



Photodiode Amplifiers

Changing Light to Electricity

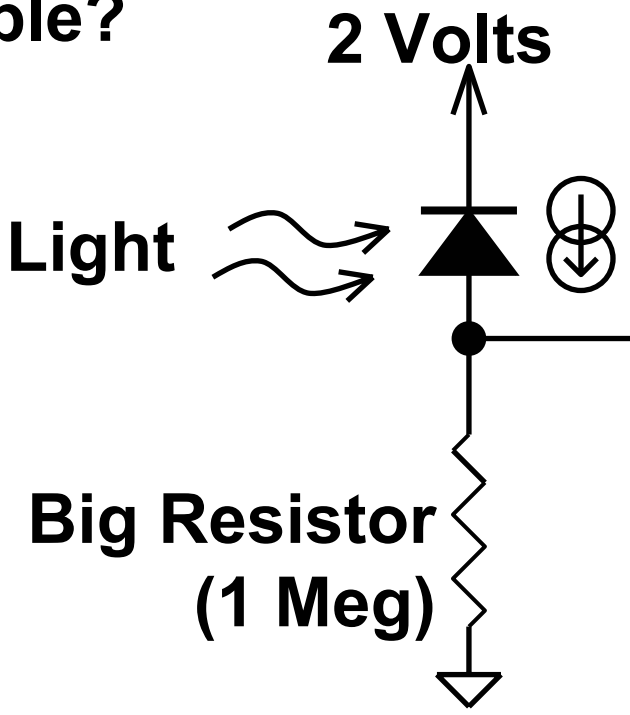
Paul Rako

Strategic Applications Engineer
Amplifier Group

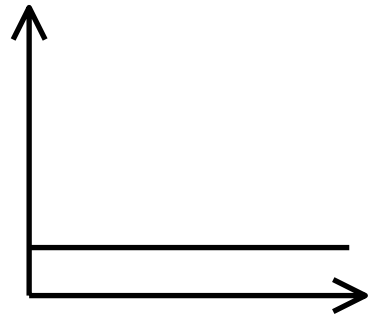


The Photodiode:

Simple?



**Tiny current
flows here (10
nanoAmperes)**

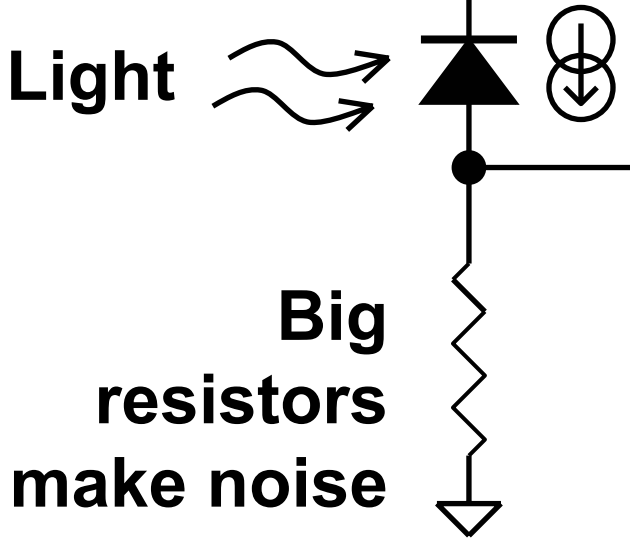


**Makes about a
10 millivolts here**



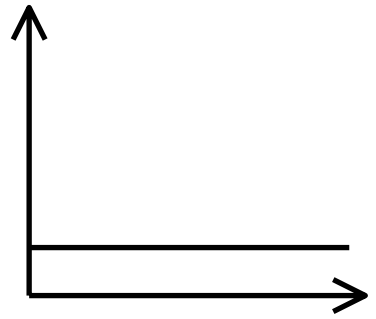
The Photodiode:

**No, not really 2 Volts
simple:**



**Big
resistors
make noise**

**Dark Current
(diode leakage)
flows too and is
worse with temp.**



**10 millivolts is
not very useful.**



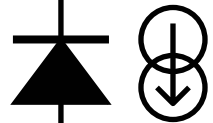
The Photodiode:

Worse yet:

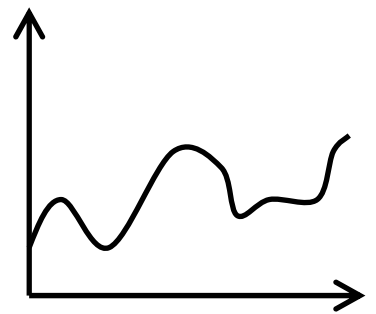
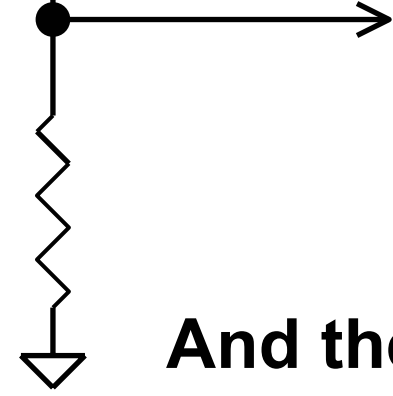
2 Volts

High impedance point difficult to interface with.

Light



Diodes are capacitors too, so fast signals are difficult.



And the capacitance changes with voltage across the diode.

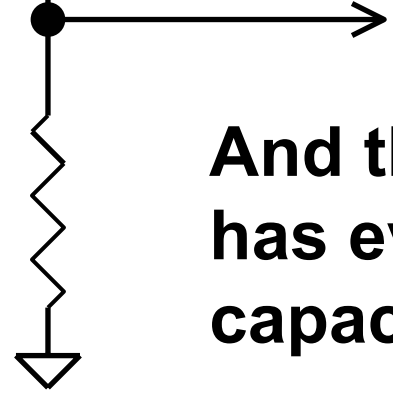


The Photodiode:

Still Worse:

2 Volts

Light



To make the diode more sensitive to light you make the P-N junction big.

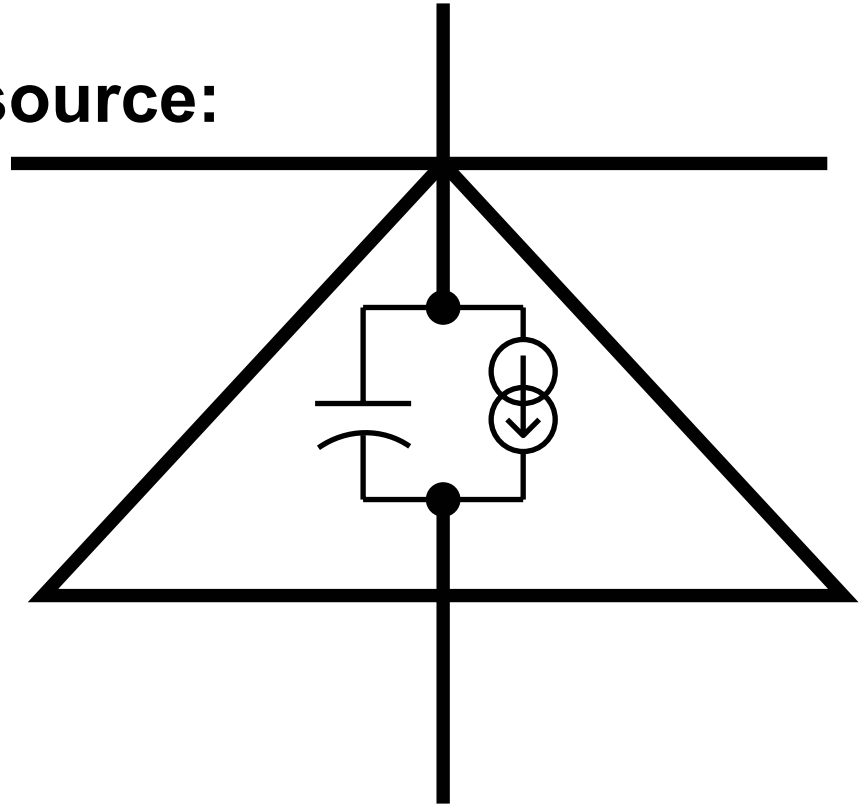
And that big junction has even more capacitance.



Inside the Photodiode:

A cap and a current source:

The bigger the voltage across the diode the further the junction boundaries are pushed apart and the lower the capacitance.

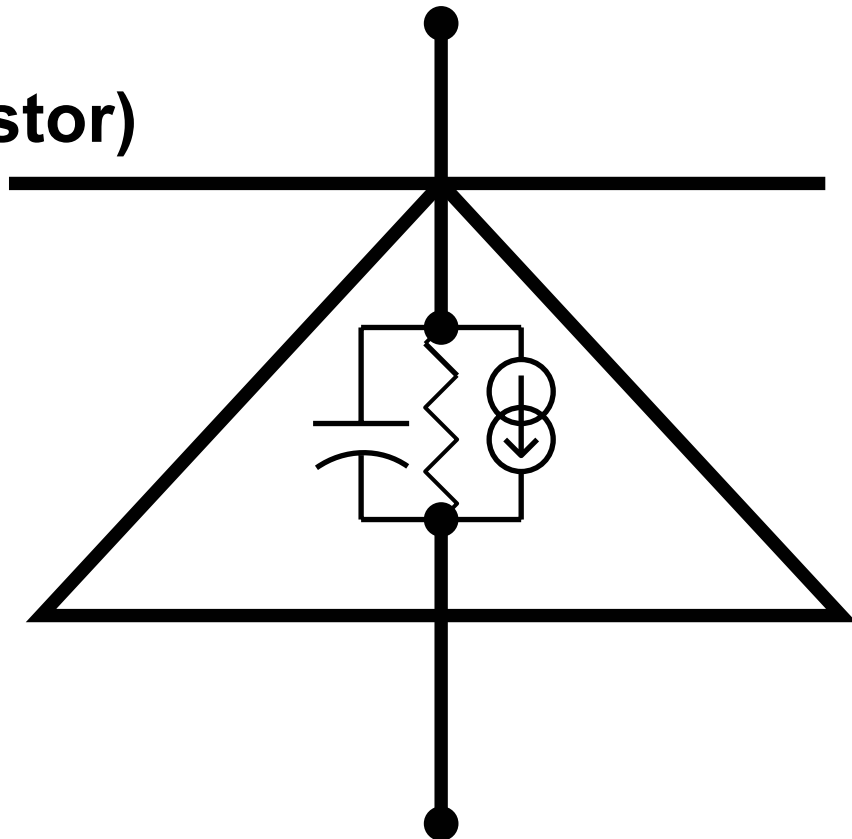




Inside the Photodiode:

(And a really big resistor)

There is also a bulk resistivity to the diode but it is usually very high (100 M Ω). This represents the “Dark Current”.

