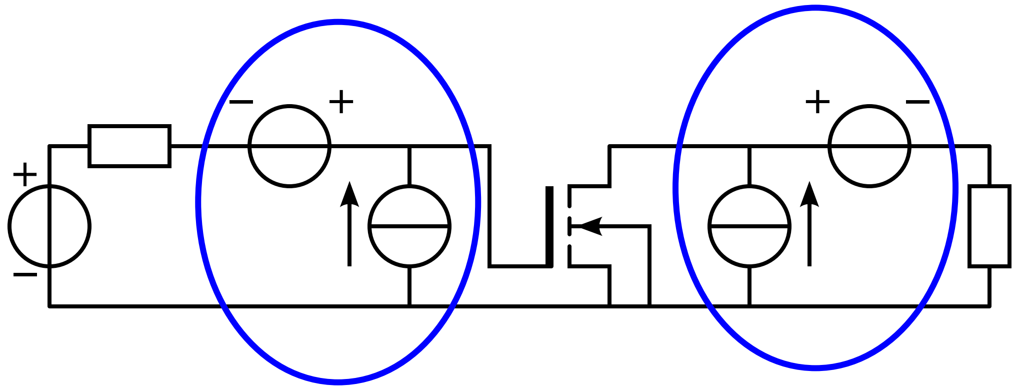


Values depend on

Bias sources at output port
Device characteristics
Temperature

Introduction to biasing

Values assigned
during design



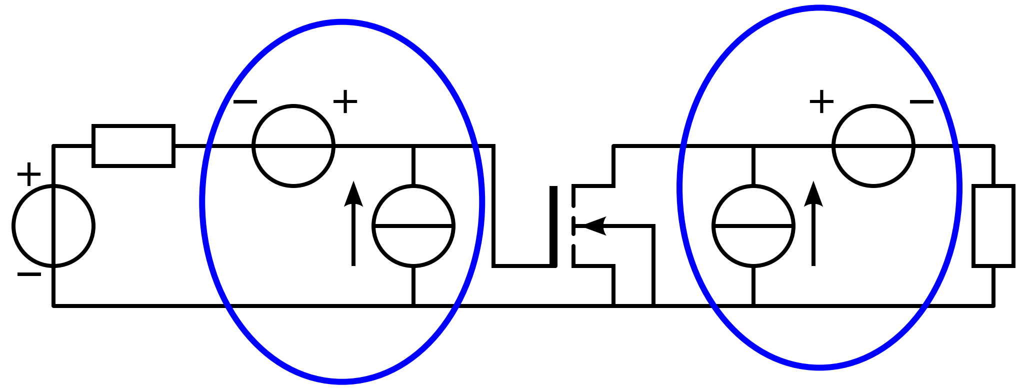
Values depend on

Bias sources at output port
Device characteristics
Temperature

Biasing

Introduction to biasing

Values assigned
during design



Values depend on

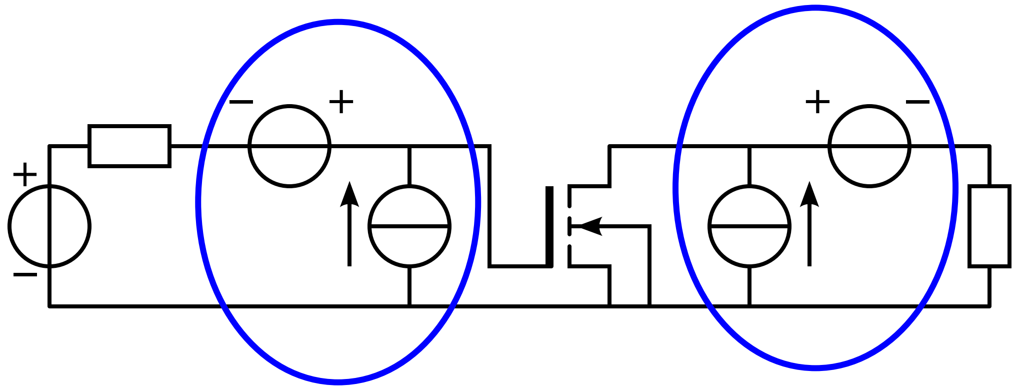
Bias sources at output port
Device characteristics
Temperature

Biasing

Set the operating voltages and currents of the devices

Introduction to biasing

Values assigned
during design



Values depend on

Bias sources at output port
Device characteristics
Temperature

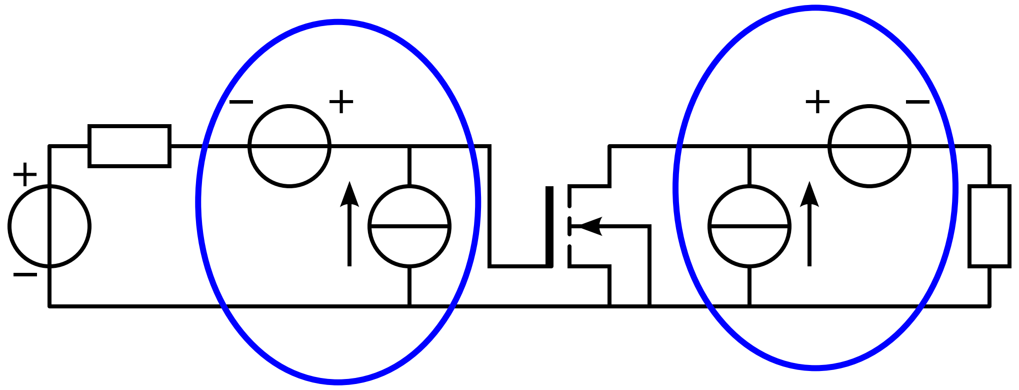
Biasing

Set the operating voltages and currents of the devices

Derive required voltages and currents from the power supply voltage

Introduction to biasing

Values assigned
during design



Values depend on

Bias sources at output port
Device characteristics
Temperature

Biasing

Set the operating voltages and currents of the devices

Derive required voltages and currents from the power supply voltage

Introduction to biasing

Introduction to biasing

Biasing is known to be difficult

Introduction to biasing

Biasing is known to be difficult

Experienced designers concurrently design biasing and signal path

Introduction to biasing

Biasing is known to be difficult

Experienced designers concurrently design biasing and signal path

Can be understood if all methods and techniques are presented in a structured way

Introduction to biasing

Biasing is known to be difficult

Experienced designers concurrently design biasing and signal path

Can be understood if all methods and techniques are presented in a structured way

So that's what we will do!

Introduction to biasing

Biasing is known to be difficult

Experienced designers concurrently design biasing and signal path

Can be understood if all methods and techniques are presented in a structured way

So that's what we will do!

Design of biasing concept

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)
  - Brute-force CM biasing

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)
  - Brute-force CM biasing
  - Model-based CM biasing

Design of biasing concept

- Connect the (conceptually biased) circuit to the power supply
- Redirect the current sources over the power supply
- Minimize the number of floating bias voltage sources
- Replace ideal sources with passive biasing elements and complete the biasing concept
- Set-up specifications for biasing elements
- If common-mode bias voltages and current are not well-defined:
  - Define CM bias voltage(s) and/or current(s)
    - Brute-force CM biasing
    - Model-based CM biasing
    - Negative feedback CM biasing

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)
  - Brute-force CM biasing
  - Model-based CM biasing
  - Negative feedback CM biasing

If differential-mode bias voltages and current are not well-defined:

- Define DM bias voltage(s) and/or current(s)

Design of biasing concept

- Connect the (conceptually biased) circuit to the power supply
- Redirect the current sources over the power supply
- Minimize the number of floating bias voltage sources
- Replace ideal sources with passive biasing elements and complete the biasing concept
- Set-up specifications for biasing elements
- If common-mode bias voltages and current are not well-defined:
  - Define CM bias voltage(s) and/or current(s)
    - Brute-force CM biasing
    - Model-based CM biasing
    - Negative feedback CM biasing
- If differential-mode bias voltages and current are not well-defined:
  - Define DM bias voltage(s) and/or current(s)
    - Brute-force DM biasing

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)
  - Brute-force CM biasing
  - Model-based CM biasing
  - Negative feedback CM biasing

If differential-mode bias voltages and current are not well-defined:

- Define DM bias voltage(s) and/or current(s)
  - Brute-force DM biasing
  - Model-based DM biasing

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)
  - Brute-force CM biasing
  - Model-based CM biasing
  - Negative feedback CM biasing

If differential-mode bias voltages and current are not well-defined:

- Define DM bias voltage(s) and/or current(s)
  - Brute-force DM biasing
  - Model-based DM biasing
  - Negative feedback DM biasing

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)
  - Brute-force CM biasing
  - Model-based CM biasing
  - Negative feedback CM biasing

If differential-mode bias voltages and current are not well-defined:

- Define DM bias voltage(s) and/or current(s)
  - Brute-force DM biasing
  - Model-based DM biasing
  - Negative feedback DM biasing
    - AC signal coupling and DC (low-pass) bias feedback over the largest possible number of stages

Design of biasing concept

- Connect the (conceptually biased) circuit to the power supply
- Redirect the current sources over the power supply
- Minimize the number of floating bias voltage sources
- Replace ideal sources with passive biasing elements and complete the biasing concept
- Set-up specifications for biasing elements
- If common-mode bias voltages and current are not well-defined:
  - Define CM bias voltage(s) and/or current(s)
    - Brute-force CM biasing
    - Model-based CM biasing
    - Negative feedback CM biasing
- If differential-mode bias voltages and current are not well-defined:
  - Define DM bias voltage(s) and/or current(s)
    - Brute-force DM biasing
    - Model-based DM biasing
    - Negative feedback DM biasing
      - AC signal coupling and DC (low-pass) bias feedback over the largest possible number of stages
      - Auto-zero biasing

Design of biasing concept

Connect the (conceptually biased) circuit to the power supply

Redirect the current sources over the power supply

Minimize the number of floating bias voltage sources

Replace ideal sources with passive biasing elements and complete the biasing concept

Set-up specifications for biasing elements

If common-mode bias voltages and current are not well-defined:

- Define CM bias voltage(s) and/or current(s)
  - Brute-force CM biasing
  - Model-based CM biasing
  - Negative feedback CM biasing

If differential-mode bias voltages and current are not well-defined:

- Define DM bias voltage(s) and/or current(s)
  - Brute-force DM biasing
  - Model-based DM biasing
  - Negative feedback DM biasing
    - AC signal coupling and DC (low-pass) bias feedback over the largest possible number of stages
    - Auto-zero biasing

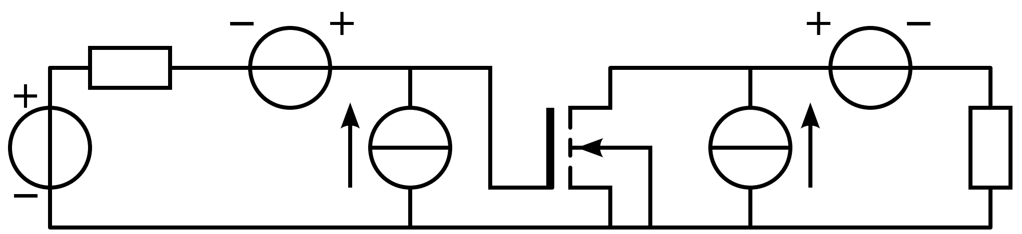
Connect the biased circuit to the power supply

Connect the biased circuit to the power supply

Initial CS-stage biasing

Connect the biased circuit to the power supply

Initial CS-stage biasing

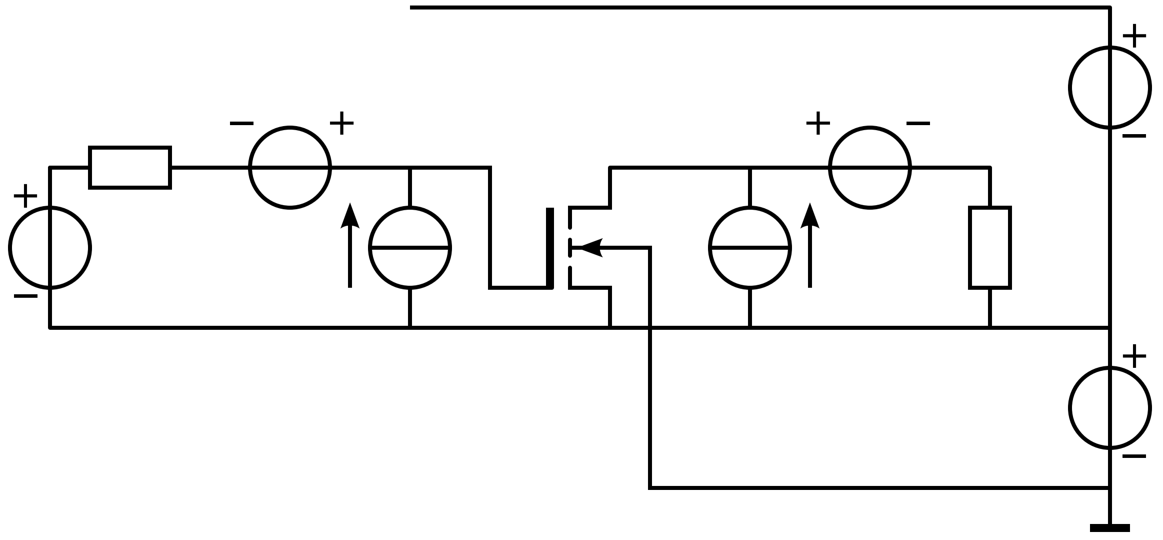


Connect the biased circuit to the power supply

Connected to supply

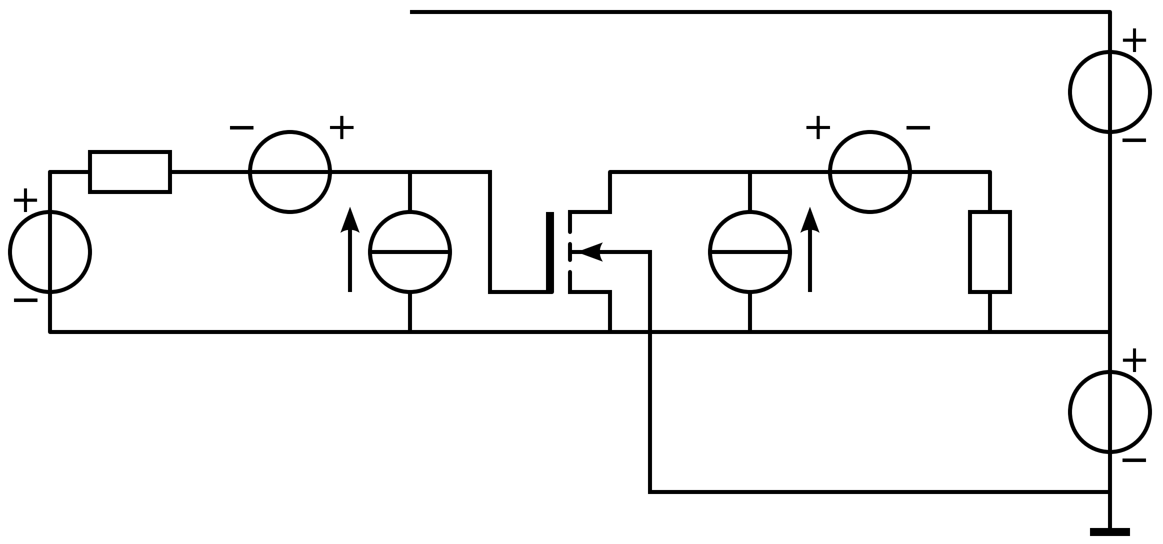
Connect the biased circuit to the power supply

Connected to supply



Connect the biased circuit to the power supply

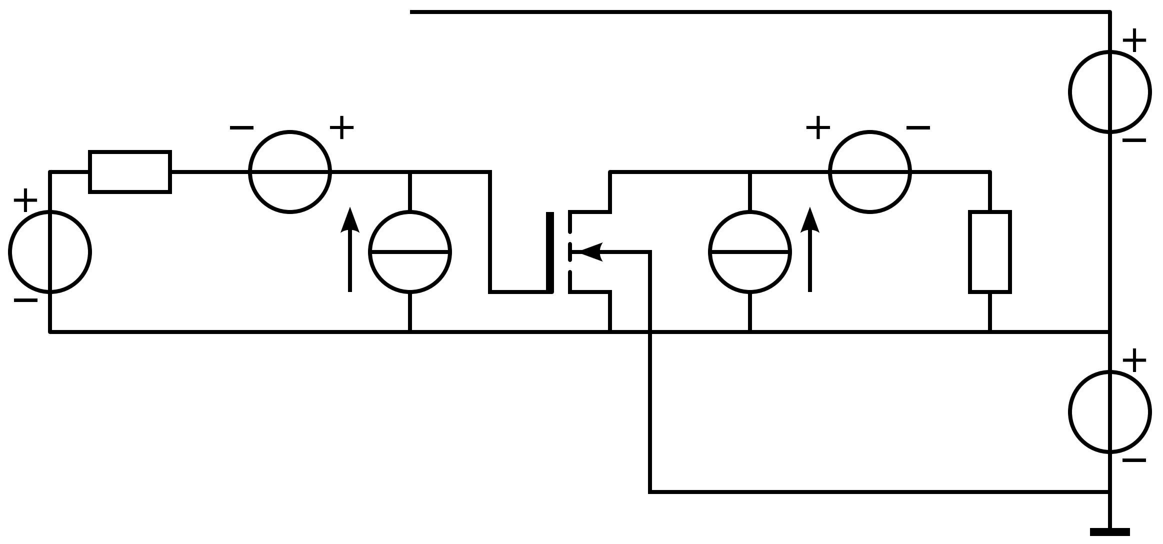
Connected to supply



For all signal levels:

