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The Sight & Sound of Information

Photodiode Amplifiers

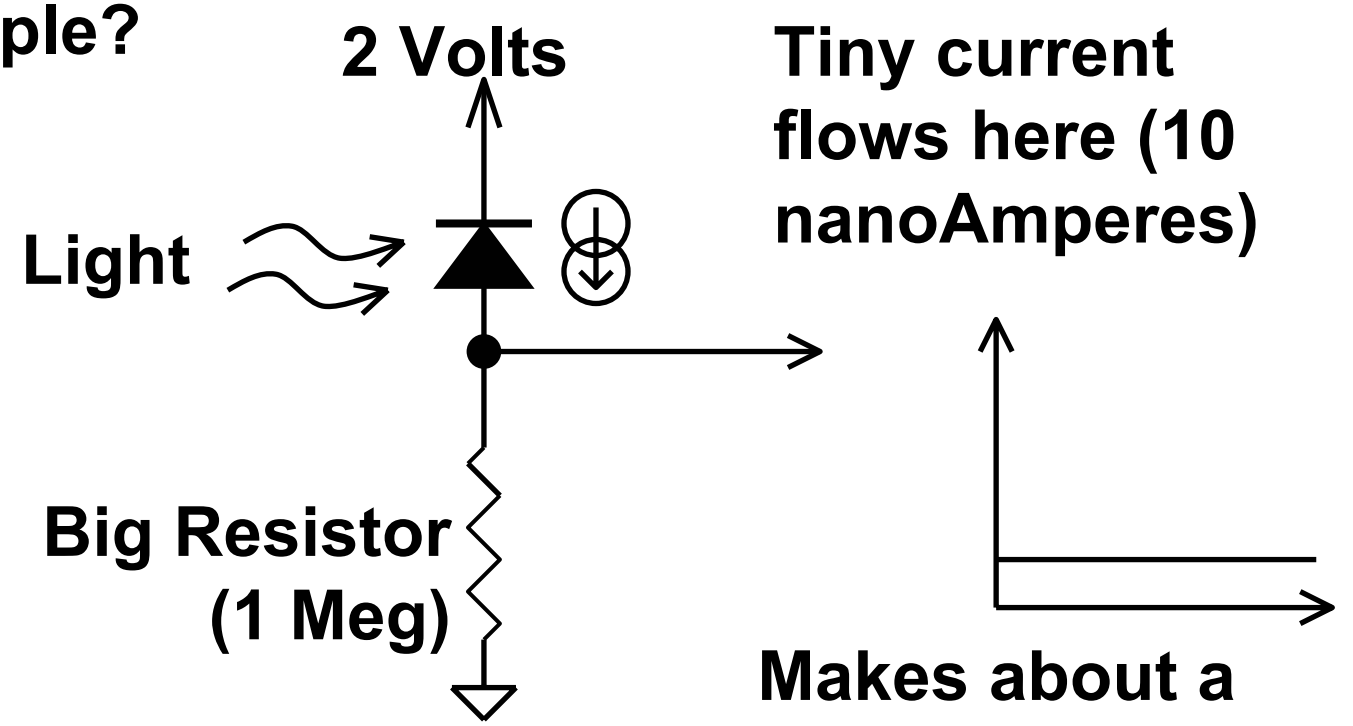
Changing Light to Electricity

Paul Rako

Strategic Applications Engineer
Amplifier Group

The Photodiode:

Simple?