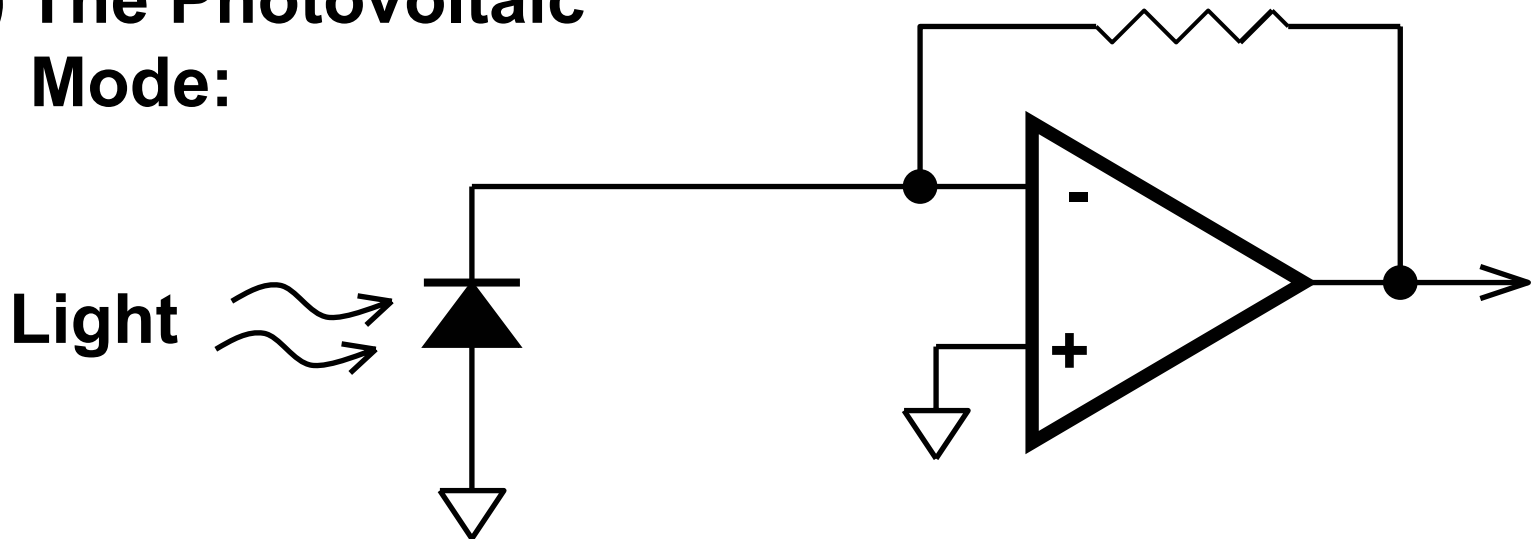




Photodiode Amplifier Types:

Two ways to use the diode:

1) The Photovoltaic Mode:



Note ground— no voltage across diode.



Photodiode Amplifier Types:

The Photovoltaic Mode:

No voltage across diode means no current though the big resistor ~

- **No dark current.**

Also:

- **Linear output**
- **Low Noise**



Photodiode Amplifier Types:

Use Photovoltaic Mode:

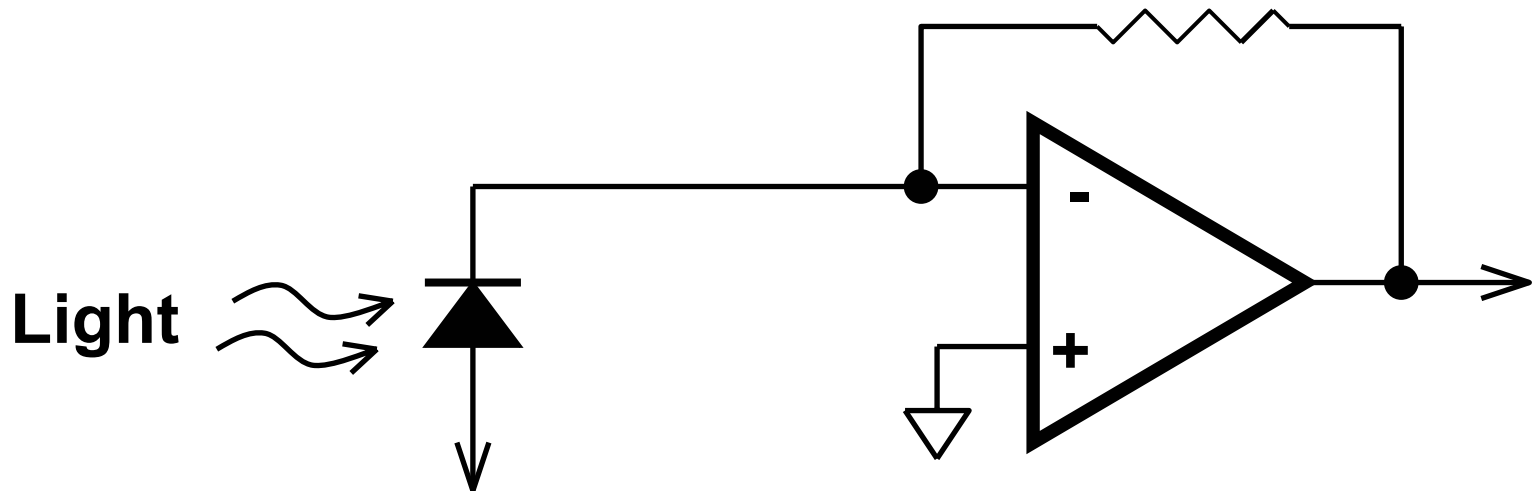
- **Where precision is more important than speed.**

The lack of dark current removes an entire error term. The lower noise makes smaller measurements possible. The linear output makes calculations trivial.



Photodiode Amplifier Types:

The Photoconductive Mode:



**- 10V, there is voltage
across the diode.**



Photodiode Amplifier Types:

Use Photoconductive Mode:

- **Where speed is more important than precision.**

The voltage across the diode lowers its capacitance. This allows faster amplifiers:

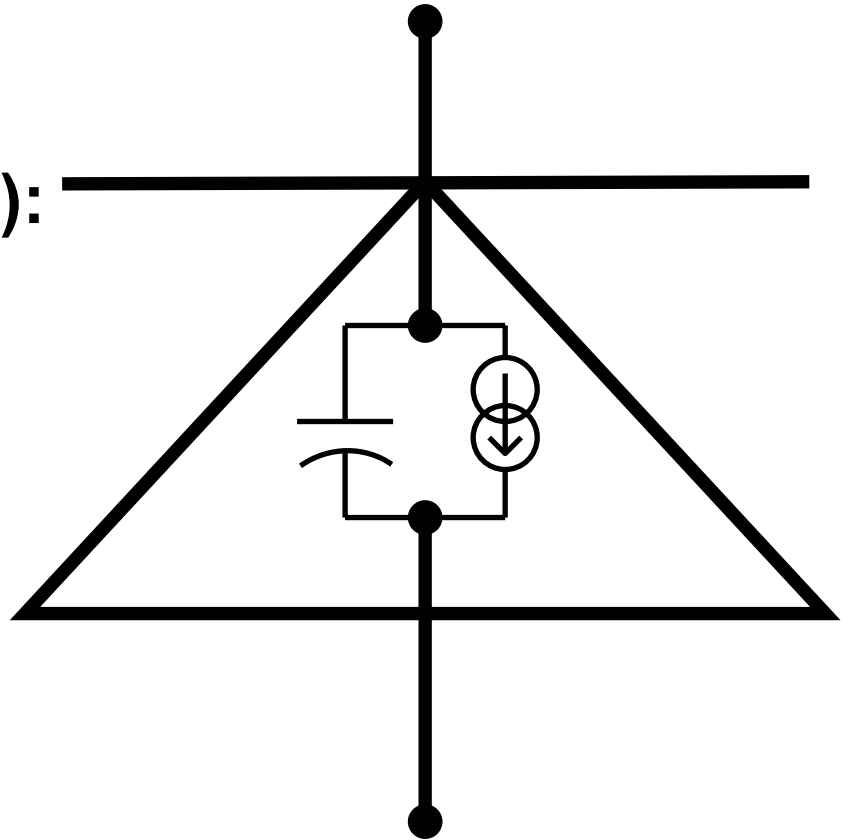
- **Less capacitance allows a faster amplifier while maintaining stability.**



Biasing the Photodiode:

- **Apply a big voltage (that doesn't change):**

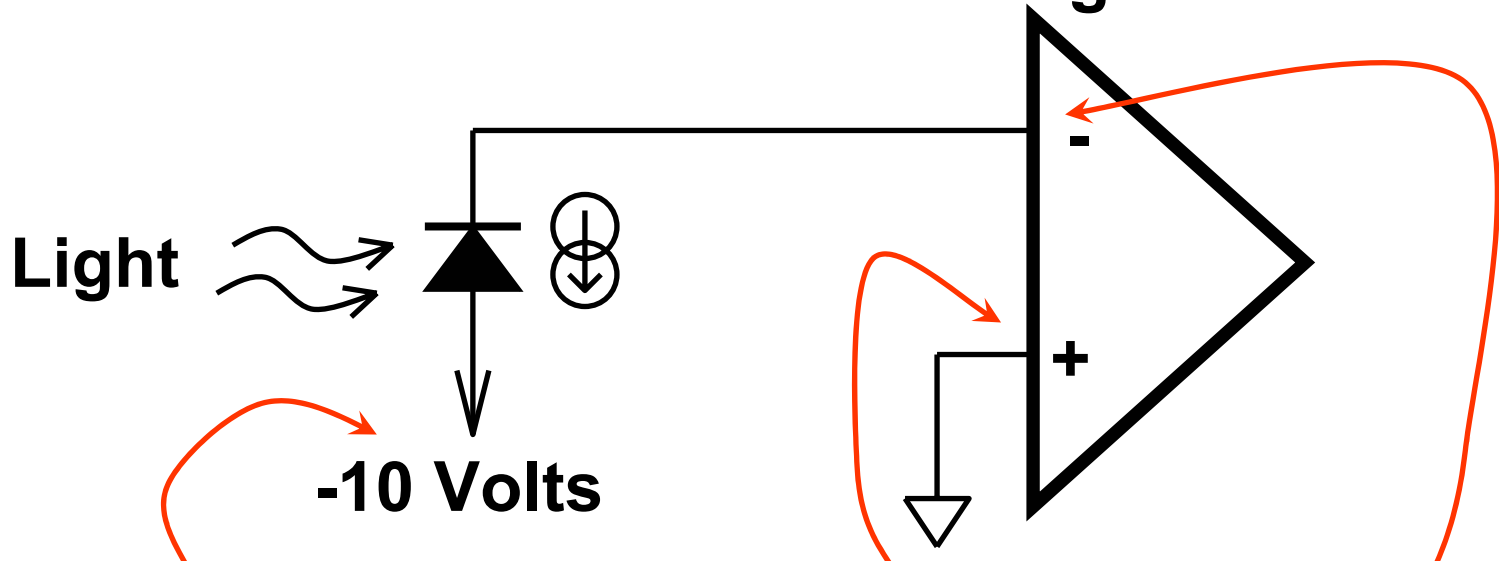
We want a low capacitance so put a big voltage across the diode. We want fast response so don't let the voltage ever change. How?





The Photodiode Amplifier:

- **Connect the diode to a virtual ground:**



As much reverse voltage as the diode can stand.

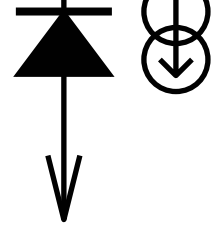
If this pin is at ground so must this pin be at ground.



The Photodiode Amplifier:

- Oh yeah, add some feedback:

Light



-10 Volts

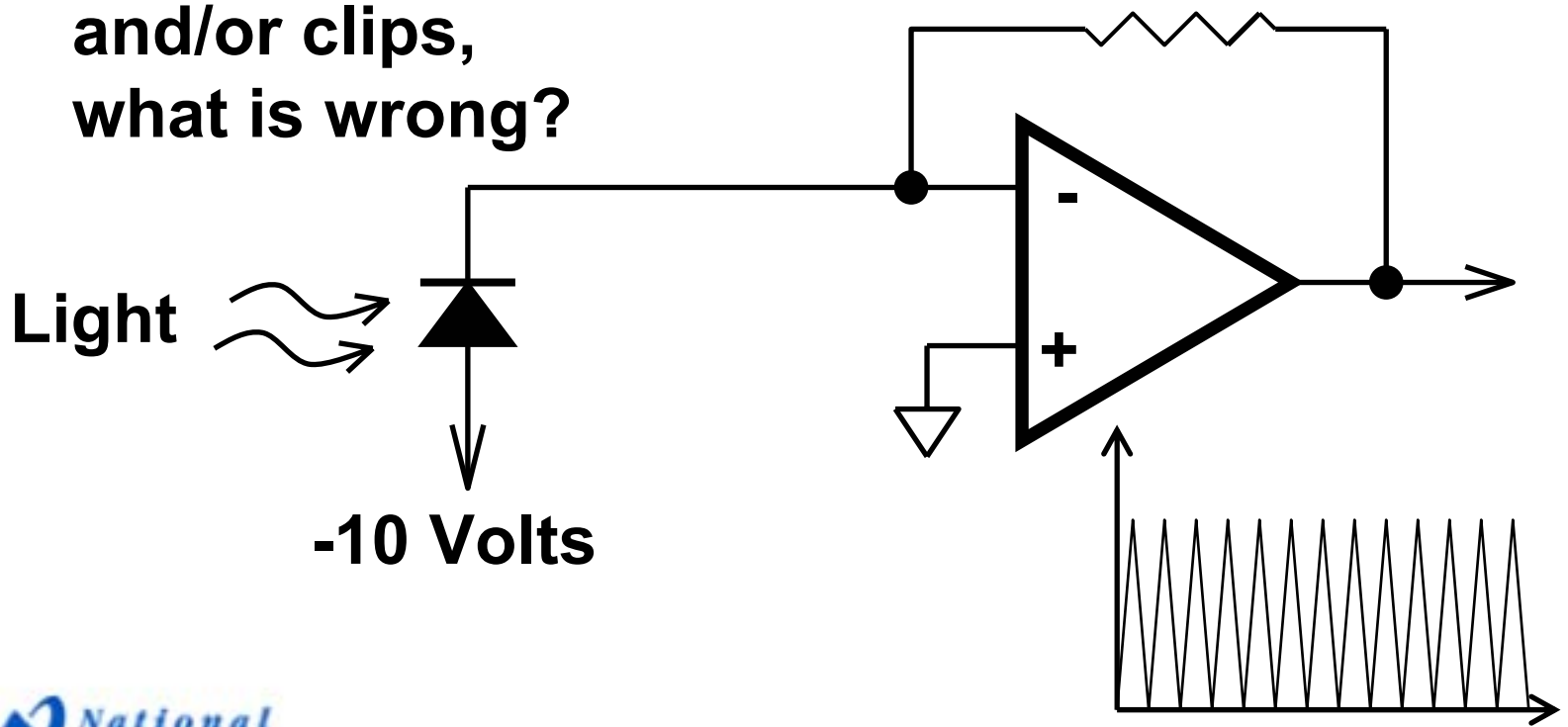
This current makes positive voltage here

This pin stays at ground so output goes more positive with more light.



The Photodiode Amplifier:

- **So it oscillates and/or clips, what is wrong?**



-10 Volts

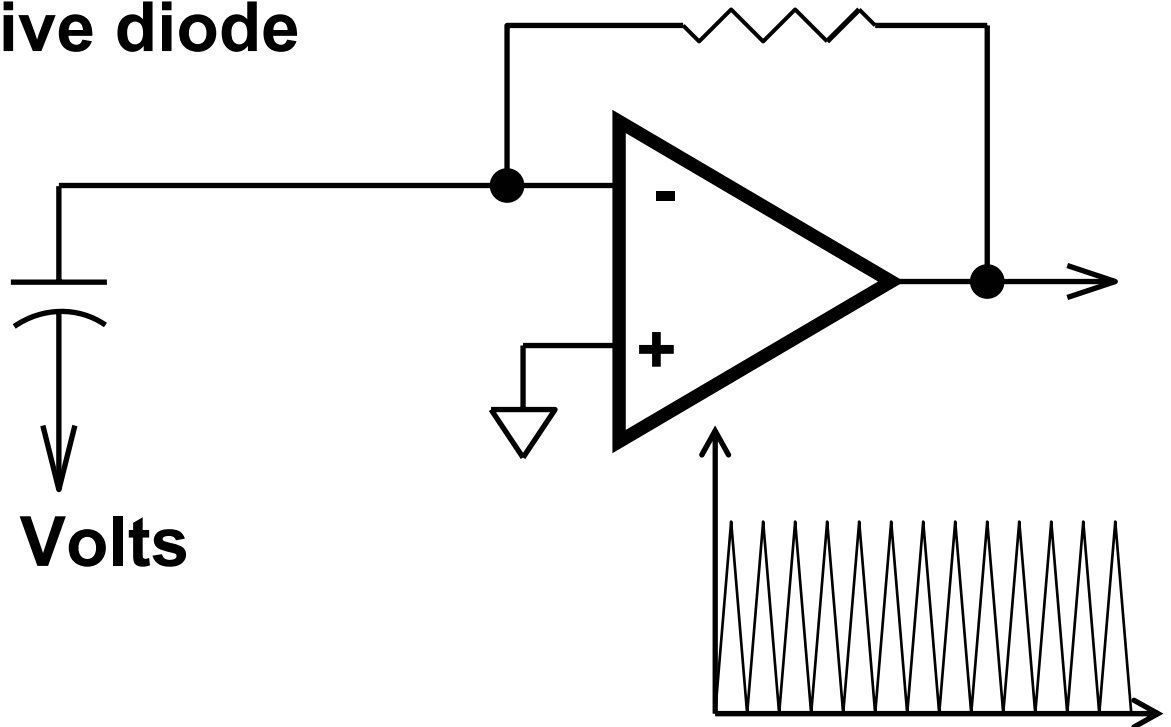


Amplifier Stability:

- **Oscillations caused by capacitive diode on input.**

Photodiode looks like cap to amp

-10 Volts



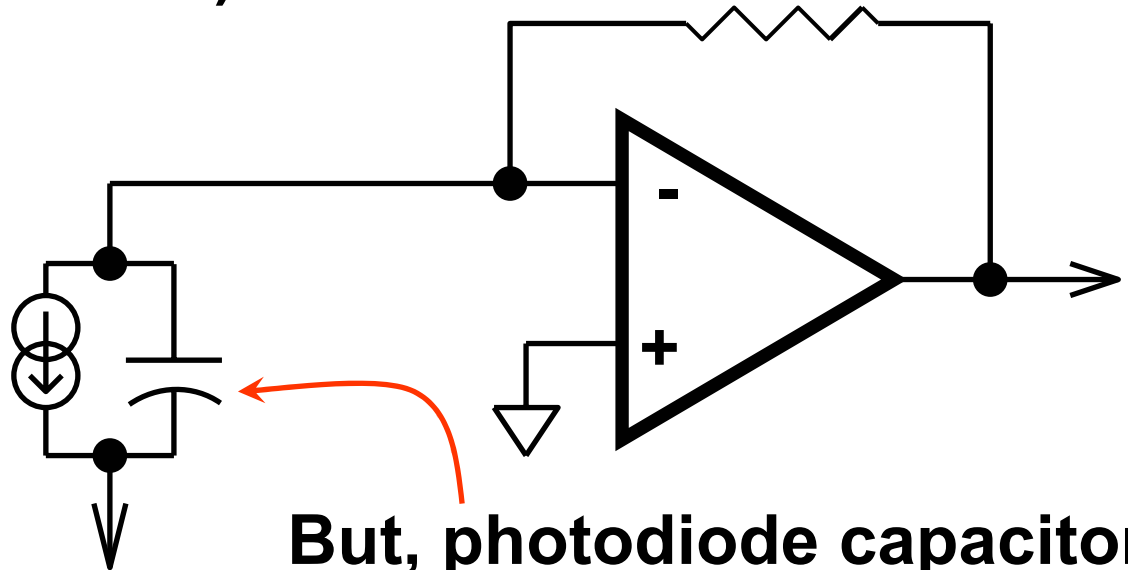


Amplifier Stability:

- **Input pole (freq domain) or feedback lag (time domain) is bad.**

Photodiode current source causes output to change.

-10 Volts



But, photodiode capacitor means feedback signal will lag the actual output change.



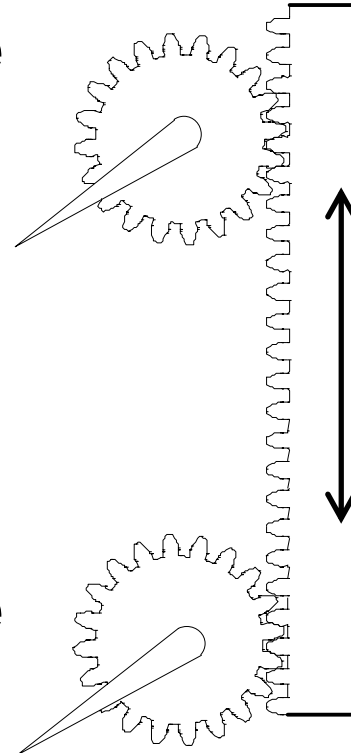
Mechanical Analogy:

- **A gear and rack mechanical servo.**

**This gear is the
amp output stage.**

**You are the amplifier
front-end trying to keep
the pointers the same.**

**This gear is the
feedback.**



**This
rack is
the
output
voltage.**

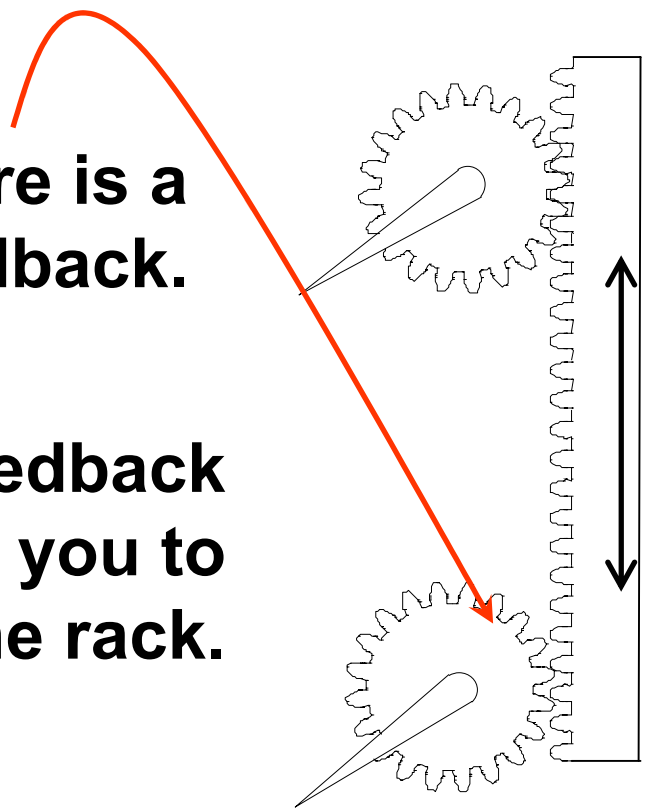


Mechanical Analogy:

- **Input cap is like backlash in feedback mechanism.**

Backlash here is a lag in the feedback.

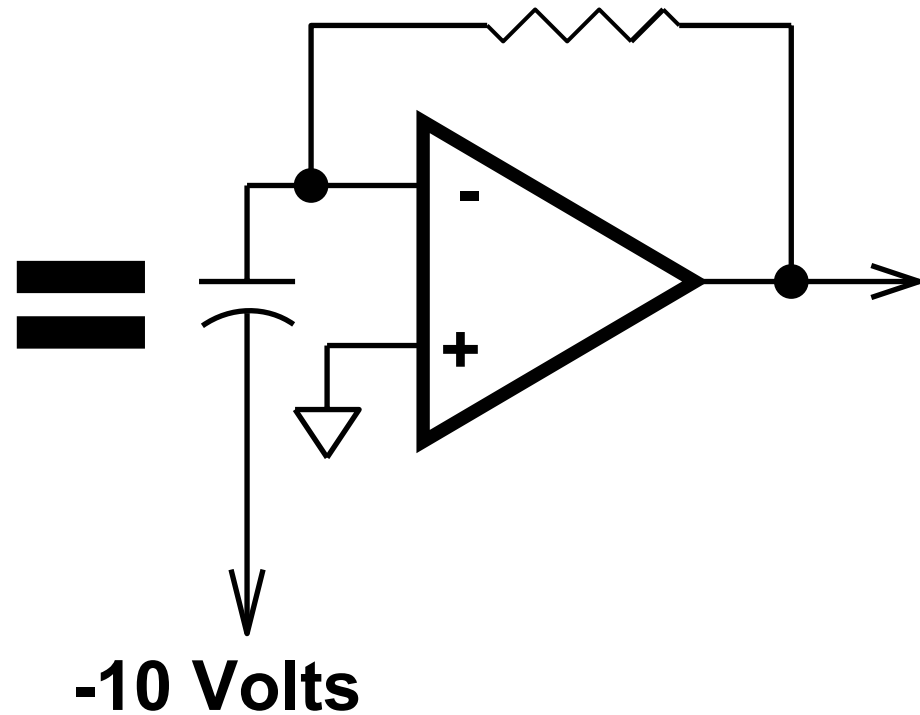
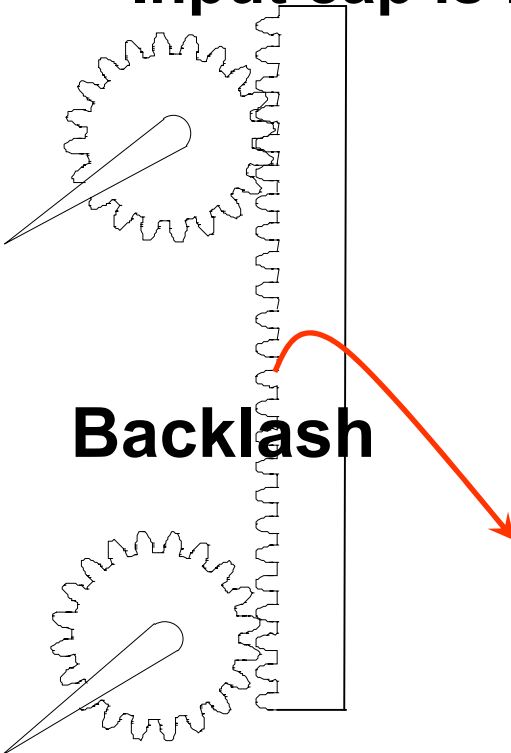
The lag in your feedback pointer will cause you to oscillate the rack.