Connect the biased circuit to the power supply

Connected to supply

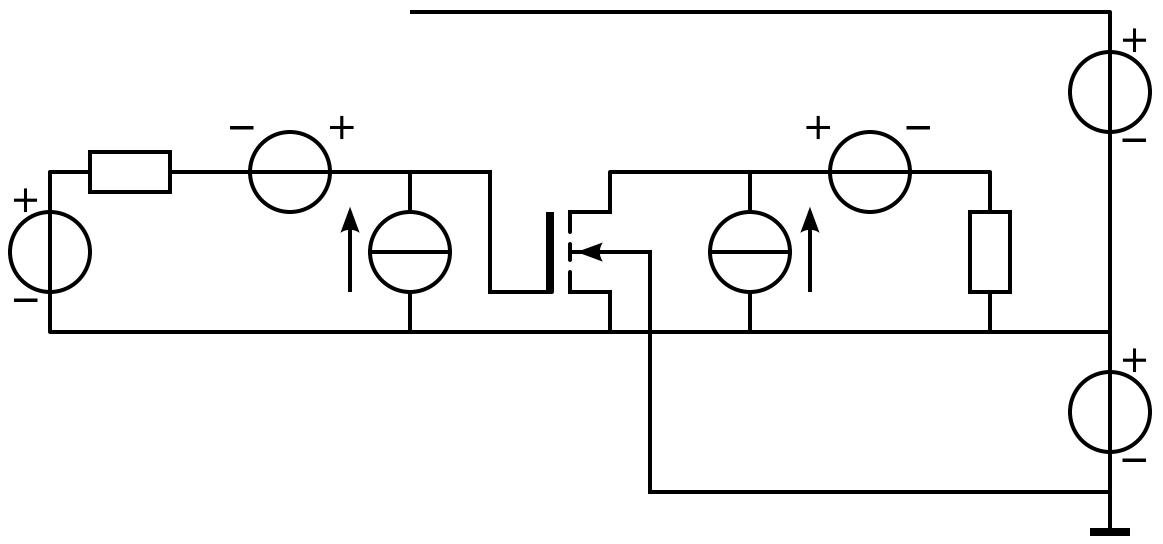


For all signal levels:

Nodal voltages should be
within valid range

Connect the biased circuit to the power supply

Connected to supply

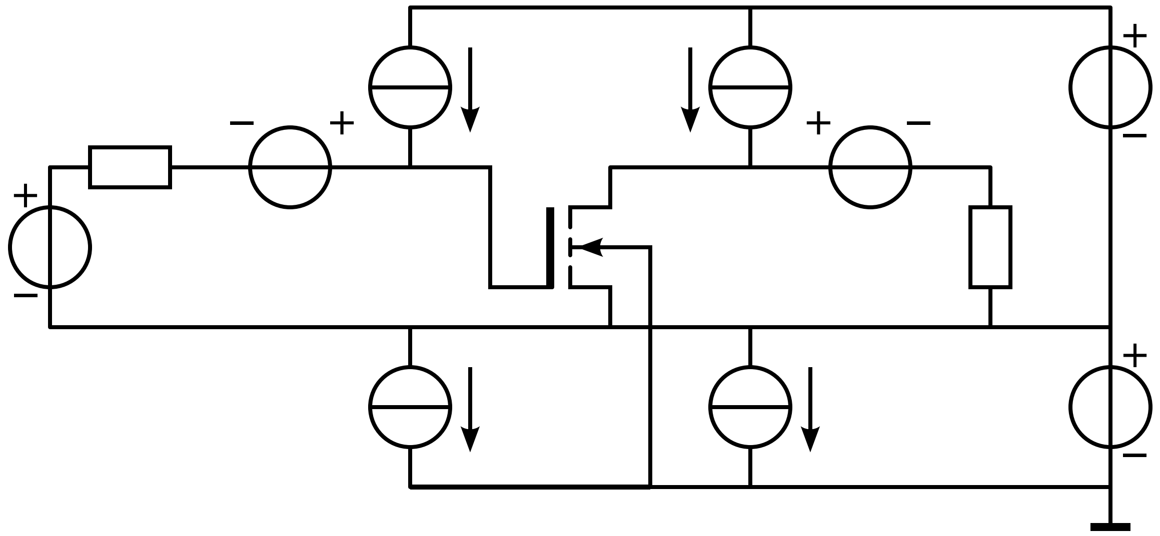


For all signal levels:

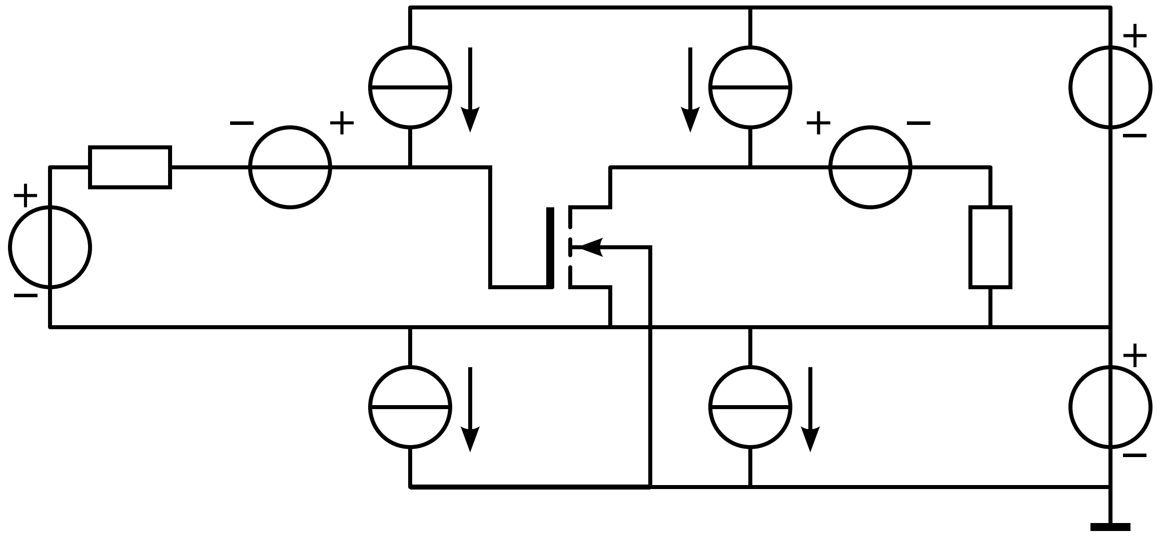
Nodal voltages should be within valid range

Redirect bias current sources

Redirect bias current sources

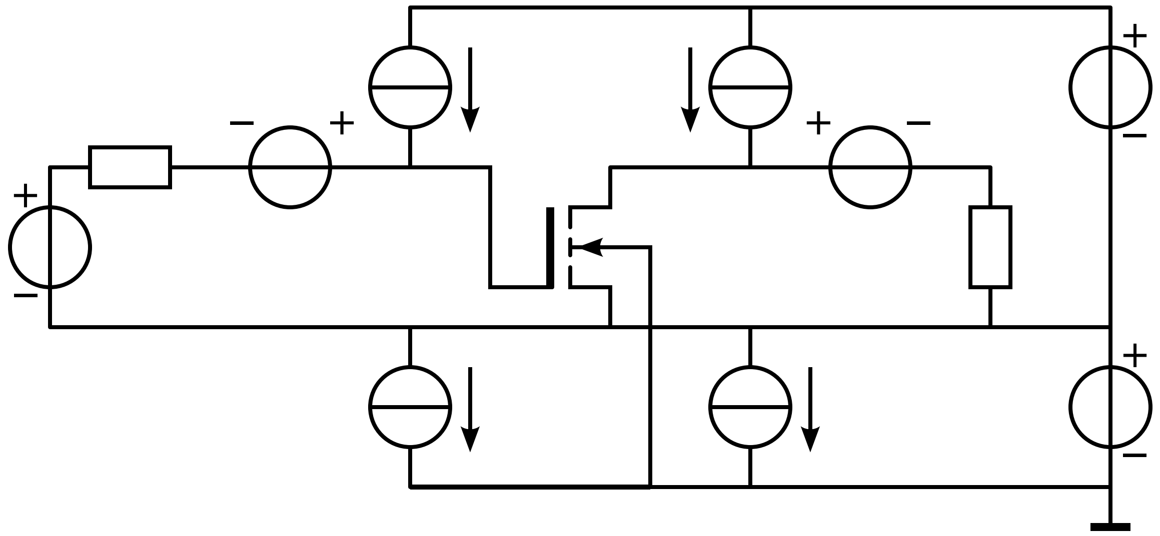


Redirect bias current sources



Soutrces can be implemented with pasive devices

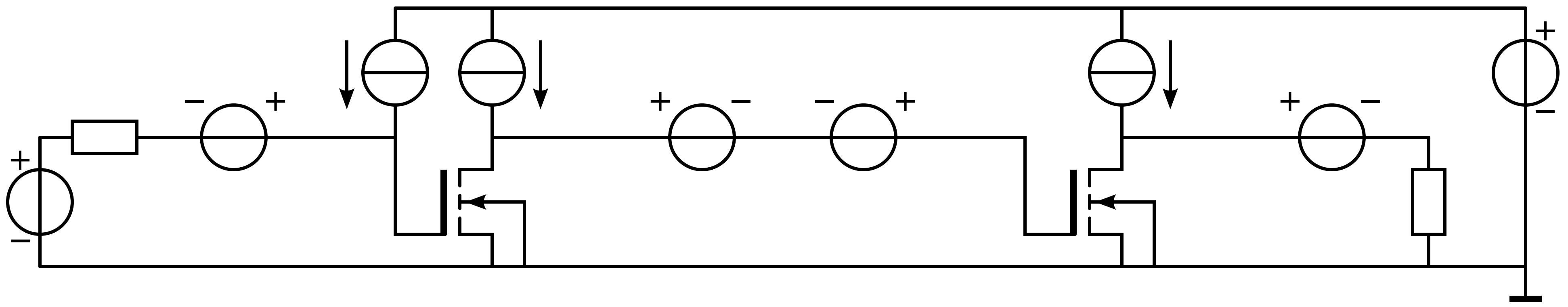
Redirect bias current sources



Soutrces can be implemented with pasive devices

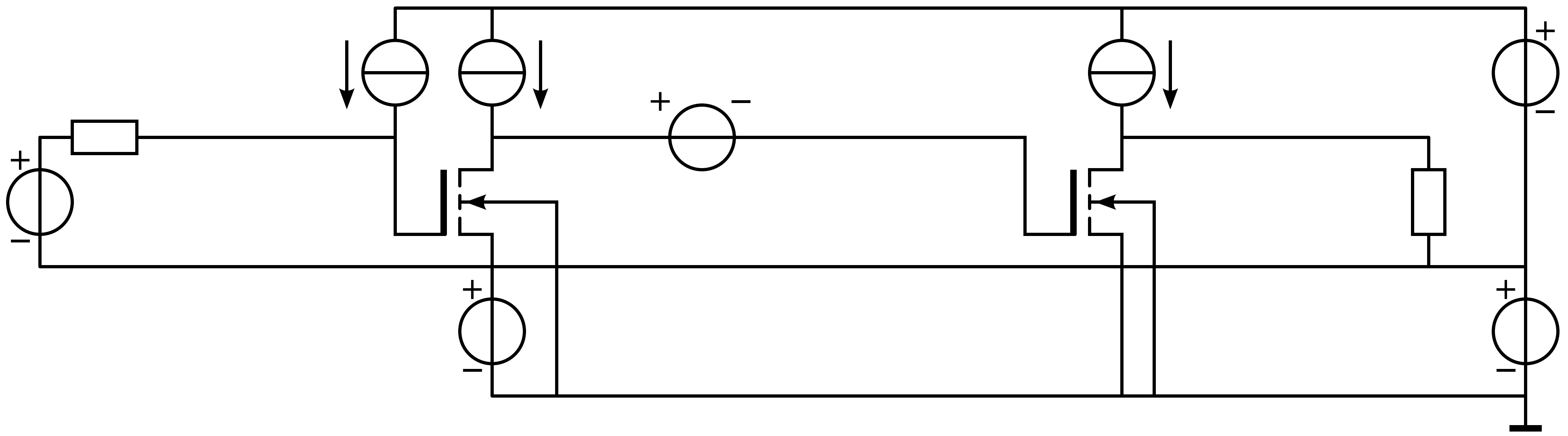
Minimize the number of floating voltage sources

Consider a two-stage amplifier



Minimize the number of floating voltage sources

Change the voltage level of a stage



Minimize the number of floating voltage sources

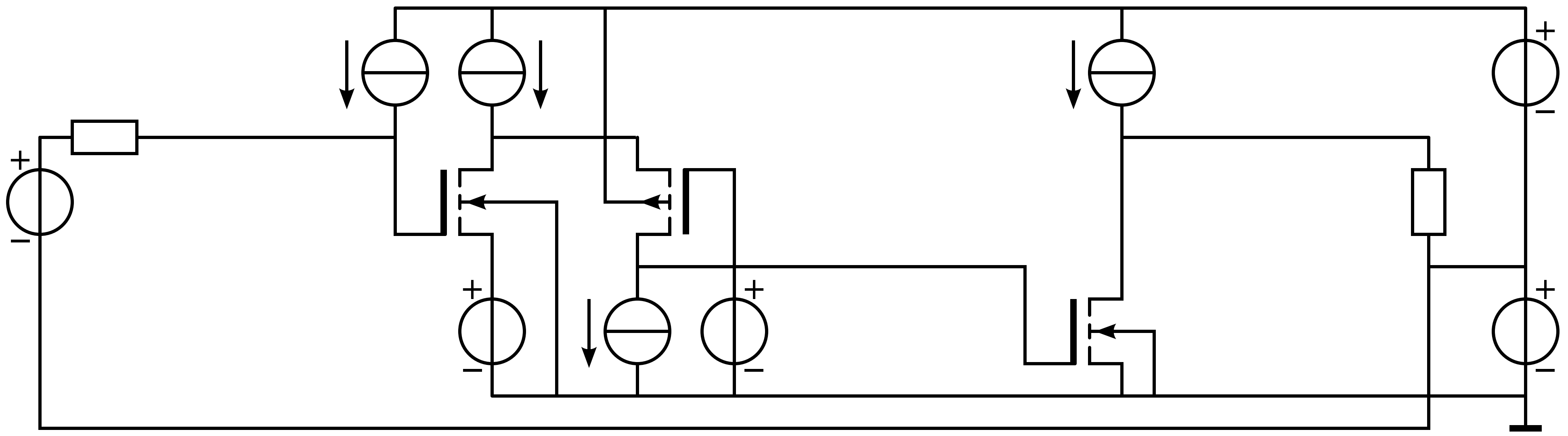
Replace a device with its complementary version

Minimize the number of floating voltage sources

Replace a stage with a local feedback stage

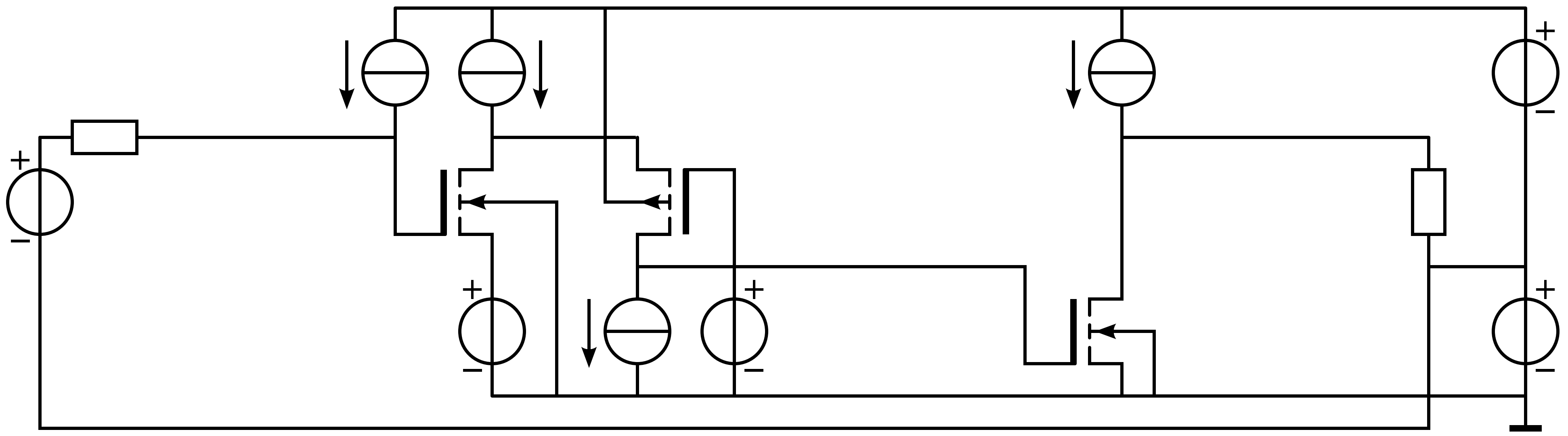
Minimize the number of floating voltage sources