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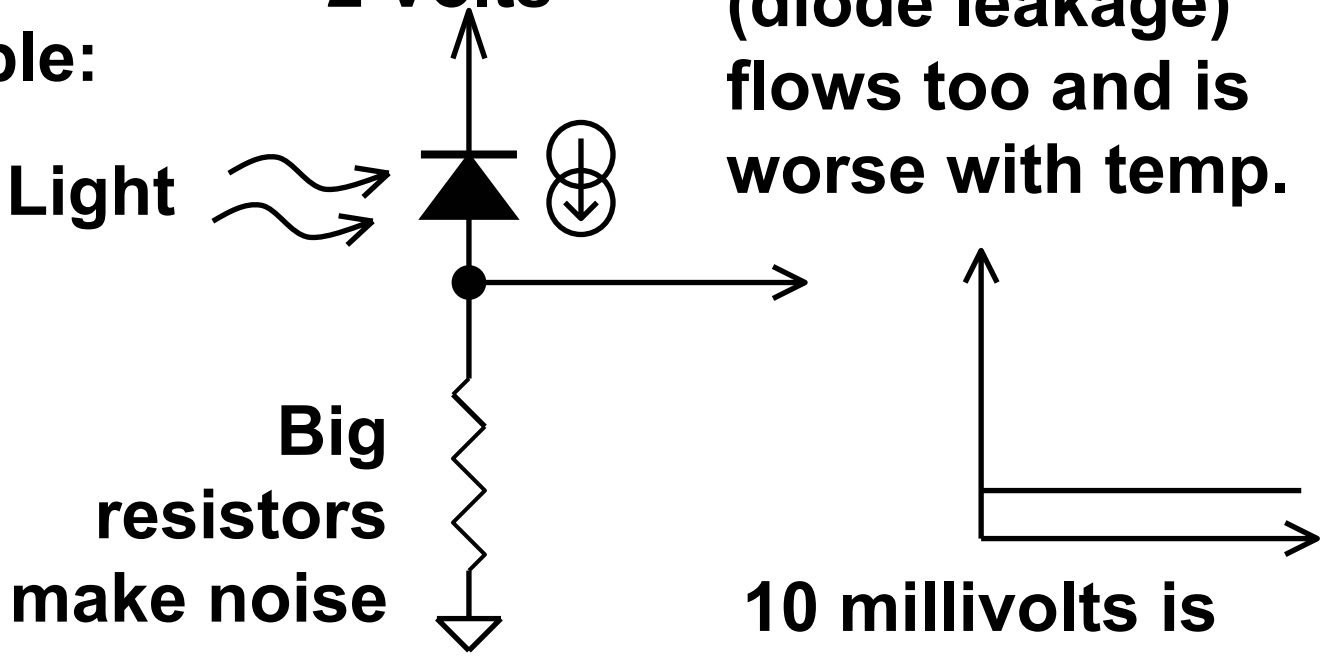
The Photodiode:

No, not really simple:



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

10 millivolts is not very useful.

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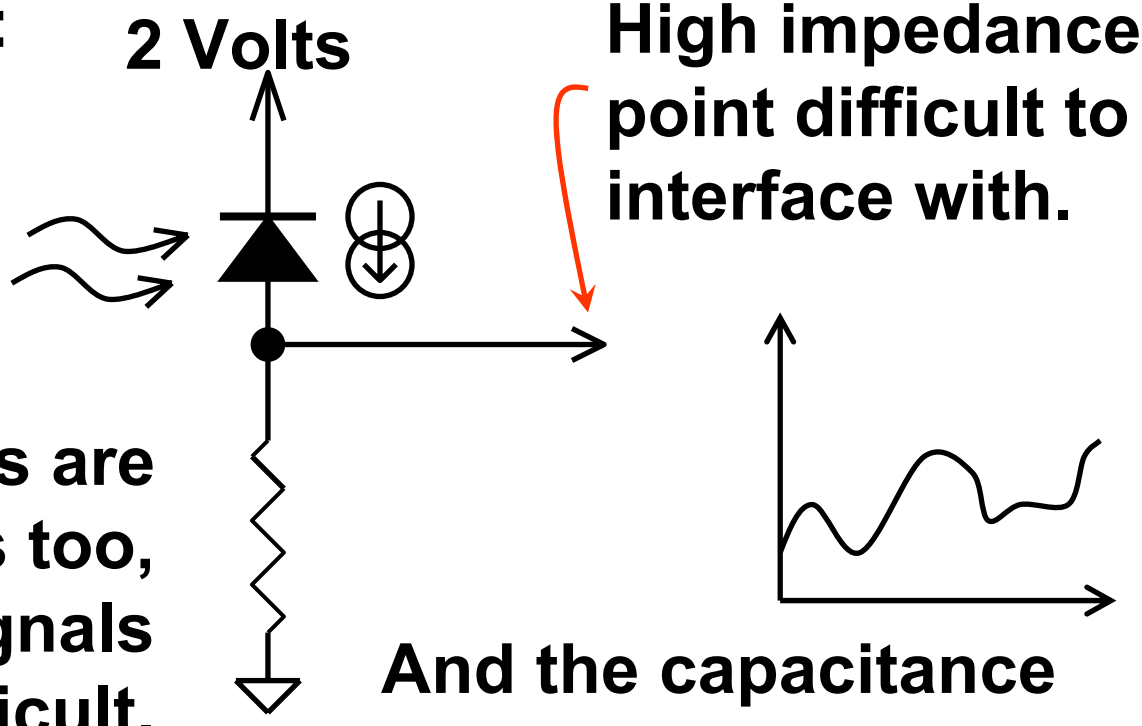
The Photodiode:

Worse yet:



Diodes are capacitors too, so fast signals are difficult.