Mechanical Analogy:

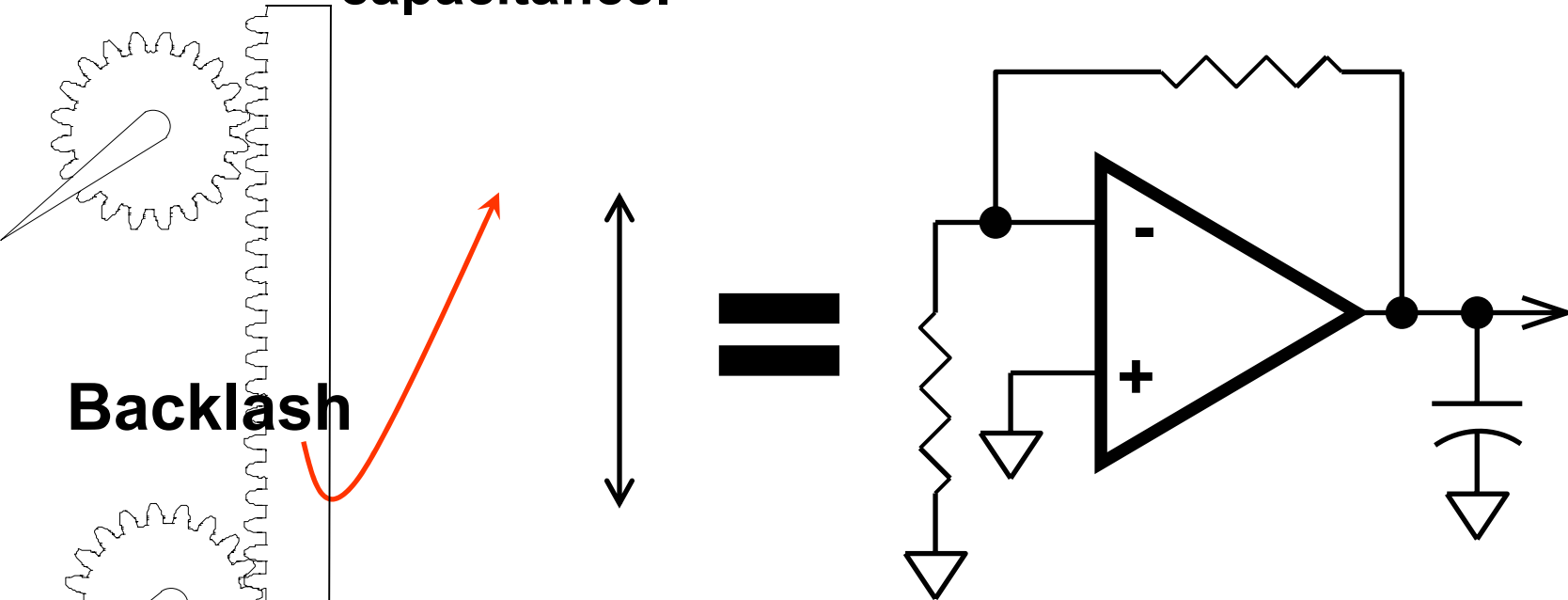
- **Input cap is like backlash in feedback mechanism.**





Mechanical Analogy:

- **Interesting note: Driver backlash is like output capacitance.**

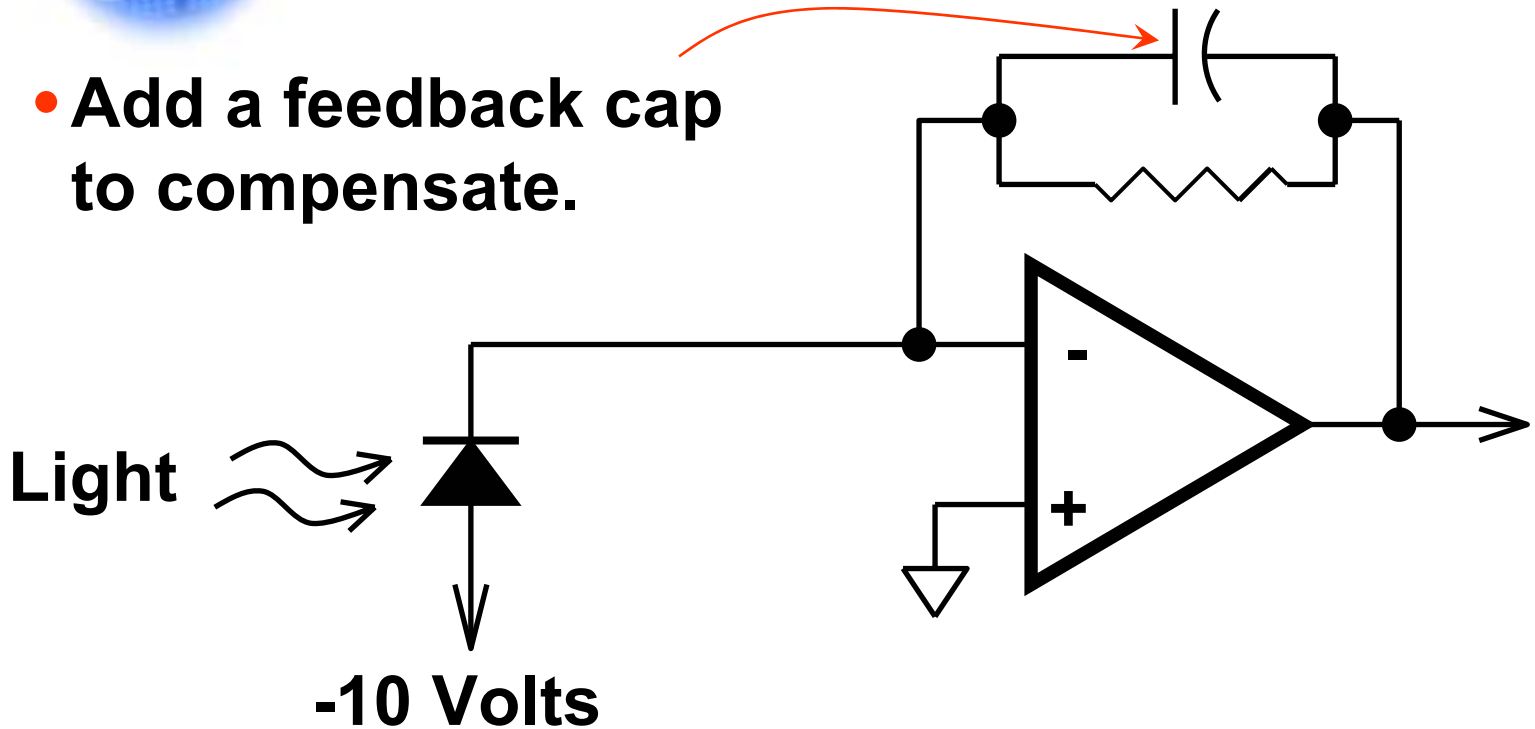


**Without compensation
either cap will cause
oscillations.**



Compensated Amplifier:

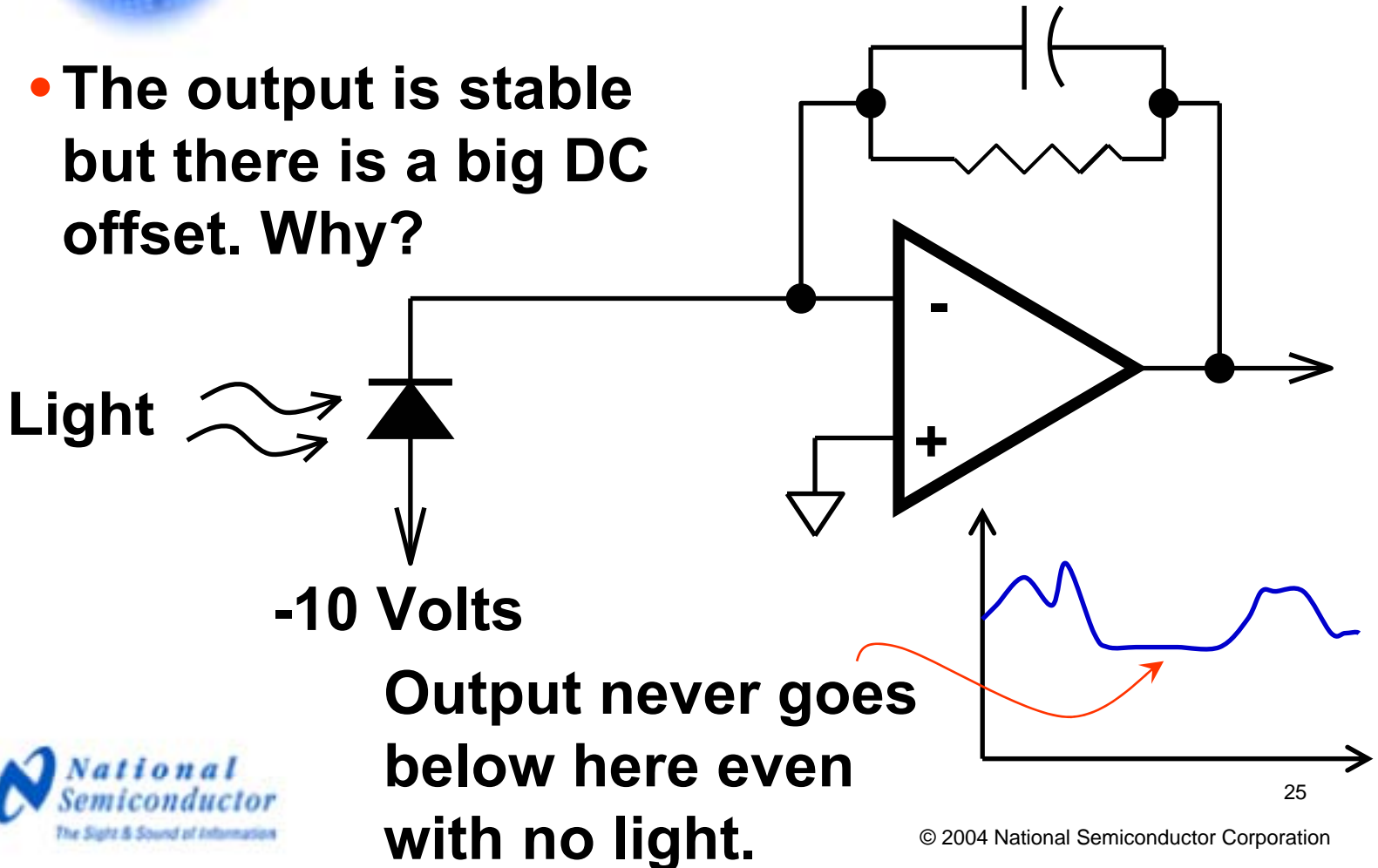
- **Add a feedback cap to compensate.**





Biassing the Amplifier:

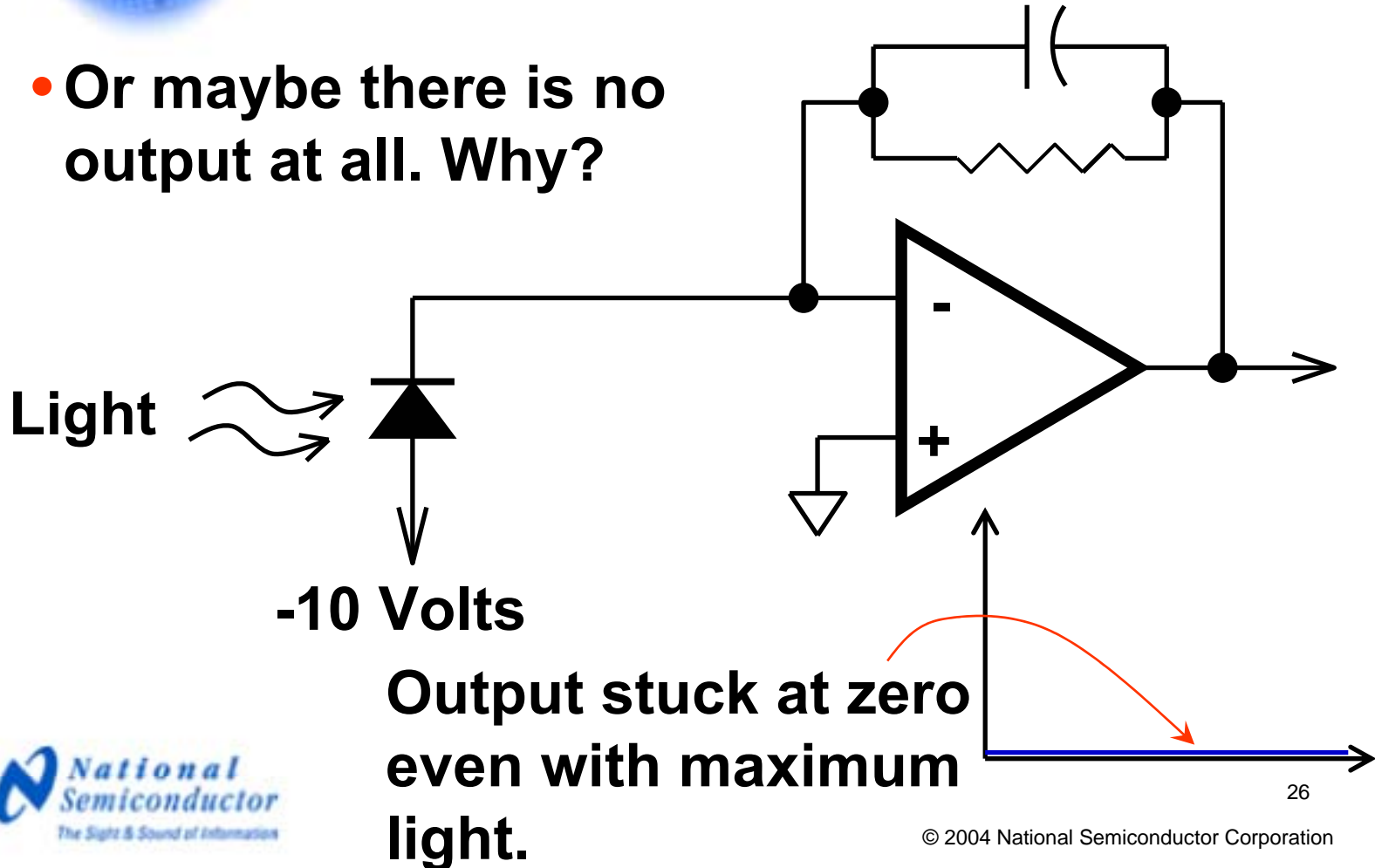
- **The output is stable but there is a big DC offset. Why?**





Biassing the Amplifier:

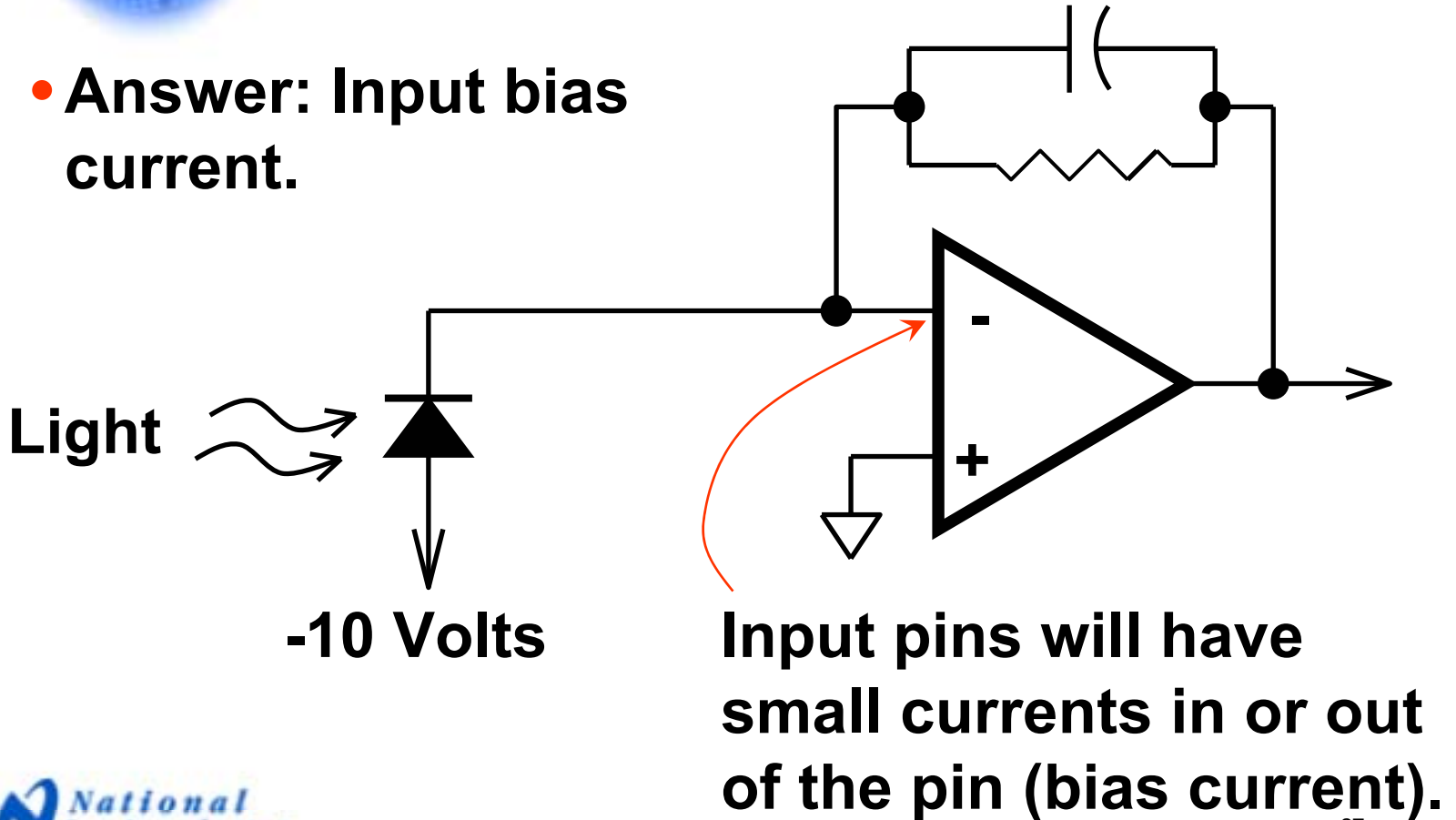
- Or maybe there is no output at all. Why?





Biassing the Amplifier:

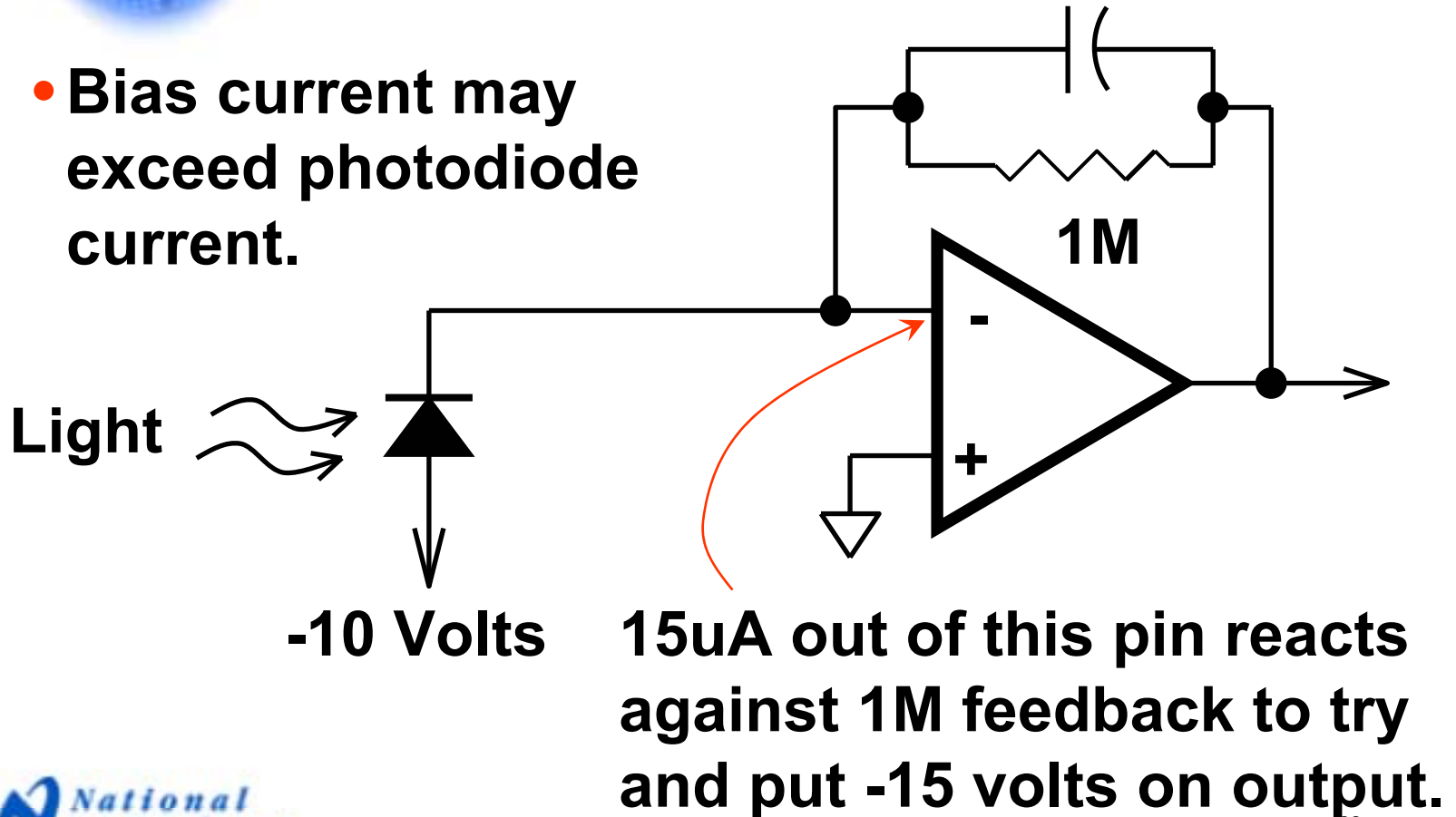
- **Answer: Input bias current.**





Biassing the Amplifier:

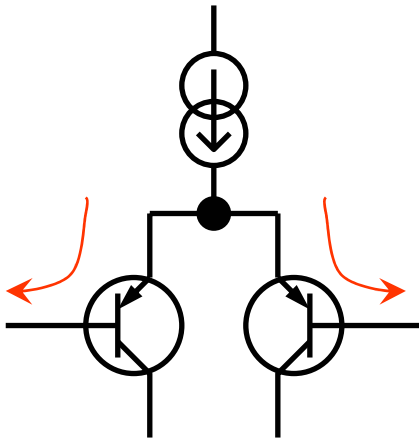
- Bias current may exceed photodiode current.





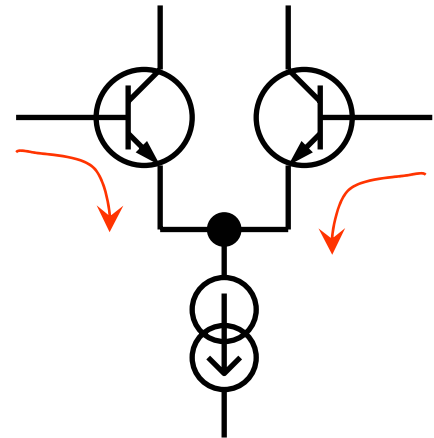
Amplifier Input Stage:

- **Input transistors have base current.**



**PNP
Input
Stage**

**Input bias
current may
be 15 μA , but
won't vary
much over
temperature.**

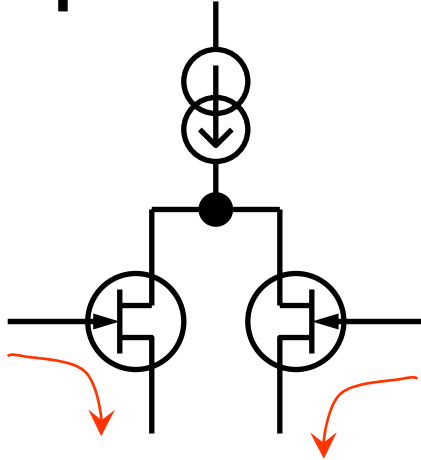


**NPN
Input
Stage**



Amplifier Input Stage:

- **Input JFETs have large drift.**



**JFET
Input
Stage**

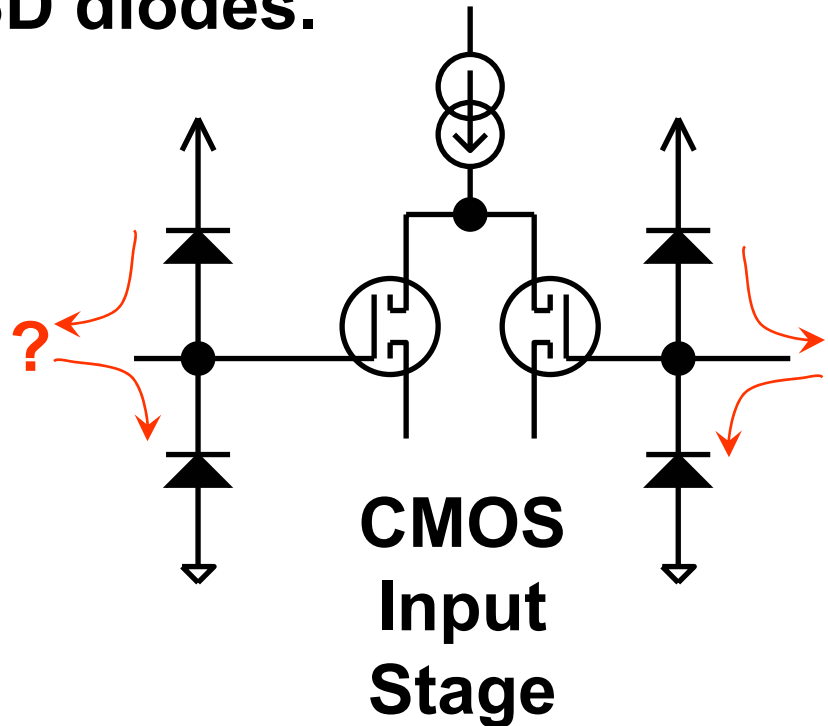
**Input bias
current may
be 15 pA, but
will double
every 10°C.**



Amplifier Input Stage:

- **CMOS parts have ESD diodes.**

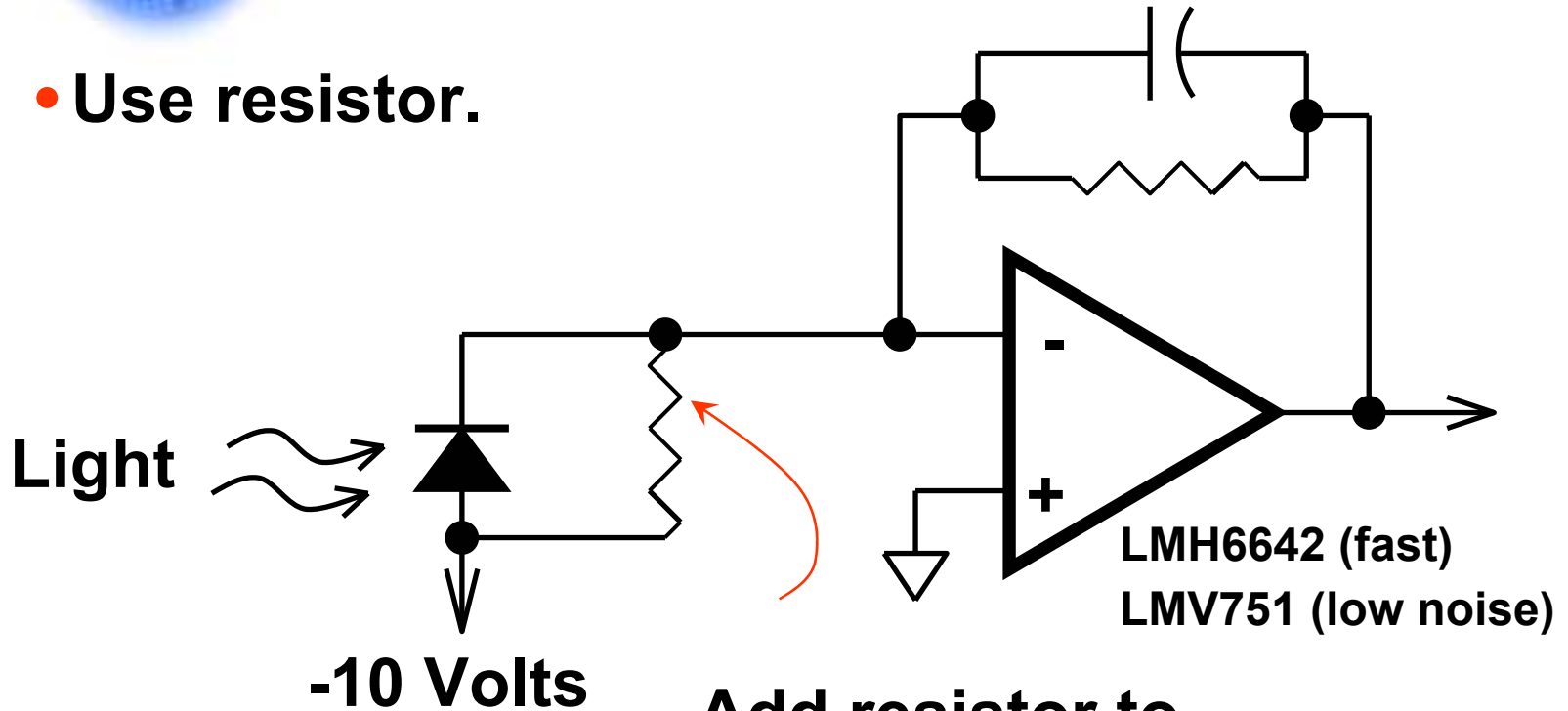
MOSFET has no DC bias current but mis-match in ESD diodes causes bias current to flow in (or out) of pin.