Add a local feedback stage and use a complementary type



Minimize the number of floating voltage sources

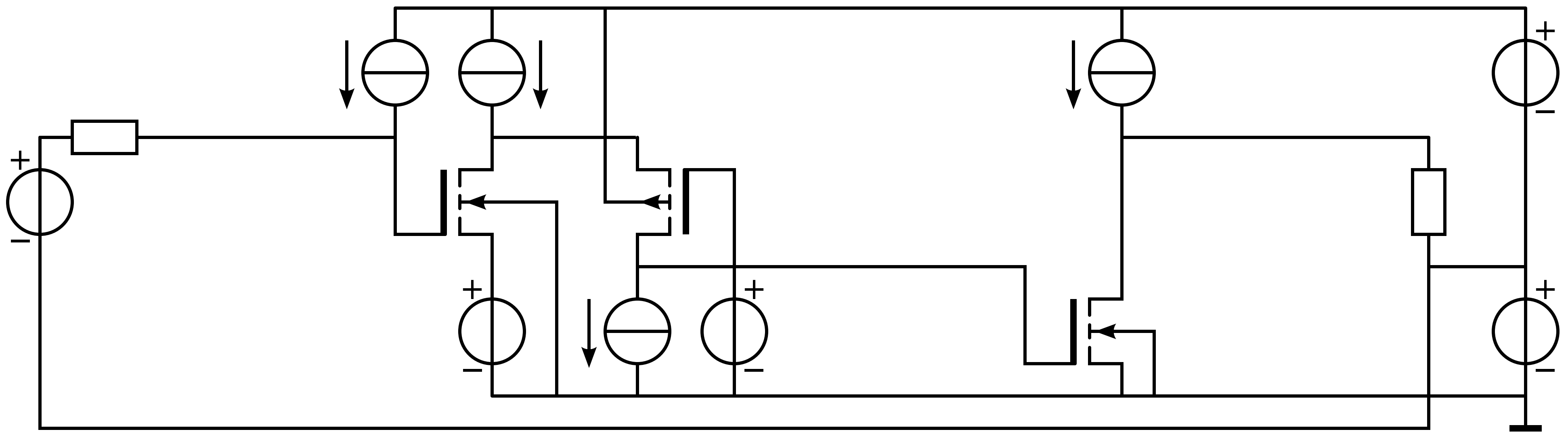
Add a local feedback stage and use a complementary type



"Folded cascode"

Minimize the number of floating voltage sources

Add a local feedback stage and use a complementary type



"Folded cascode"

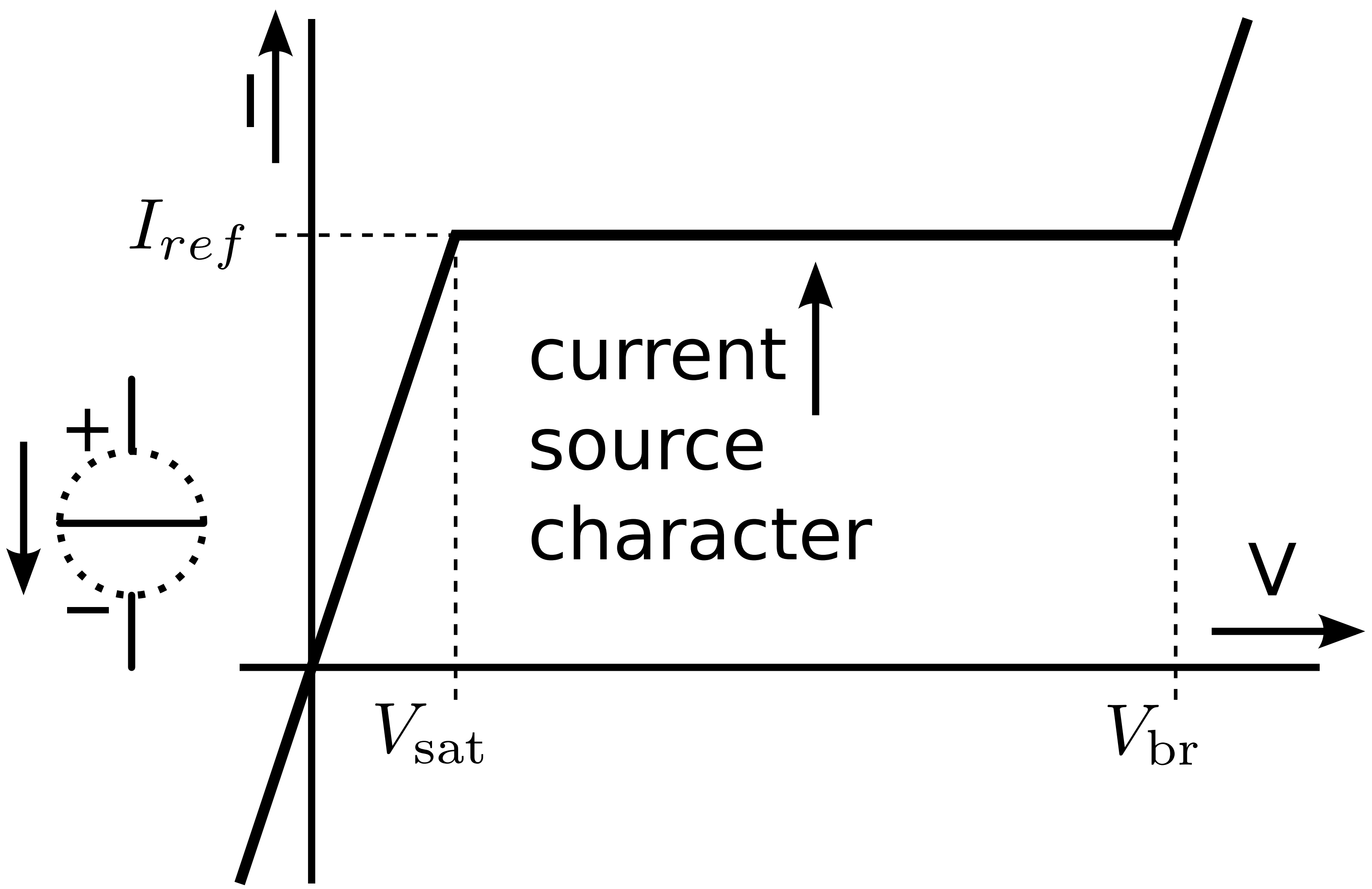
Complete biasing concept with passive biasing elements

Complete biasing concept with passive biasing elements

Nonlinear resistive elements

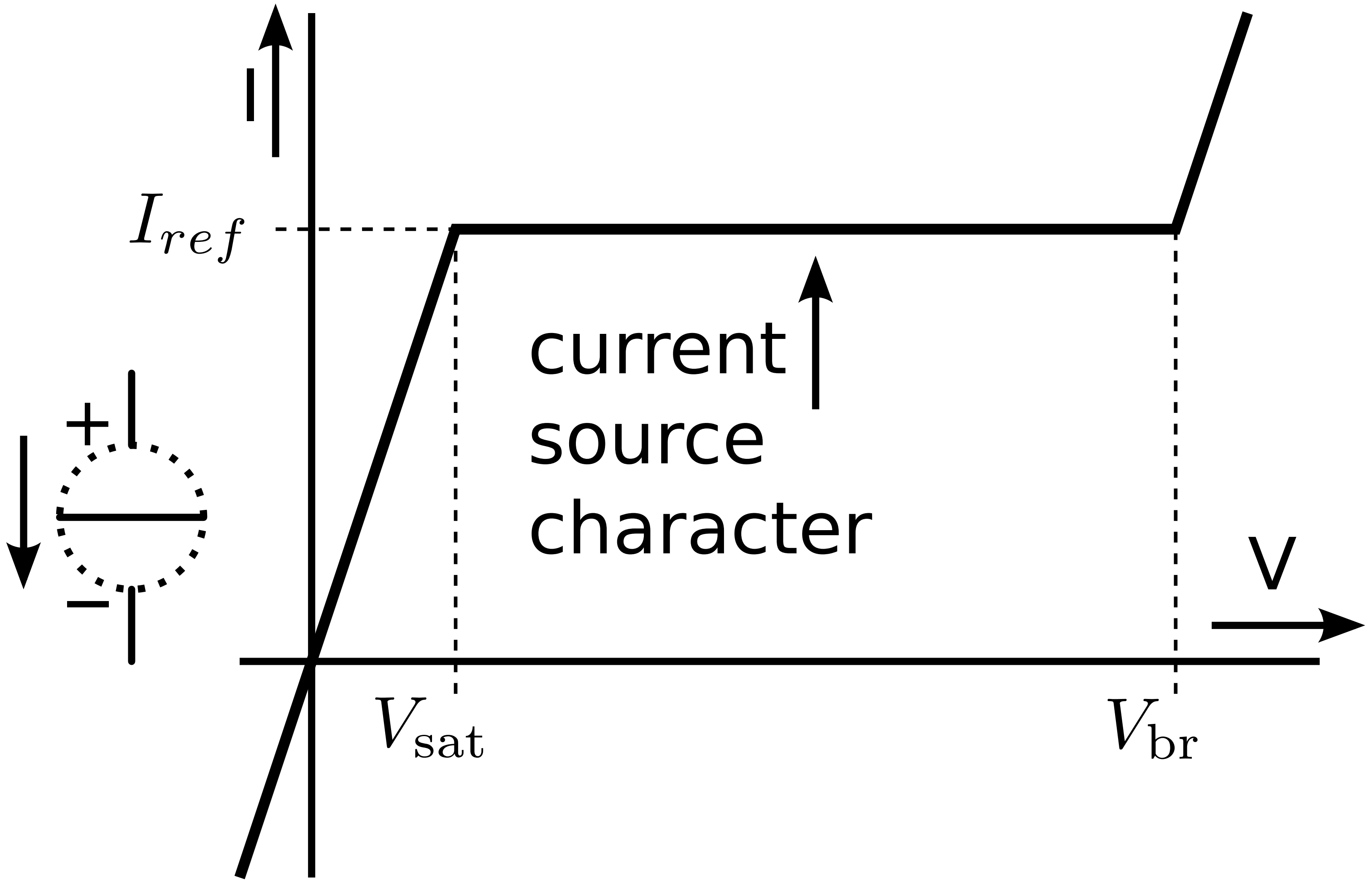
Complete biasing concept with passive biasing elements

Nonlinear resistive elements



Complete biasing concept with passive biasing elements

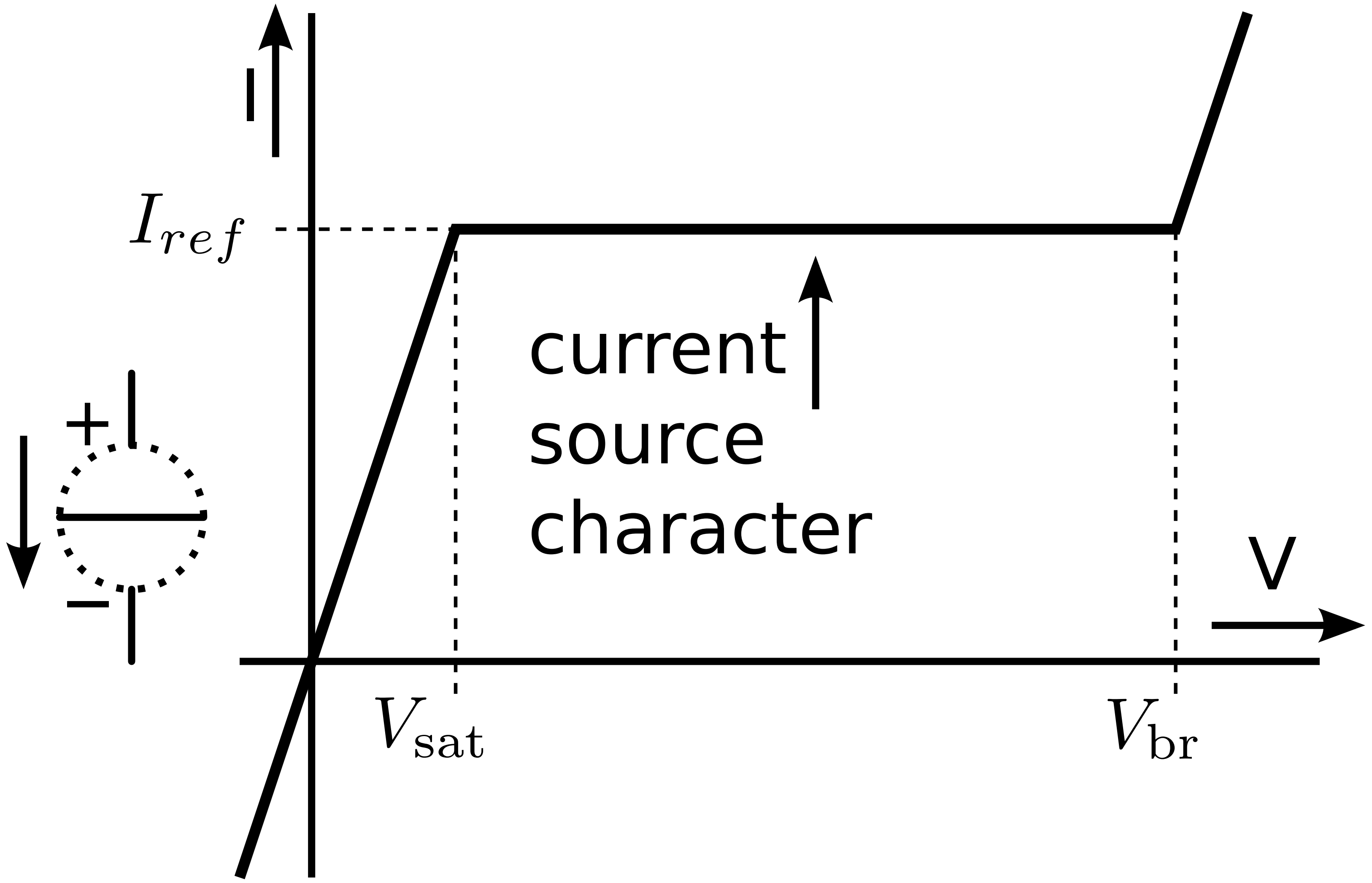
Nonlinear resistive elements



Current source behavior requires voltage drop:

Complete biasing concept with passive biasing elements

Nonlinear resistive elements

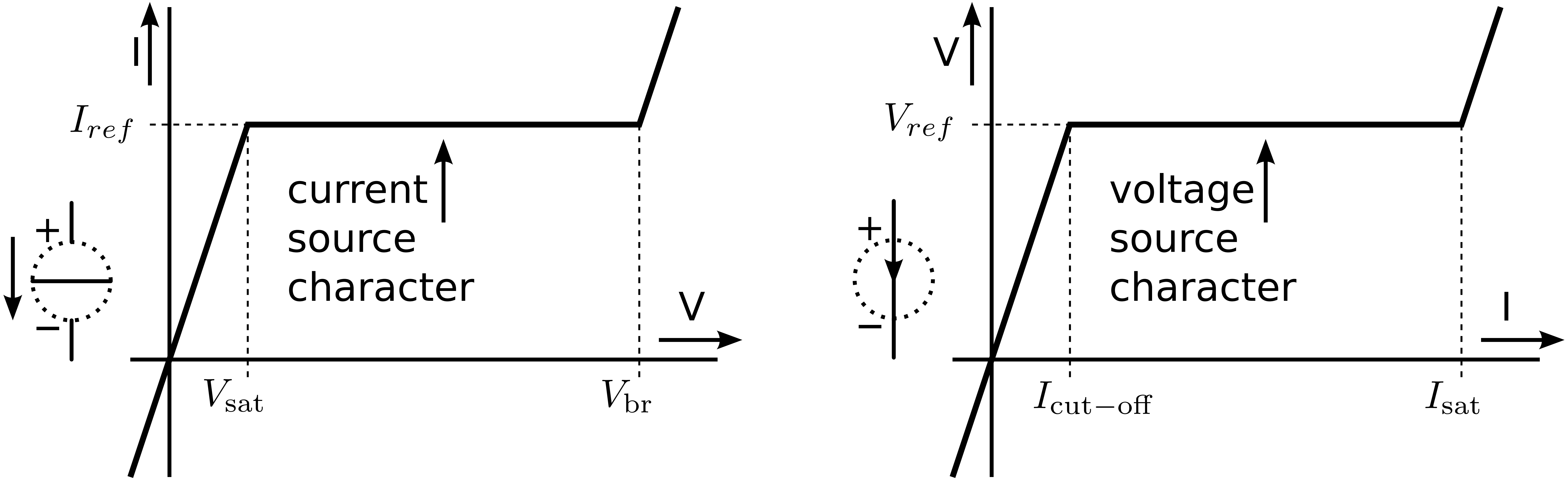


Current source behavior requires voltage drop:

Voltage between saturation and breakdown

Complete biasing concept with passive biasing elements

Nonlinear resistive elements

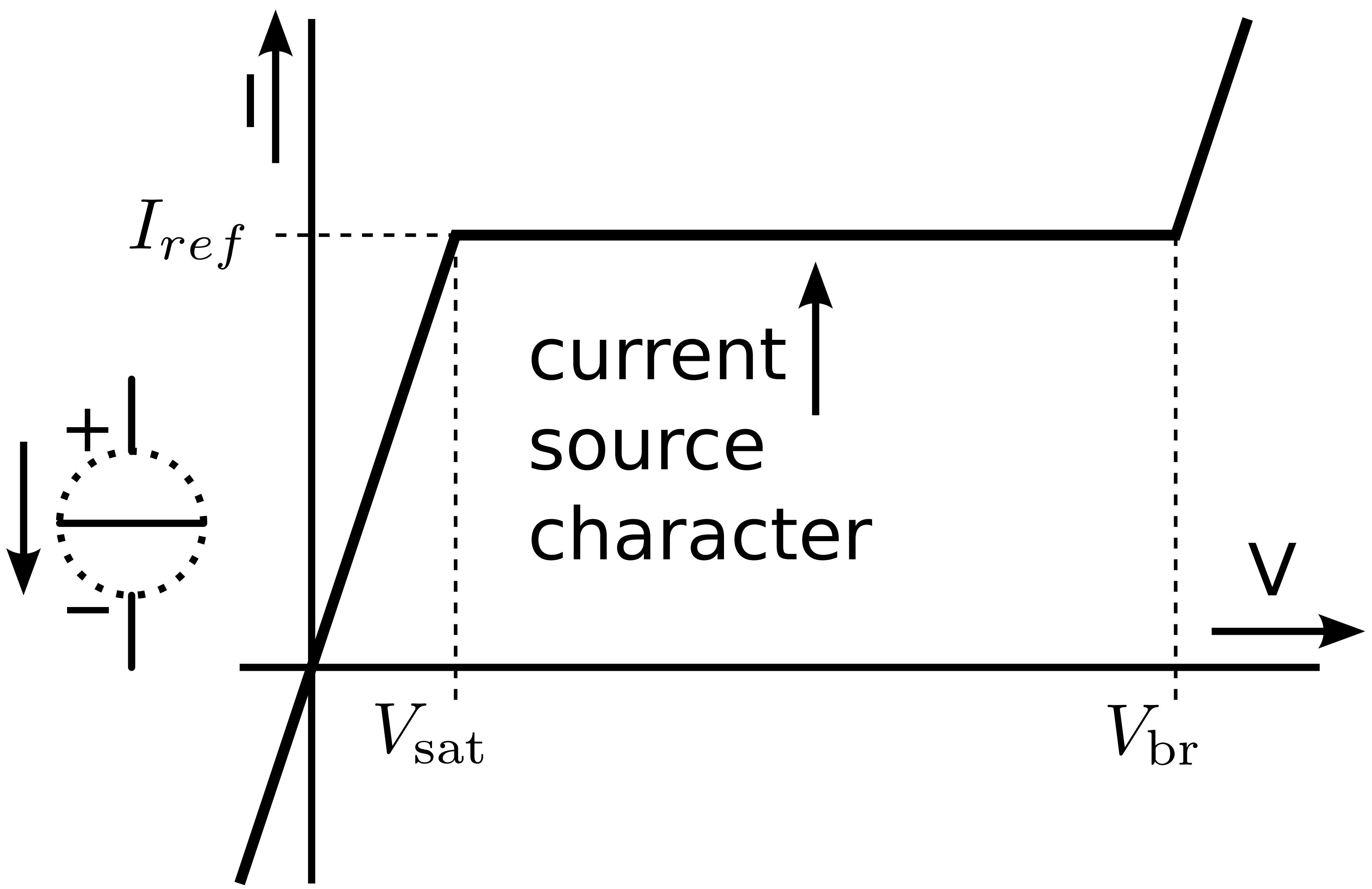


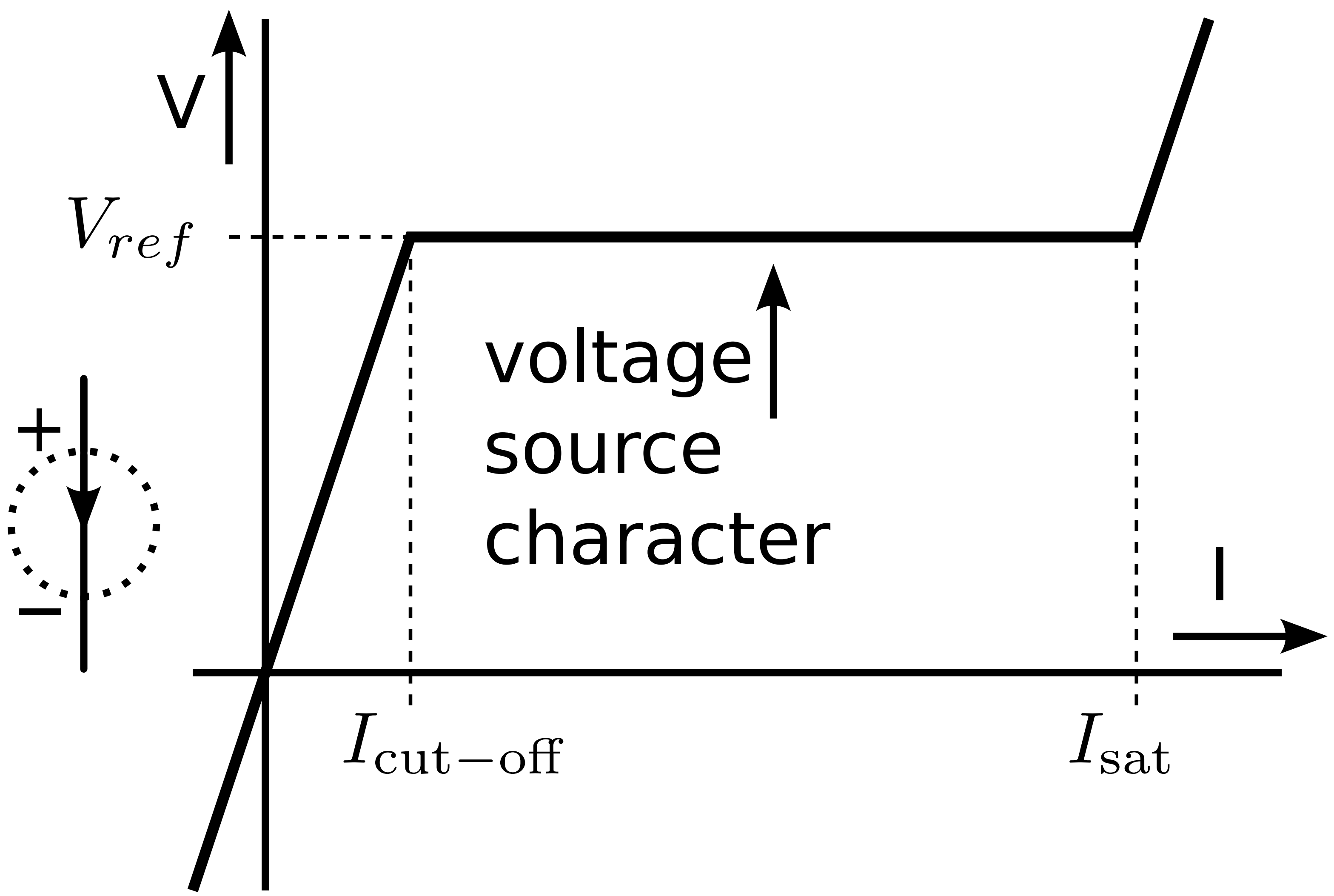
Current source behavior requires voltage drop:

Voltage between saturation and breakdown

Complete biasing concept with passive biasing elements

Nonlinear resistive elements





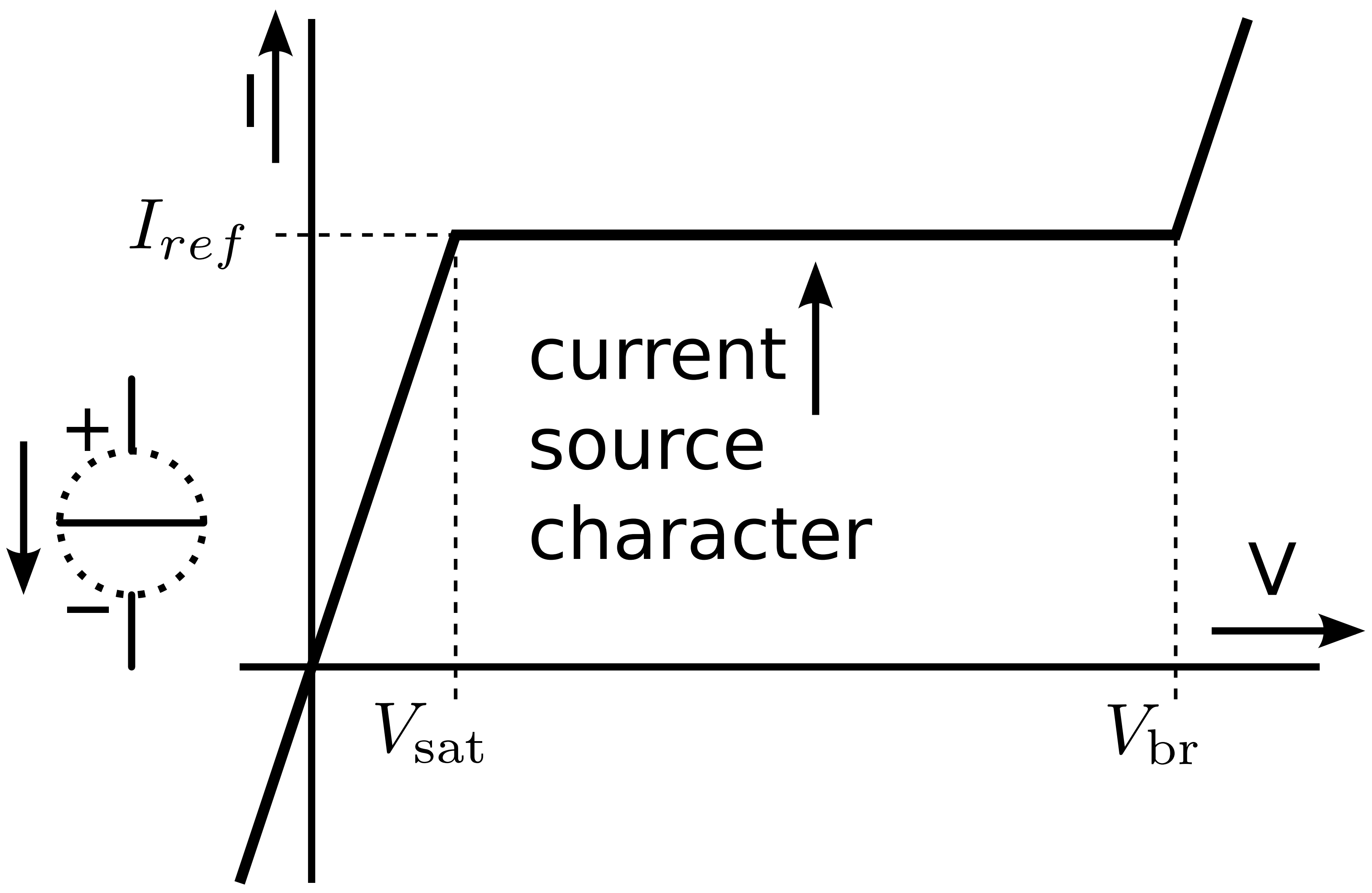
Current source behavior requires voltage drop:

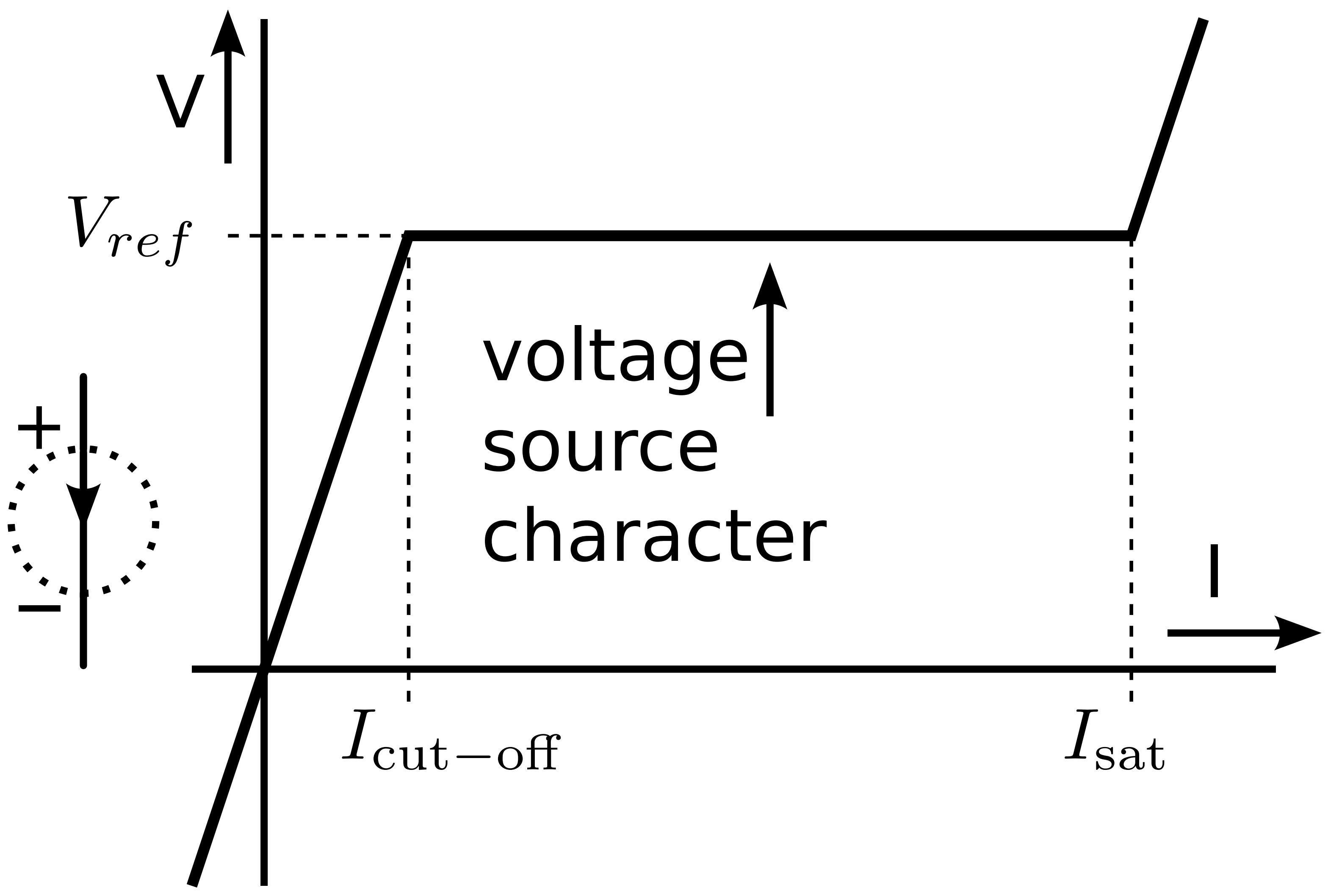
Voltage between saturation and breakdown

Voltage source behavior requires current flow:

Complete biasing concept with passive biasing elements

Nonlinear resistive elements





Current source behavior requires voltage drop:

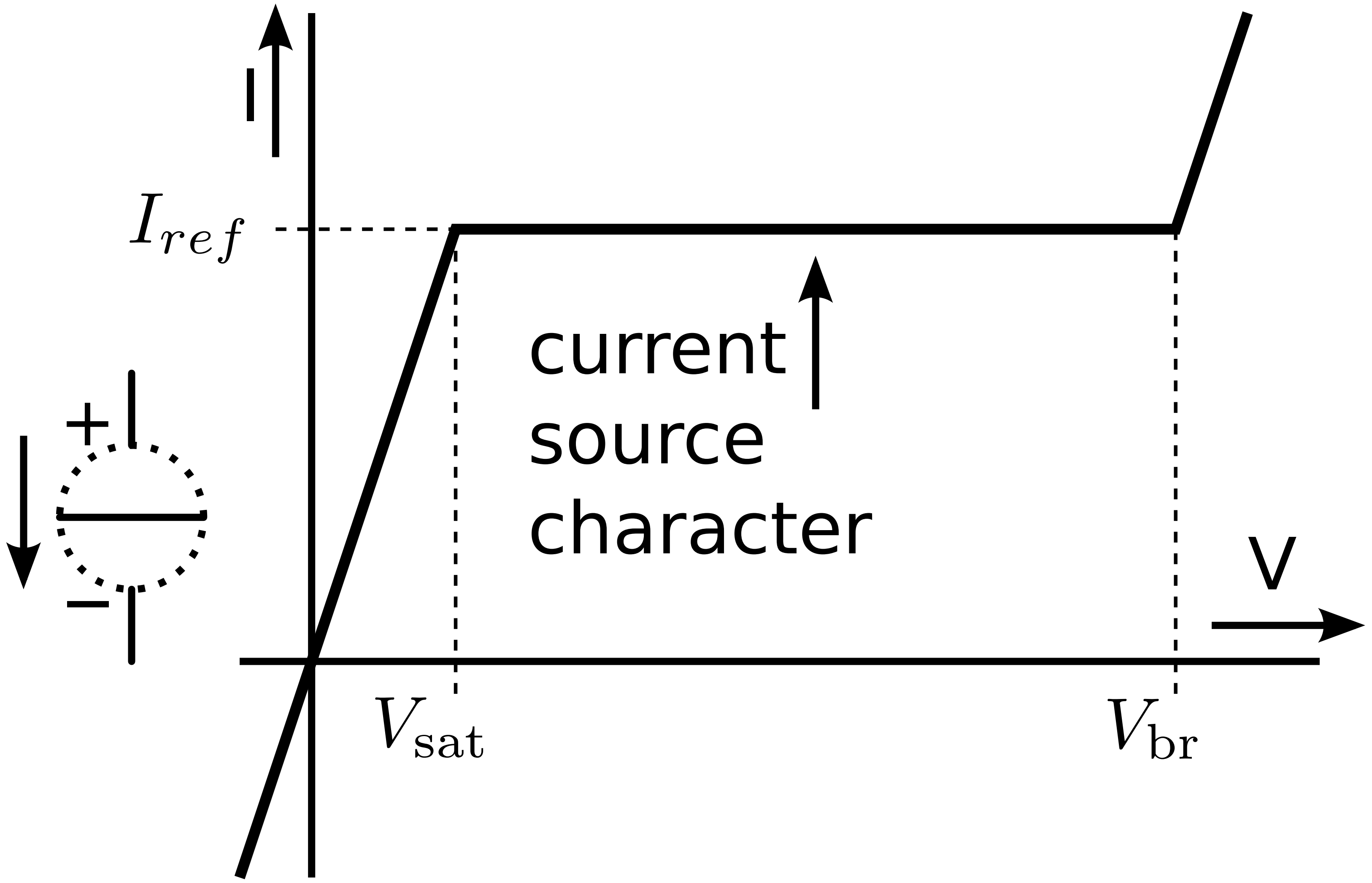
Voltage between saturation and breakdown

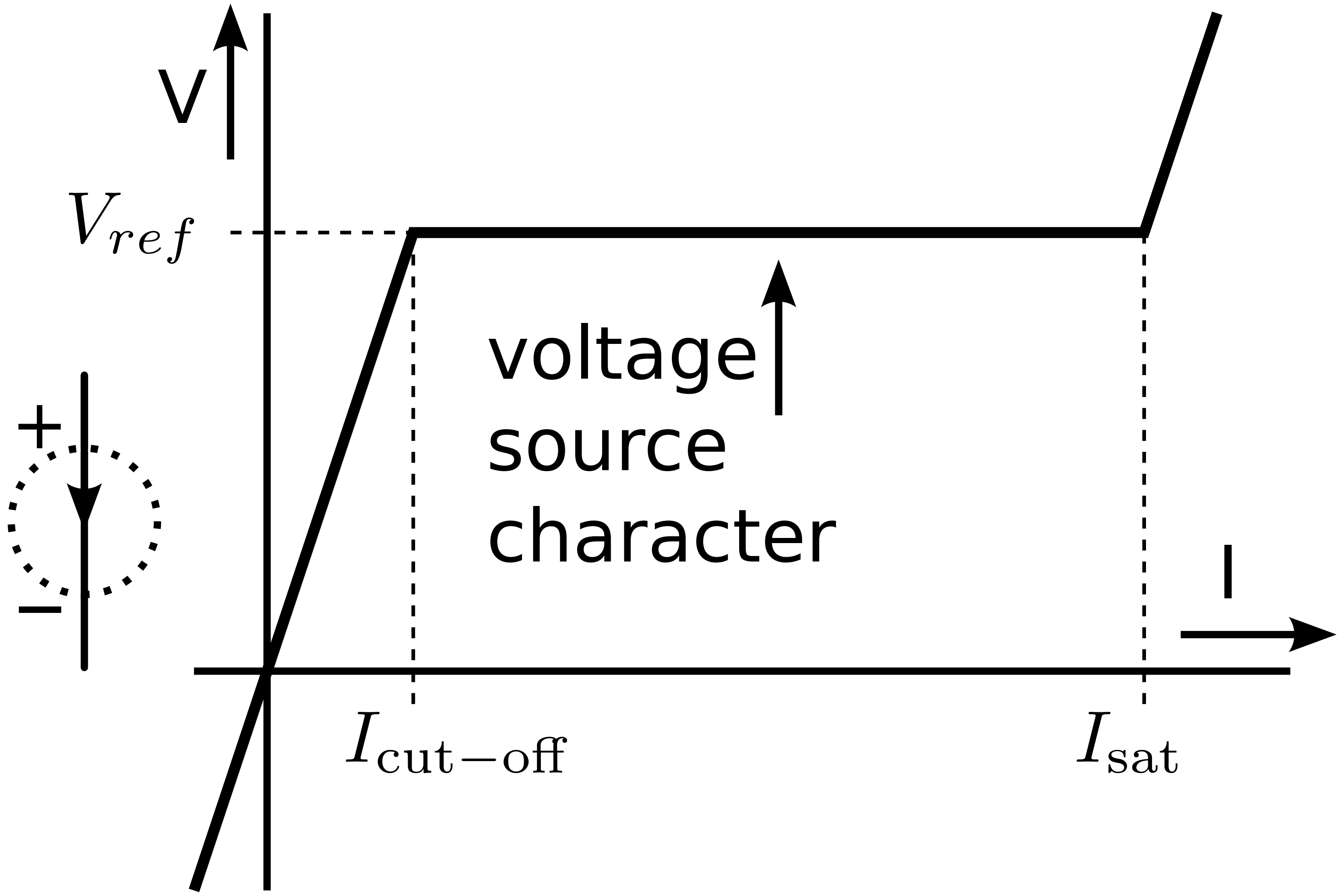
Voltage source behavior requires current flow:

Current between cut-off and saturation

Complete biasing concept with passive biasing elements

Nonlinear resistive elements





Current source behavior requires voltage drop:

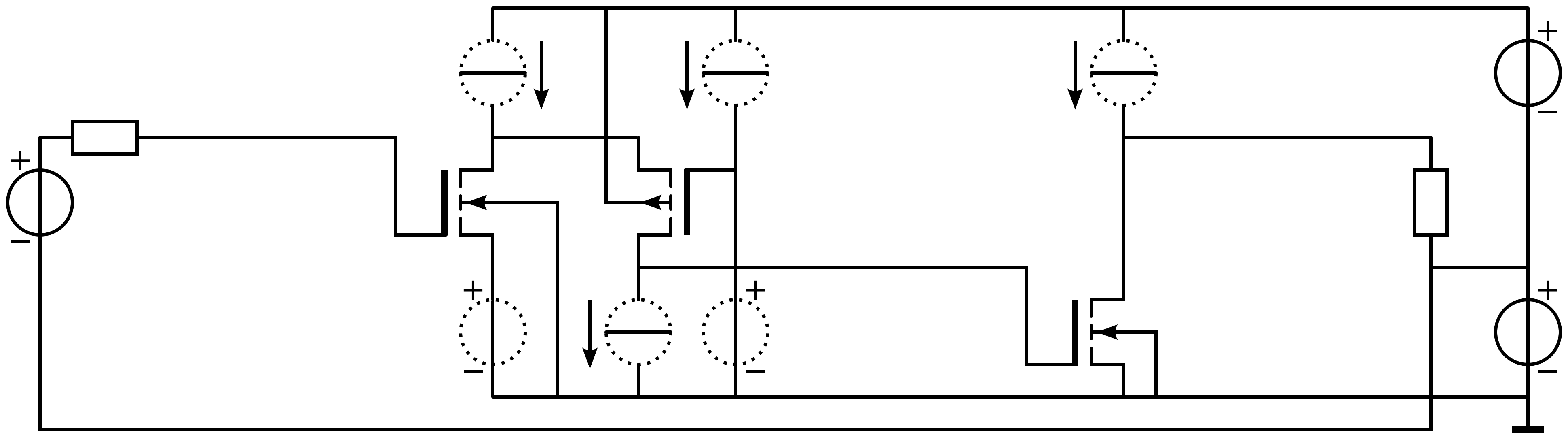
Voltage between saturation and breakdown

Voltage source behavior requires current flow:

Current between cut-off and saturation

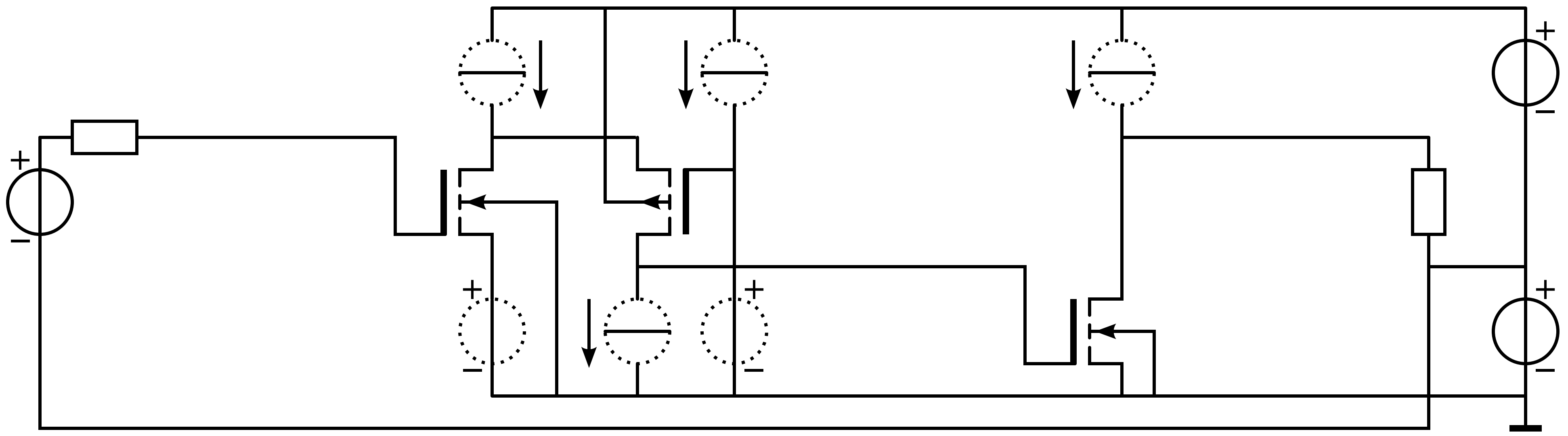
Complete biasing with passive biasing elements

Added current source element for biasing
the voltage source element of the cascode



Complete biasing with passive biasing elements

Added current source element for biasing
the voltage source element of the cascode



Specify biasing elements

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Specify biasing elements

Relate amplifier specifications to those of biasing elements

- Noise
- Drive capability
- Power consumption
- PSRR
- CMRR (in case of a floating port)
- Gain inaccuracy
- Weak nonlinearity (distortion)
- Temperature dependency

Bias voltage sources:

- Voltage
- Total error
- Saturation current
- Cut-off current
- Small-signal impedance
- Noise spectral density

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error

Bias current sources:

Current
Total error

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance

Specify biasing elements

Relate amplifier specifications to those of biasing elements

- Noise
- Drive capability
- Power consumption
- PSRR
- CMRR (in case of a floating port)
- Gain inaccuracy
- Weak nonlinearity (distortion)
- Temperature dependency

Bias voltage sources:

- Voltage
- Total error
- Saturation current
- Cut-off current
- Small-signal impedance
- Noise spectral density

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Current

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Current
Total error

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Current
Total error
Saturation voltage

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Current
Total error
Saturation voltage
Breakdown voltage

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Current
Total error
Saturation voltage
Breakdown voltage
Small-signal impedance

Specify biasing elements

Relate amplifier specifications to those of biasing elements

- Noise
- Drive capability
- Power consumption
- PSRR
- CMRR (in case of a floating port)
- Gain inaccuracy
- Weak nonlinearity (distortion)
- Temperature dependency

Bias voltage sources:

- Voltage
- Total error
- Saturation current
- Cut-off current
- Small-signal impedance
- Noise spectral density

Bias current sources:

- Current
- Total error
- Saturation voltage
- Breakdown voltage
- Small-signal impedance
- Noise spectral density

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Current
Total error
Saturation voltage
Breakdown voltage
Small-signal impedance
Noise spectral density

Check performance after implementation of bias sources

Design improvements if necessary

Specify biasing elements

Relate amplifier specifications to those of biasing elements

- Noise
- Drive capability
- Power consumption
- PSRR
- CMRR (in case of a floating port)
- Gain inaccuracy
- Weak nonlinearity (distortion)
- Temperature dependency

Bias voltage sources:

- Voltage
- Total error
- Saturation current
- Cut-off current
- Small-signal impedance
- Noise spectral density

Bias current sources:

- Current
- Total error
- Saturation voltage
- Breakdown voltage
- Small-signal impedance
- Noise spectral density

Check performance after implementation of bias sources

Design improvements if necessary

Specify biasing elements

Relate amplifier specifications to those of biasing elements

Noise
Drive capability
Power consumption
PSRR
CMRR (in case of a floating port)
Gain inaccuracy
Weak nonlinearity (distortion)
Temperature dependency

Bias voltage sources:

Voltage
Total error
Saturation current
Cut-off current
Small-signal impedance
Noise spectral density

Bias current sources:

Current
Total error
Saturation voltage
Breakdown voltage
Small-signal impedance
Noise spectral density

Check performance after implementation of bias sources

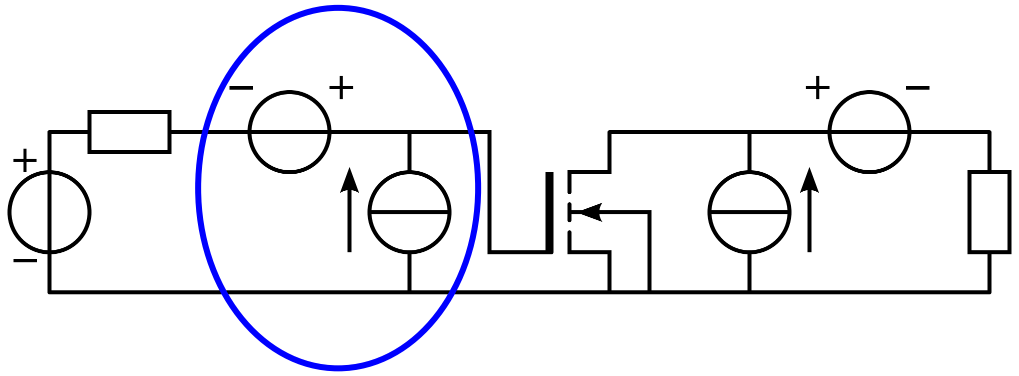
Design improvements if necessary

Define differential-mode quantities

Define differential-mode quantities

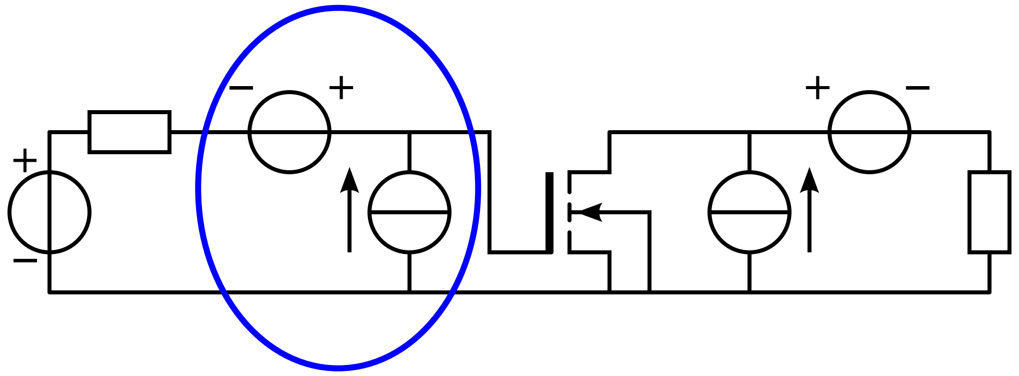
With n transistors we need to control 2n bias quantities:

Define differential-mode quantities



With n transistors we need to control 2n bias quantities:

Define differential-mode quantities



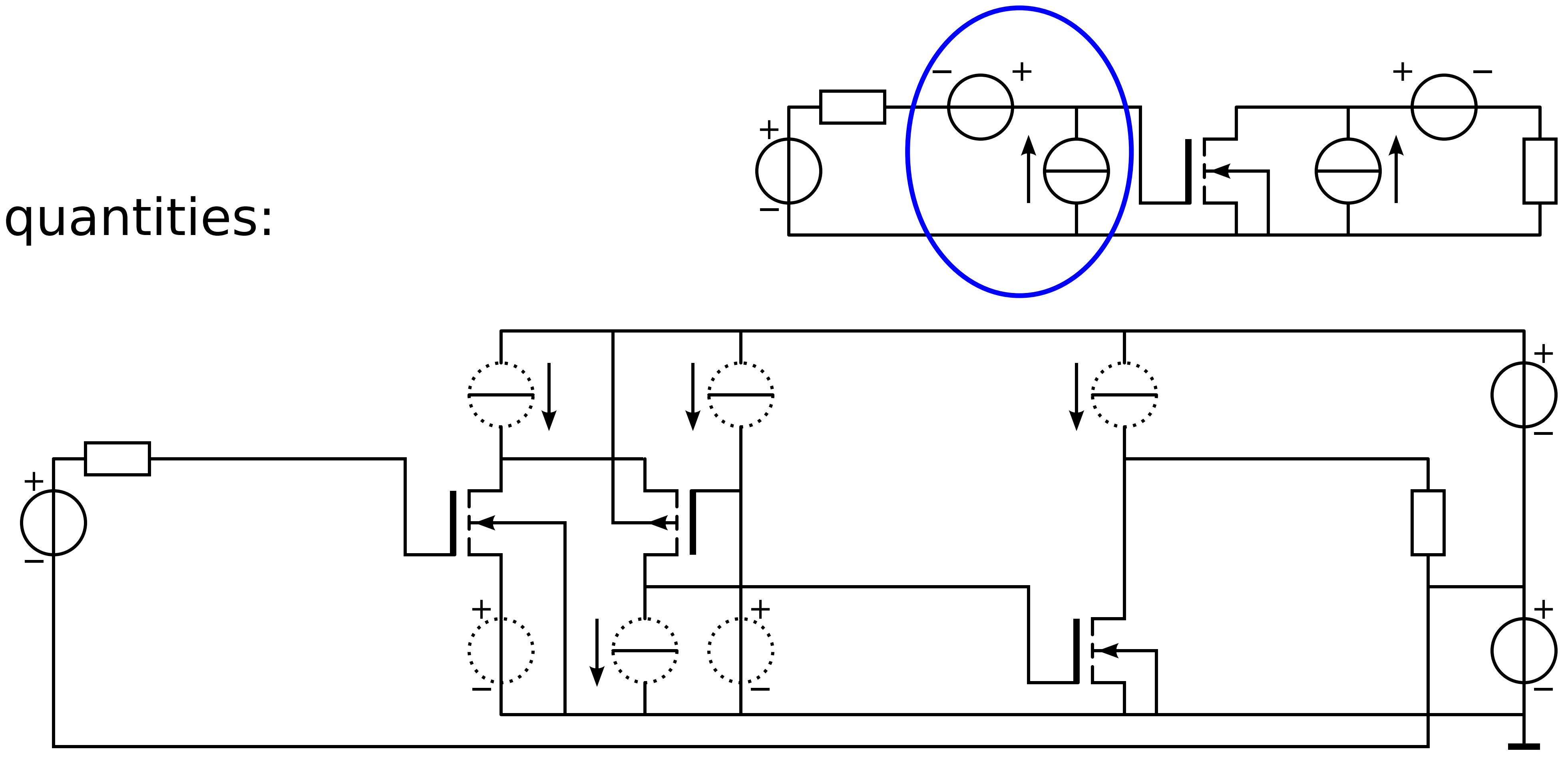
With n transistors we need to control 2n bias quantities:

Where have they gone?

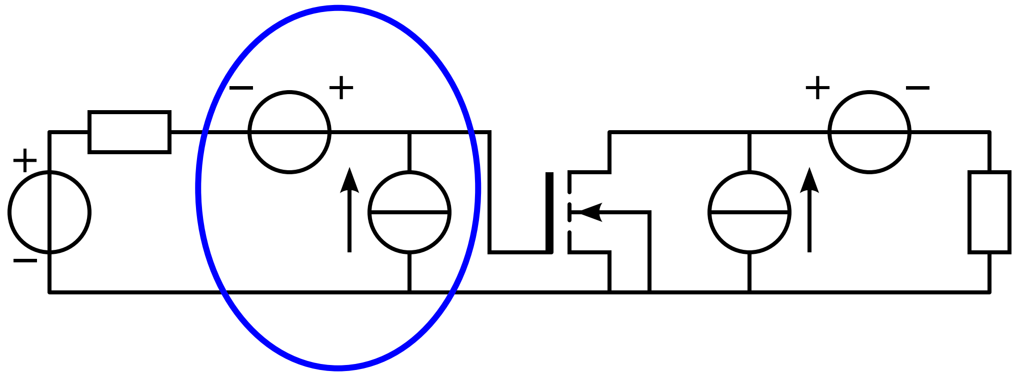
Define differential-mode quantities

With n transistors we need to control 2n bias quantities:

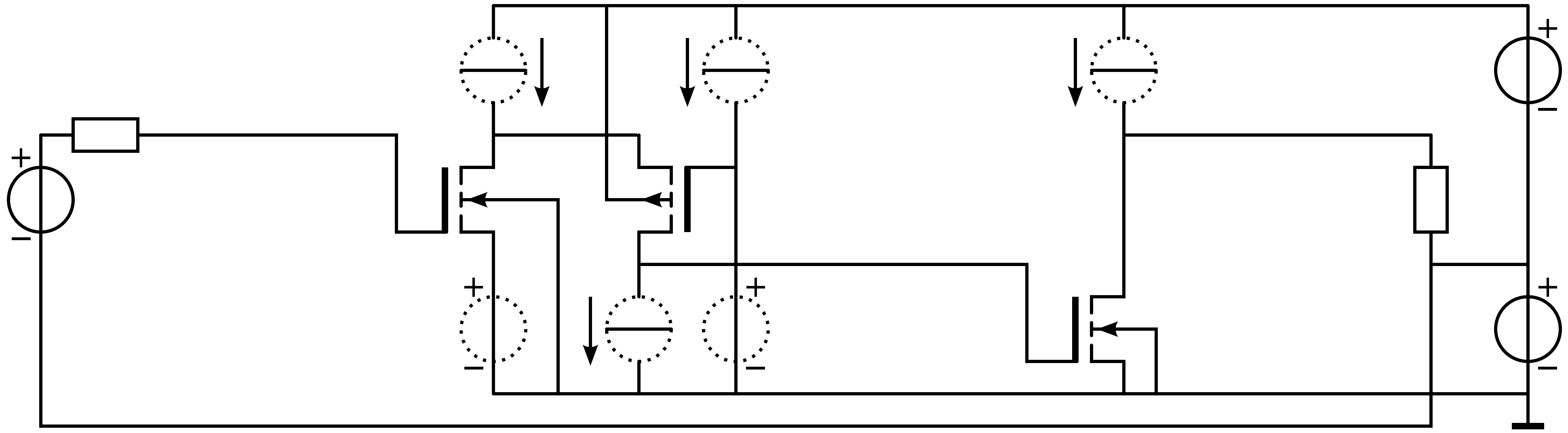
Where have they gone?



Define differential-mode quantities



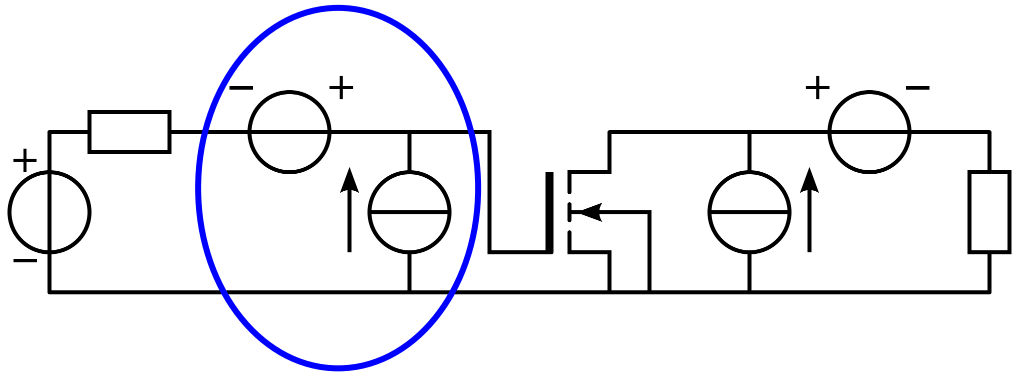
With n transistors we need to control 2n bias quantities:



Where have they gone?

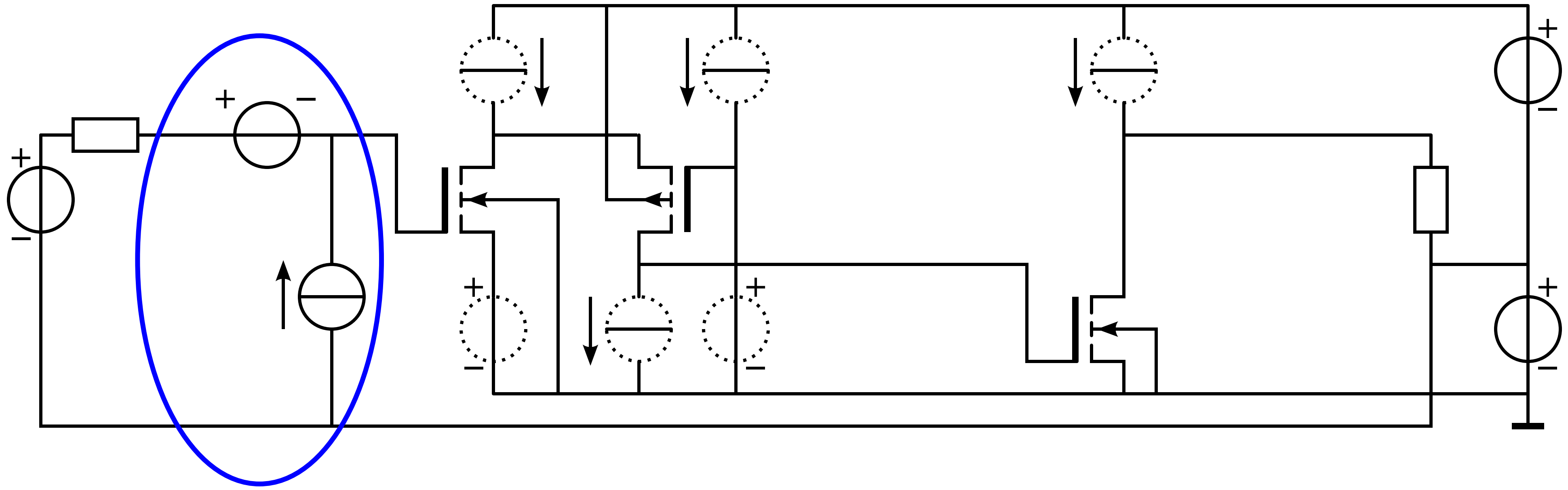
If all stages are DC coupled, biasing errors propagate

Define differential-mode quantities



With n transistors we need to control 2n bias quantities:

Where have they gone?

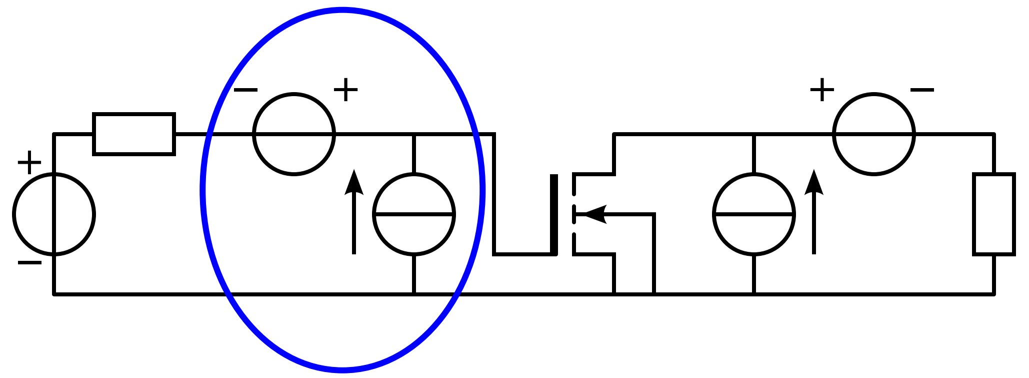


If all stages are DC coupled, biasing errors propagate

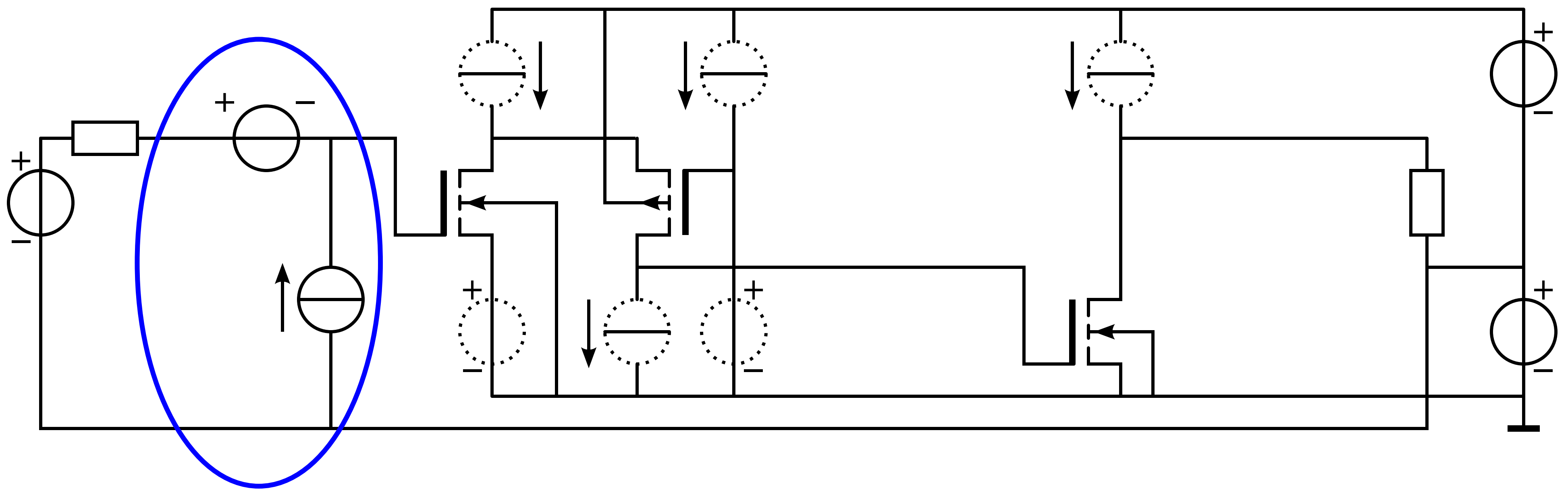
If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources

Define differential-mode quantities

With n transistors we need to control 2n bias quantities:



Where have they gone?