And the capacitance changes with voltage across the diode.

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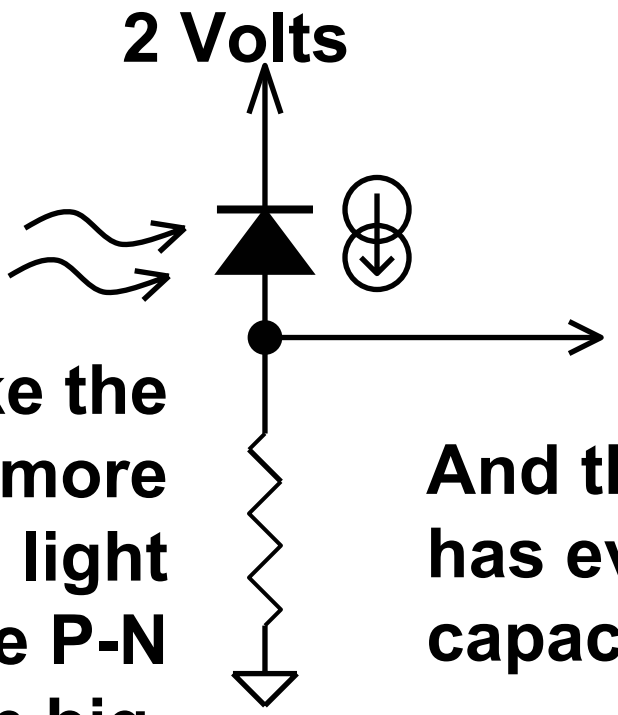
The Photodiode:

Still Worse:



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

And that big junction has even more capacitance.

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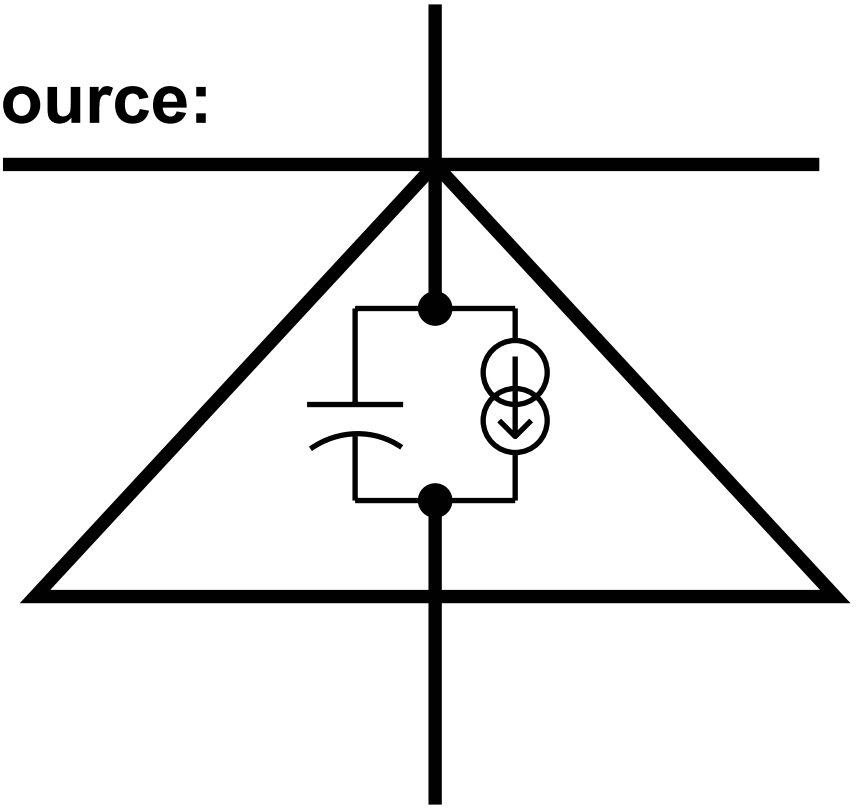
Inside the Photodiode:

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.