Correcting DC Bias

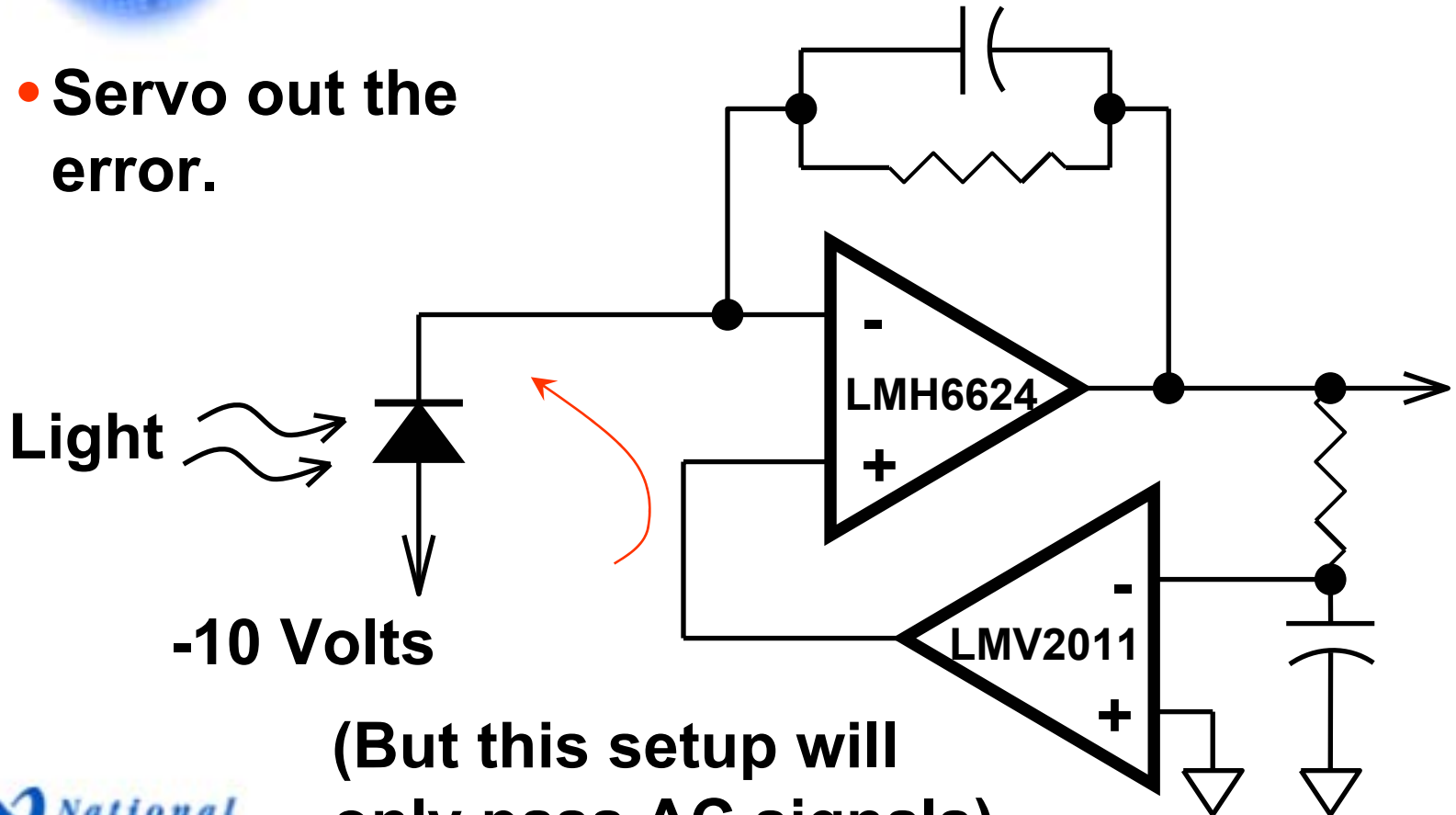
- Use resistor.





Correcting DC Bias

- Servo out the error.



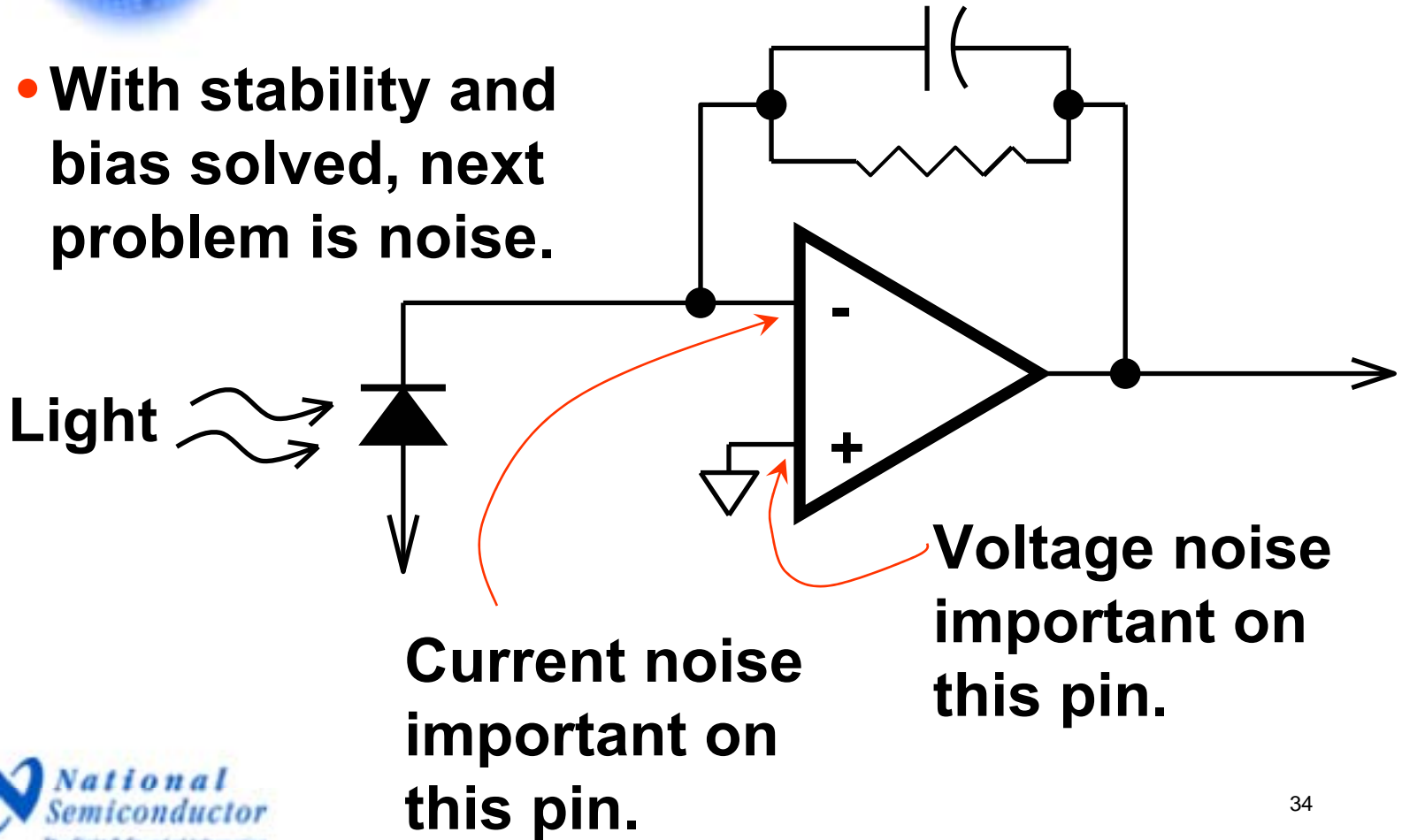
-10 Volts

(But this setup will only pass AC signals)



Amplifier noise:

- **With stability and bias solved, next problem is noise.**





Amplifier noise:

- **Low current and low voltage noise in the same part is hard.**
- **JFET amplifiers have low current noise.**
- **Bipolar amplifiers have low voltage noise.**
- **Choppers can cause problems.**



Some Potential Parts:

| Device | Input Noise Voltage (nV/RtHz) | Input Noise Current (pA/RtHz) | Input Capacitance (pF) | I _{bias} (max) | GBWP (MHz) | GBWP/C _{in} (MHz/pF) |
|---------------|-------------------------------|-------------------------------|------------------------|-------------------------|------------|-------------------------------|
| LMH6628 | 2 | 2 | 1.5 | 20μA | 200 | 133 |
| LMH6626* | 1.0 | 1.8 | 0.9 | 20μA | 500 | 556 |
| LMH6624* | 0.92 | 2.3 | 0.9 | 20μA | 500 | 556 |
| LMH6622 | 1.6 | 1.5 | 0.9 | 10μA | 200 | 222 |
| LMH6654 /6655 | 4.5 | 1.7 | 1.8 | 12μA | 150 | 83 |
| LMH6672 | 4.5 | 1.7 | 2 | 14μA | 100 | 50 |
| LF411A | 25 | 0.01 | 4 | 200pA | 4 | 1 |
| LMV751 | 7 | 0.005 | 5 | 100pA | 5 | 1 |
| LMC662 | 22 | 0.0002 | 4 | 0.01pA (typical) | 1.4 | 0.3 |
| LMV771 | 8 | 0.001 | 4 | 100pA | 4 | 1 |



Conclusions:

- **Photodiode amplifiers are tricky.**
- **The design should be tailored for the application, DC, Data, etc.**
- **The design requires a lot of trial and error.**
- **Be prepared to do a lot of study.**
- **National Applications Engineering is here to help you.**



Resources:

- **AN-1244: Photo-Diode Current-to-Voltage Converters.**
- **Amplifier WEBENCH®– On-line simulation of amplifier performance**
- **Photodiode Amplifiers: OP AMP Solutions by Jerald Graeme**
- **Photodetection and Measurement: Maximizing Performance in Optical Systems by Mark Johnson**
- **Photodetectors: Devices, Circuits and Applications by Silvano Donati**



Thank You!

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