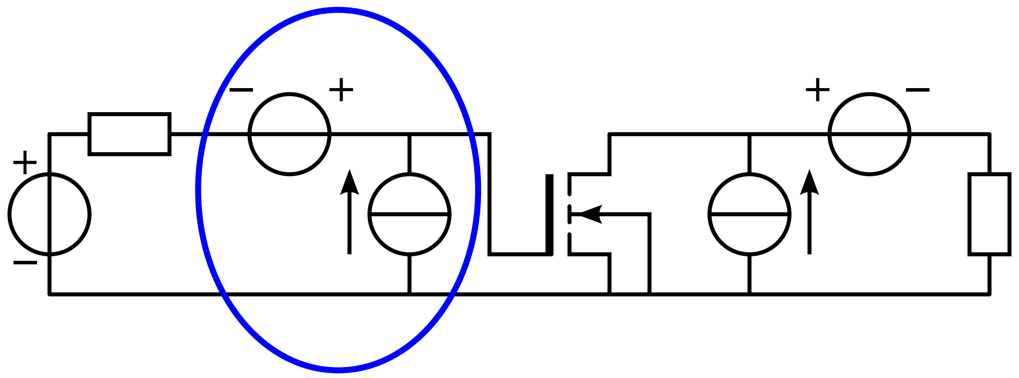


If all stages are DC coupled, biasing errors propagate

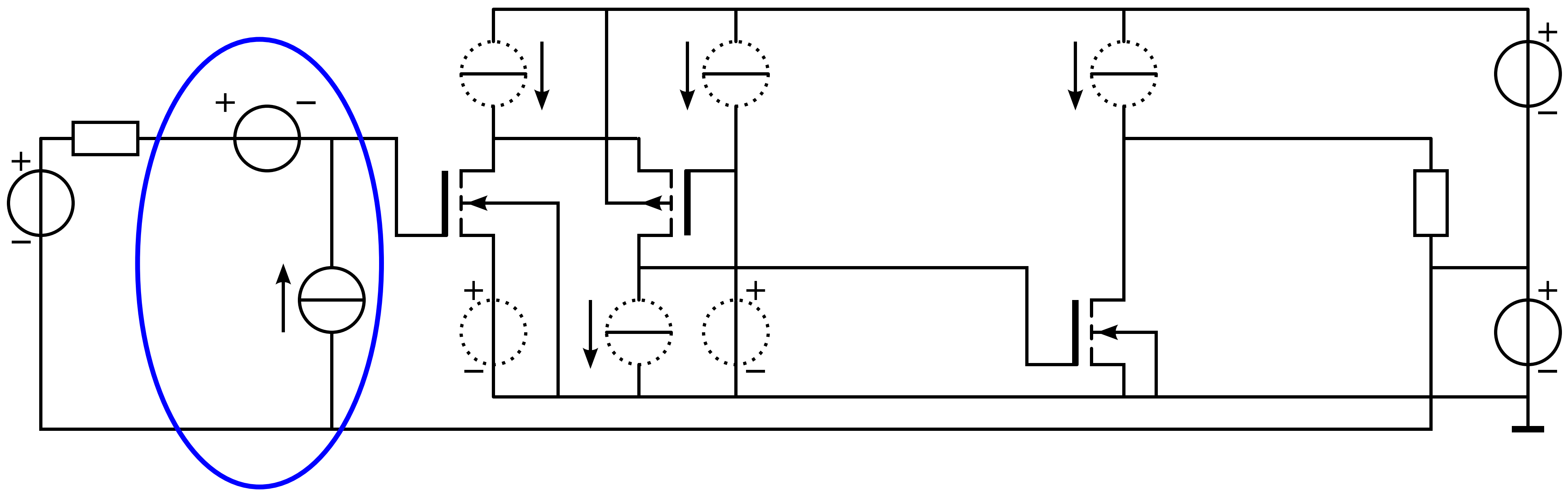
- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:

Define differential-mode quantities

With n transistors we need to control 2n bias quantities:



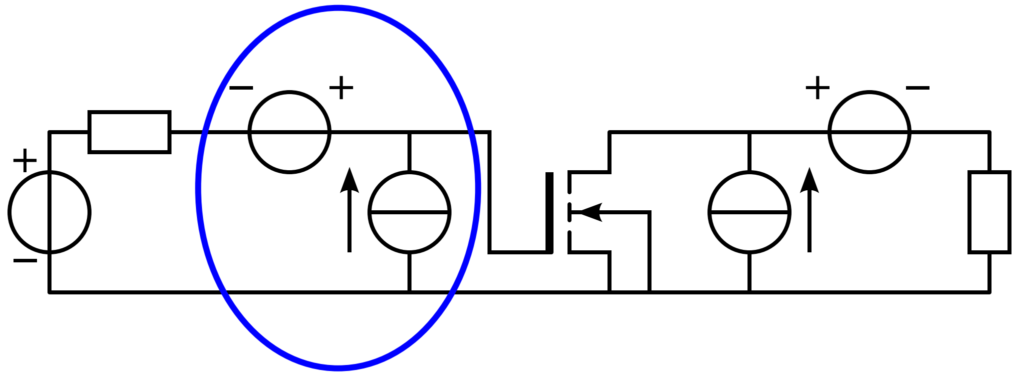
Where have they gone?



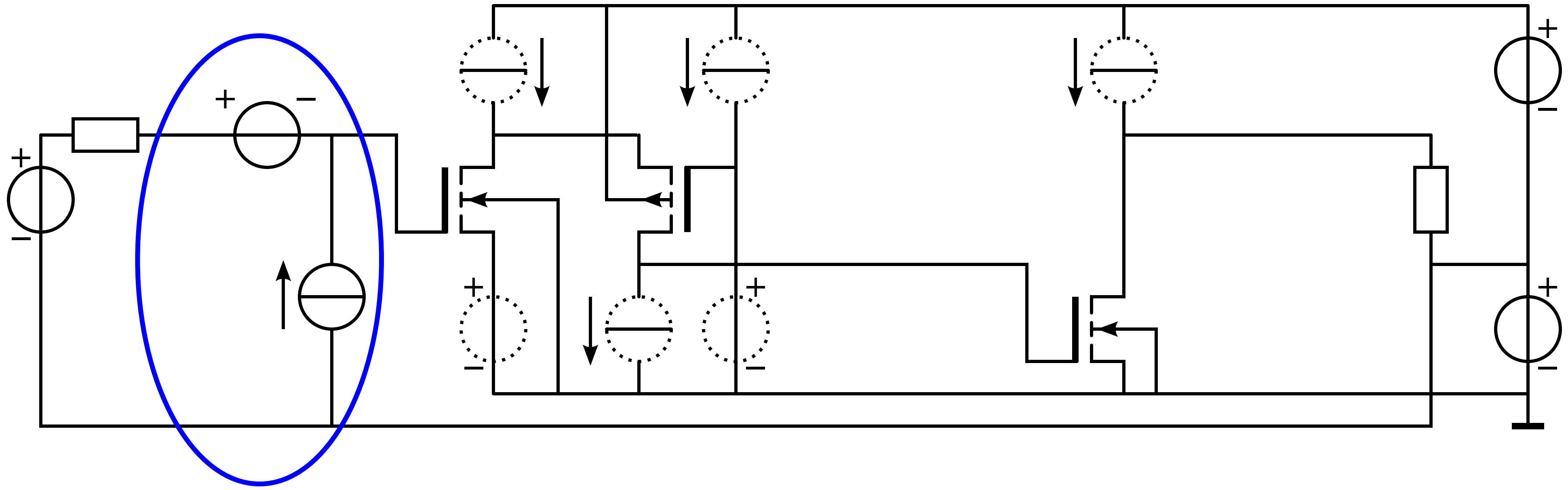
If all stages are DC coupled, biasing errors propagate

- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing

Define differential-mode quantities



With n transistors we need to control 2n bias quantities:



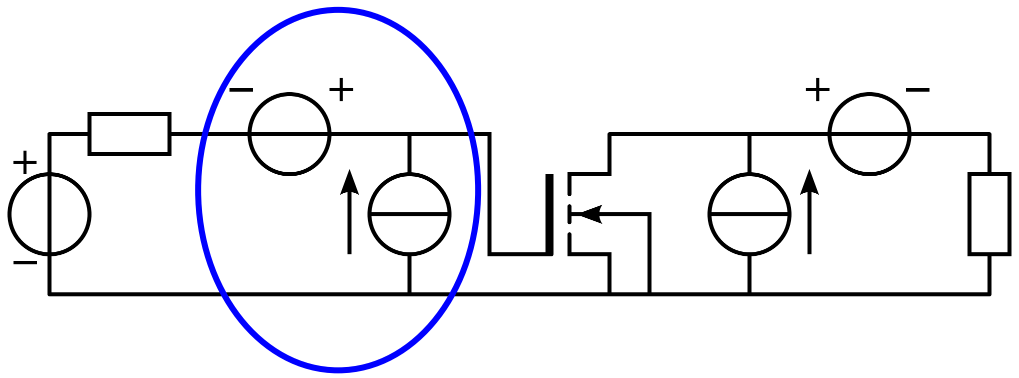
Where have they gone?

If all stages are DC coupled, biasing errors propagate

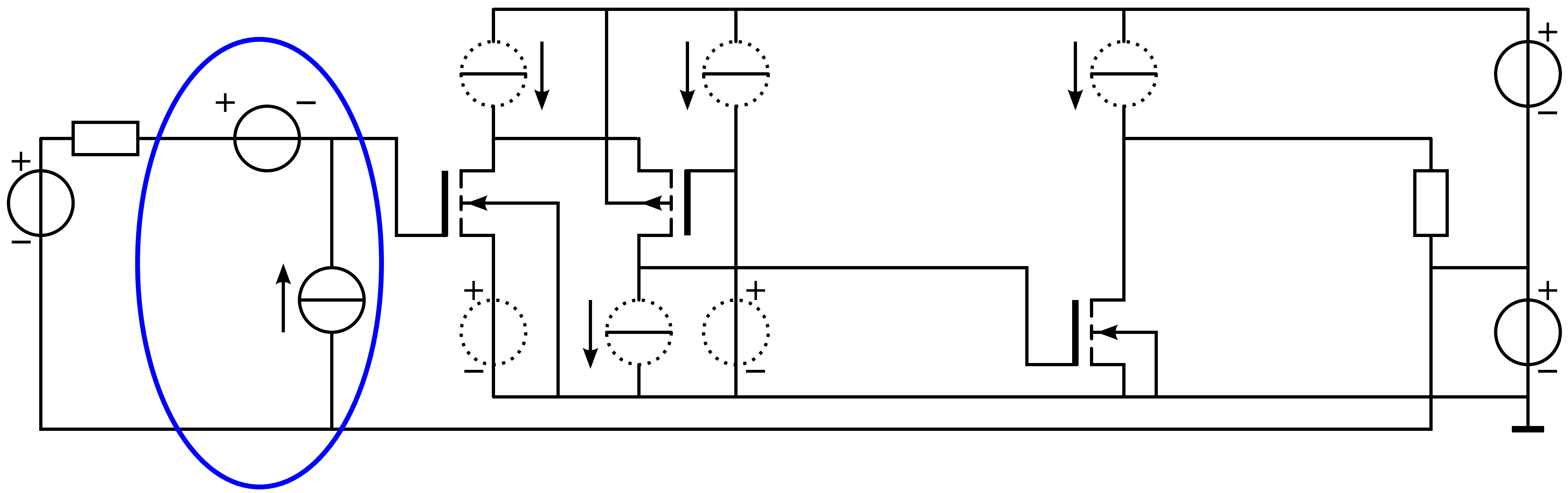
- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing
  - Over-all negative-feedback biasing

Define differential-mode quantities

With n transistors we need to control 2n bias quantities:



Where have they gone?

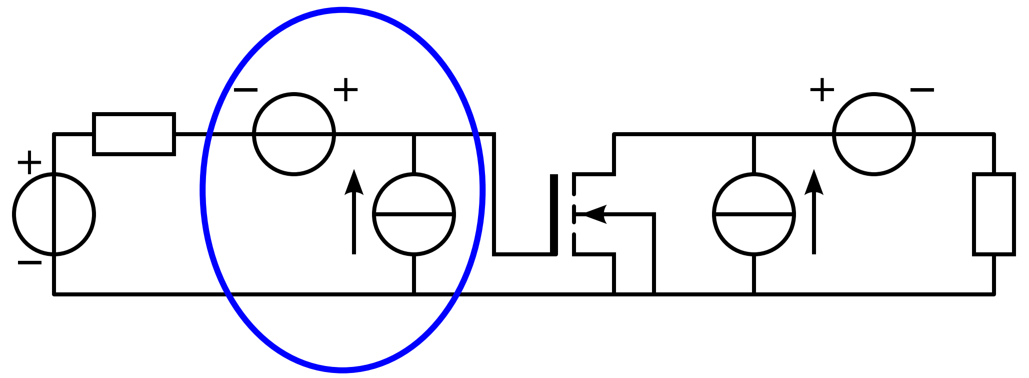


If all stages are DC coupled, biasing errors propagate

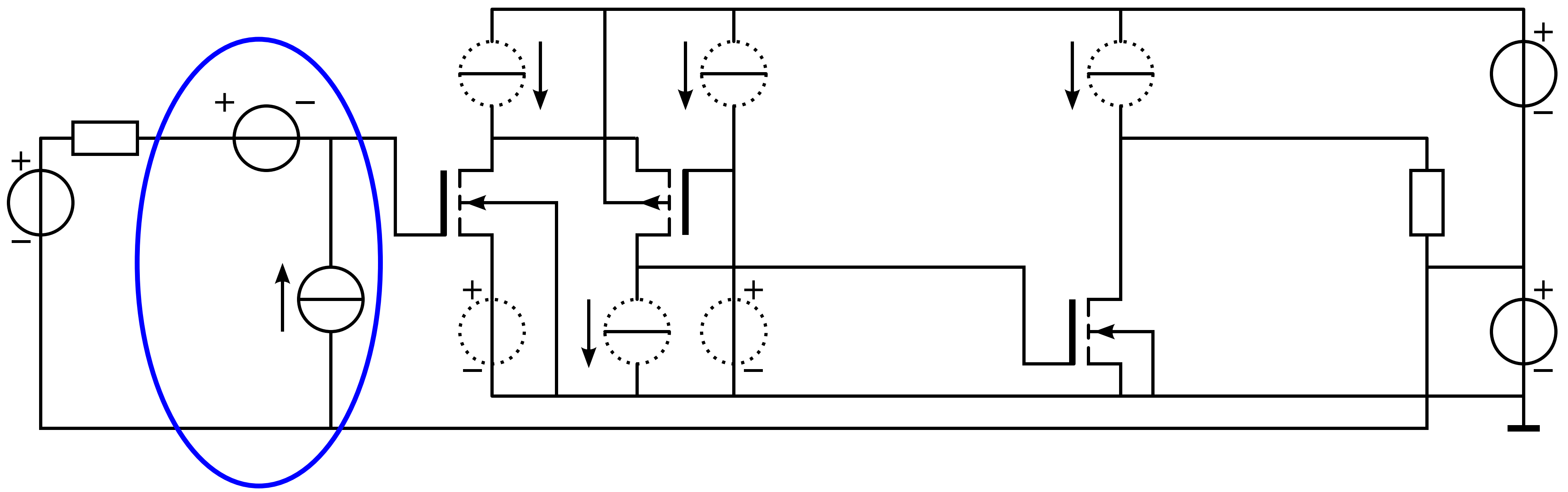
- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing
  - Over-all negative-feedback biasing
  - Over-all auto-zeroing

Define differential-mode quantities

With n transistors we need to control 2n bias quantities:



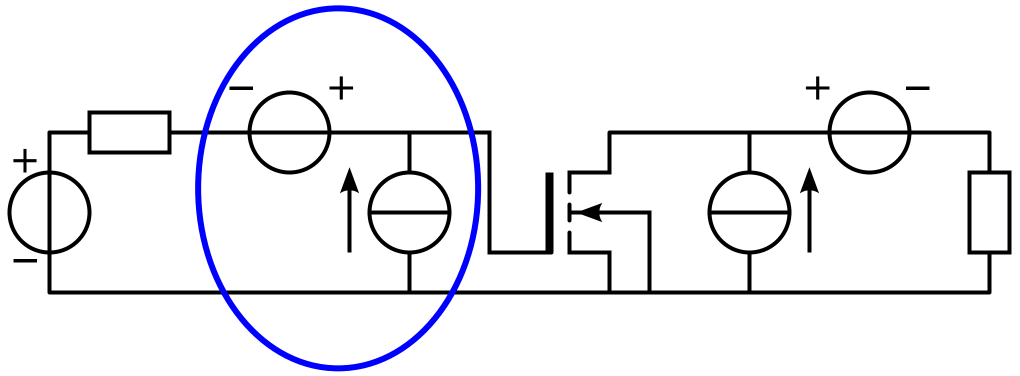
Where have they gone?



If all stages are DC coupled, biasing errors propagate

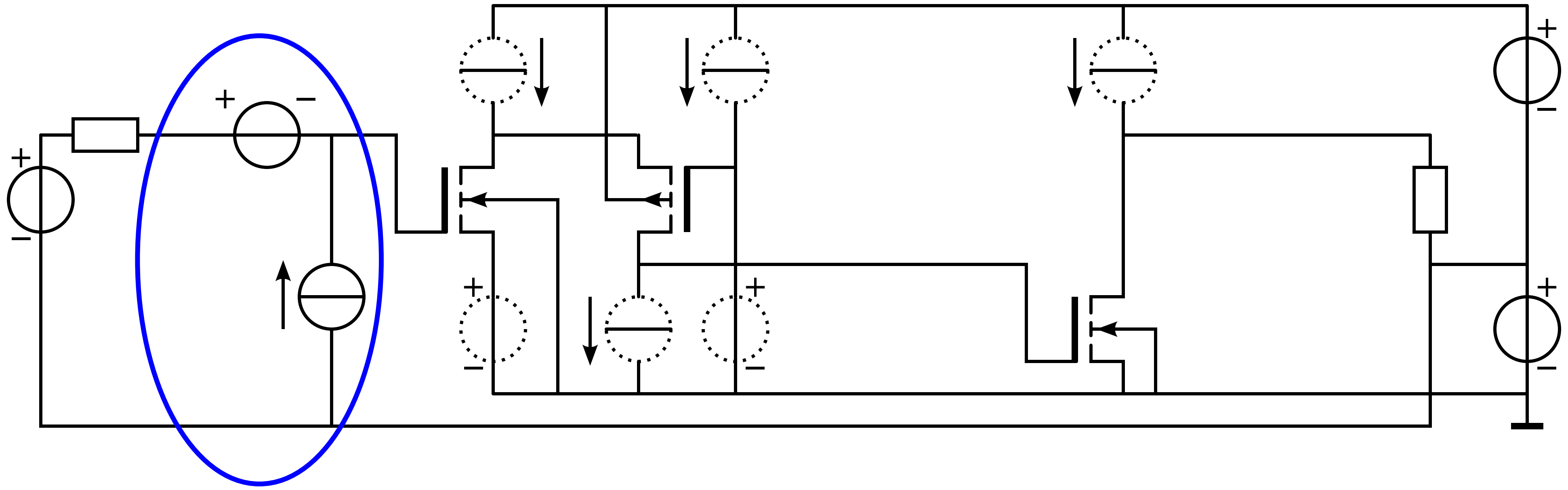
- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing
  - Over-all negative-feedback biasing
  - Over-all auto-zeroing
- If one of the stages is clipping, it can be observed at the output, and the accuracy of local biasing has to be improved

Define differential-mode quantities



With n transistors we need to control 2n bias quantities:

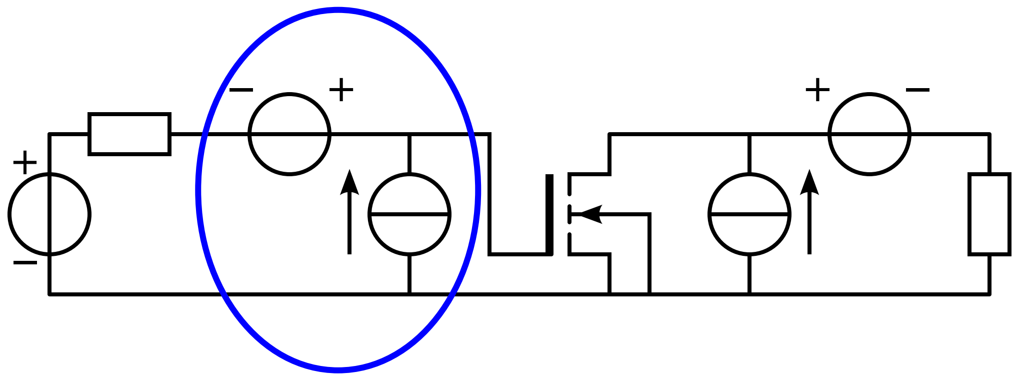
Where have they gone?



If all stages are DC coupled, biasing errors propagate

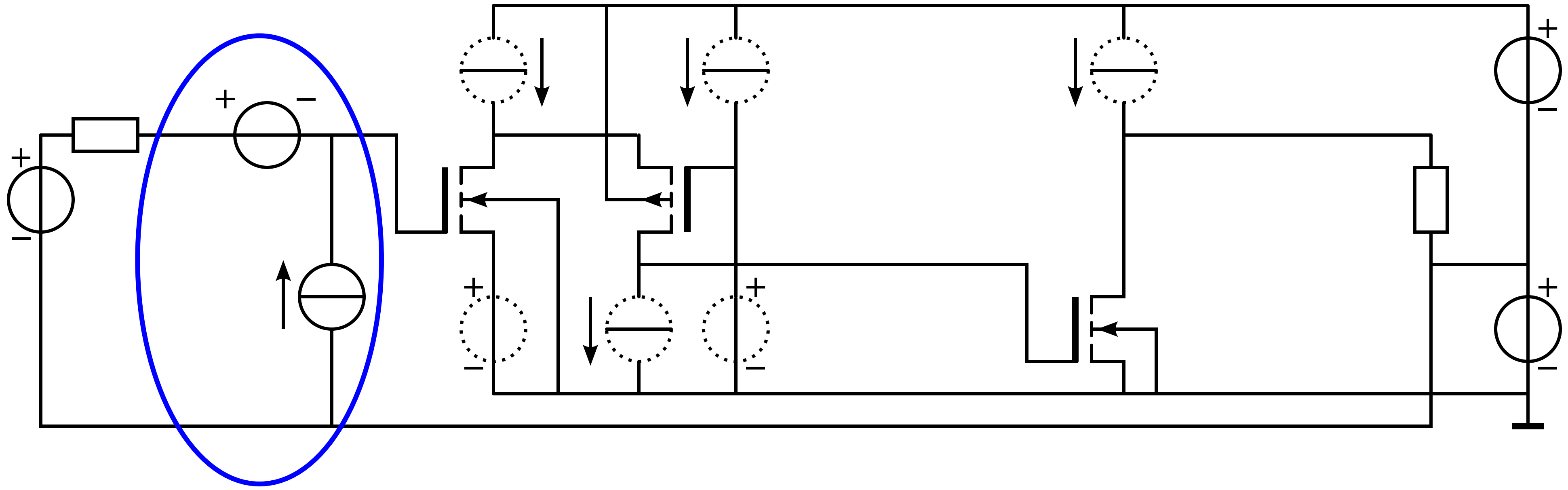
- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing
  - Over-all negative-feedback biasing
  - Over-all auto-zeroing
- If one of the stages is clipping, it can be observed at the output, and the accuracy of local biasing has to be improved
  - Local model-based biasing

Define differential-mode quantities



With n transistors we need to control 2n bias quantities:

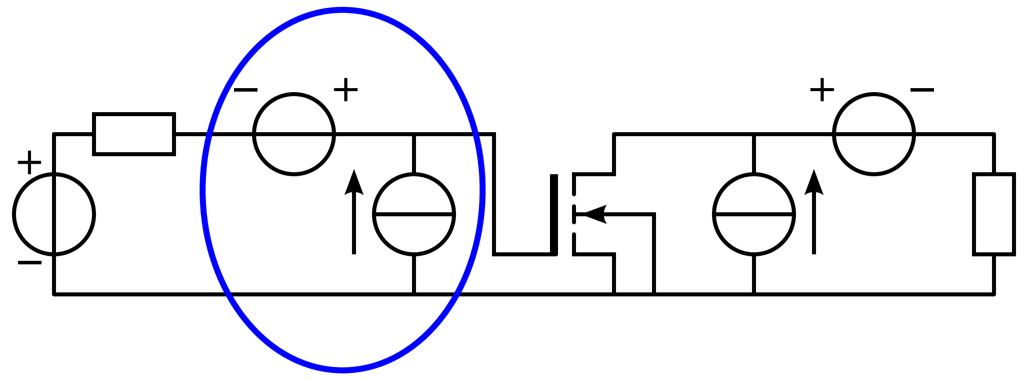
Where have they gone?



If all stages are DC coupled, biasing errors propagate

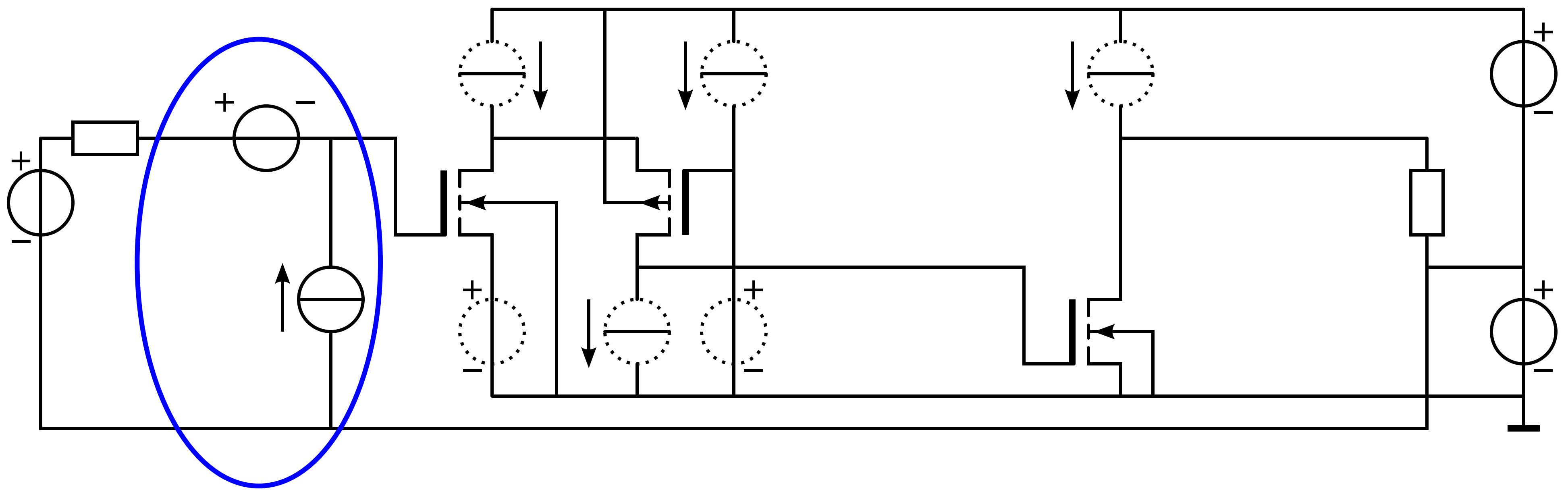
- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing
  - Over-all negative-feedback biasing
  - Over-all auto-zeroing
- If one of the stages is clipping, it can be observed at the output, and the accuracy of local biasing has to be improved
  - Local model-based biasing
  - Local negative-feedback biasing

Define differential-mode quantities



With n transistors we need to control 2n bias quantities:

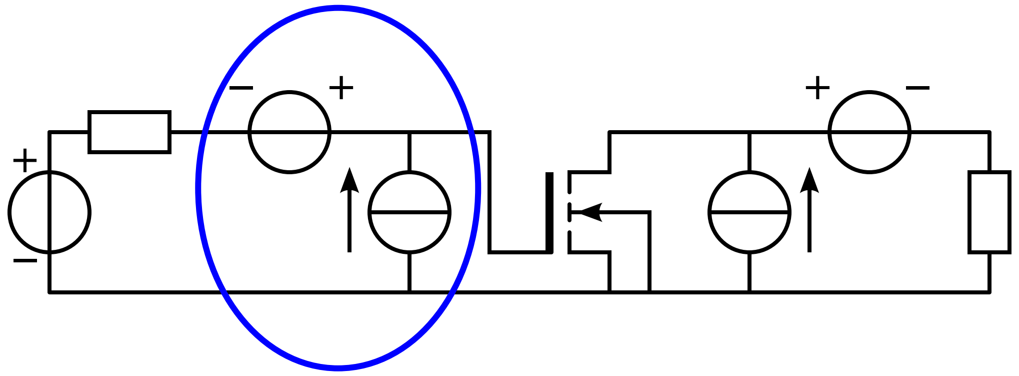
Where have they gone?



If all stages are DC coupled, biasing errors propagate

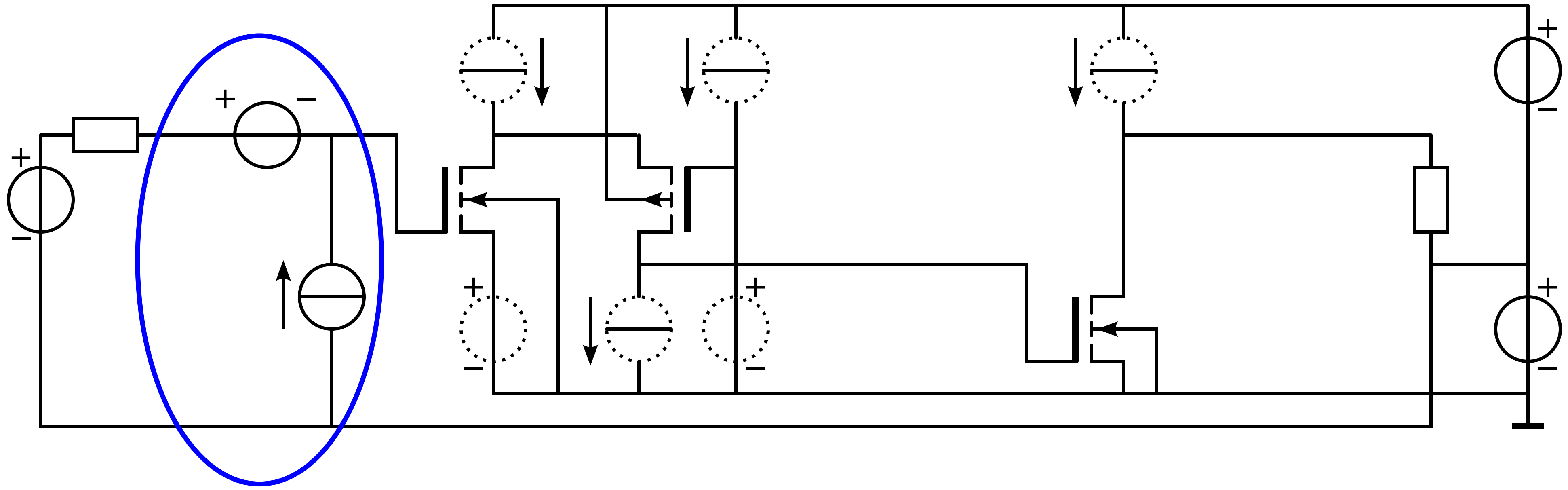
- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing
  - Over-all negative-feedback biasing
  - Over-all auto-zeroing
- If one of the stages is clipping, it can be observed at the output, and the accuracy of local biasing has to be improved
  - Local model-based biasing
  - Local negative-feedback biasing
  - Local auto-zeroing

Define differential-mode quantities



With n transistors we need to control 2n bias quantities:

Where have they gone?



If all stages are DC coupled, biasing errors propagate

- If non of the stages is clipping, biasing errors add up to equivalent-input voltage and current bias sources
- If the biasing error at the output is too large, over-all error-reduction can be applied:
  - Over-all model-based biasing
  - Over-all negative-feedback biasing
  - Over-all auto-zeroing
- If one of the stages is clipping, it can be observed at the output, and the accuracy of local biasing has to be improved
  - Local model-based biasing
  - Local negative-feedback biasing
  - Local auto-zeroing

Define common-mode quantities

Define common-mode quantities

Common-mode biasing errors only propagate if:

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing

Define common-mode quantities

Common-mode biasing errors only propagate if:

Stages are DC coupled
Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

Common-mode voltage or current can be defined in one stage:

- Local brute-force common-mode biasing
- Local model-based common-mode biasing
- Local common-mode feedback biasing

Over-all common-mode feedback can be applied as error-reduction technique

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing
- Over-all common-mode feedback can be applied as error-reduction technique
  - Low-pass filtering is not required if common-mode to differential-mode conversion is negligible

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing
- Over-all common-mode feedback can be applied as error-reduction technique
  - Low-pass filtering is not required if common-mode to differential-mode conversion is negligible

Else:

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing
- Over-all common-mode feedback can be applied as error-reduction technique
  - Low-pass filtering is not required if common-mode to differential-mode conversion is negligible

Else:

- Common-mode voltage or current needs to be defined locally:

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing
- Over-all common-mode feedback can be applied as error-reduction technique
  - Low-pass filtering is not required if common-mode to differential-mode conversion is negligible

Else:

- Common-mode voltage or current needs to be defined locally:
  - Local brute-force common-mode biasing

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing
- Over-all common-mode feedback can be applied as error-reduction technique
  - Low-pass filtering is not required if common-mode to differential-mode conversion is negligible

Else:

- Common-mode voltage or current needs to be defined locally:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing

Define common-mode quantities

Common-mode biasing errors only propagate if:

Stages are DC coupled
Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

Common-mode voltage or current can be defined in one stage:

- Local brute-force common-mode biasing
- Local model-based common-mode biasing
- Local common-mode feedback biasing

Over-all common-mode feedback can be applied as error-reduction technique

- Low-pass filtering is not required if common-mode to differential-mode conversion is negligible

Else:

Common-mode voltage or current needs to be defined locally:

- Local brute-force common-mode biasing
- Local model-based common-mode biasing
- Local common-mode feedback biasing

Define common-mode quantities

Common-mode biasing errors only propagate if:

- Stages are DC coupled
- Stages have common-mode transfer or common-mode to differential-mode conversion

If over-all (source-to-load) common-mode tansfer exists:

- Common-mode voltage or current can be defined in one stage:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing
- Over-all common-mode feedback can be applied as error-reduction technique
  - Low-pass filtering is not required if common-mode to differential-mode conversion is negligible

Else:

- Common-mode voltage or current needs to be defined locally:
  - Local brute-force common-mode biasing
  - Local model-based common-mode biasing
  - Local common-mode feedback biasing