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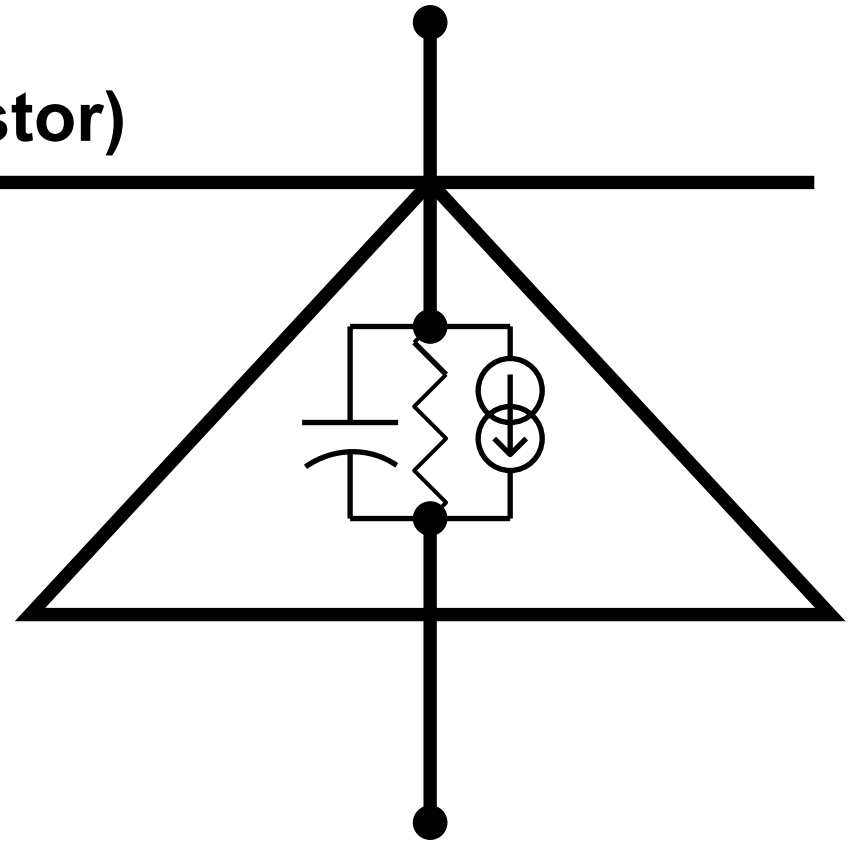
Inside the Photodiode:

(And a really big resistor)

There is also a bulk resisistivity to the diode but it is usually very high (100 MΩ). This represents the "Dark Current".



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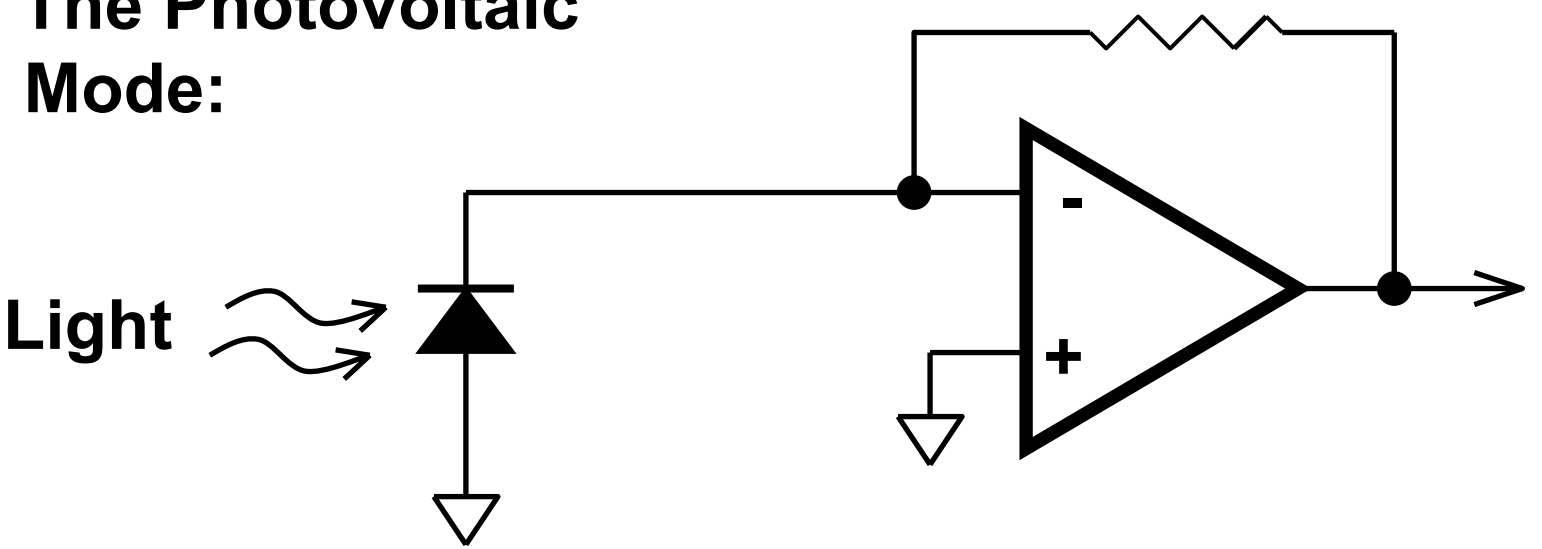
Photodiode Amplifier Types:

Two ways to use the diode:

1) The Photovoltaic Mode:



Note ground– no voltage across diode.

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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

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Photodiode Amplifier Types:

Use Photovoltaic Mode:

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

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

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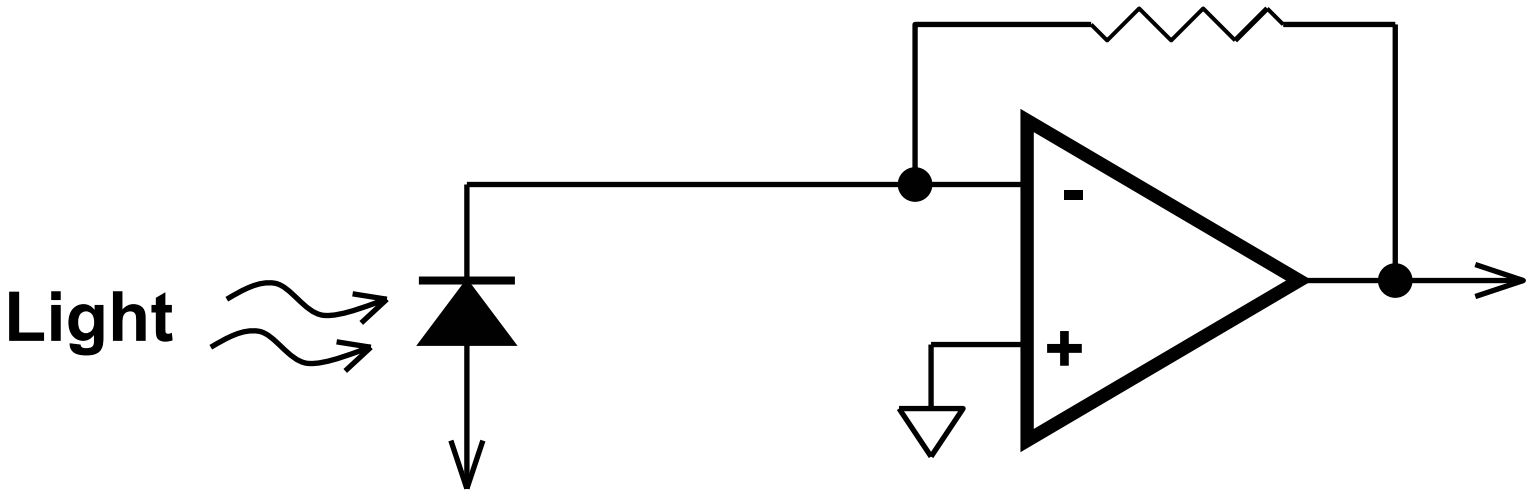
Photodiode Amplifier Types:

The Photoconductive Mode:



- 10V, there is voltage across the diode.

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Photodiode Amplifier Types:

Use Photoconductive Mode:

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

The voltage across the diode lowers it's capacitance. This allows faster amplifiers:

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

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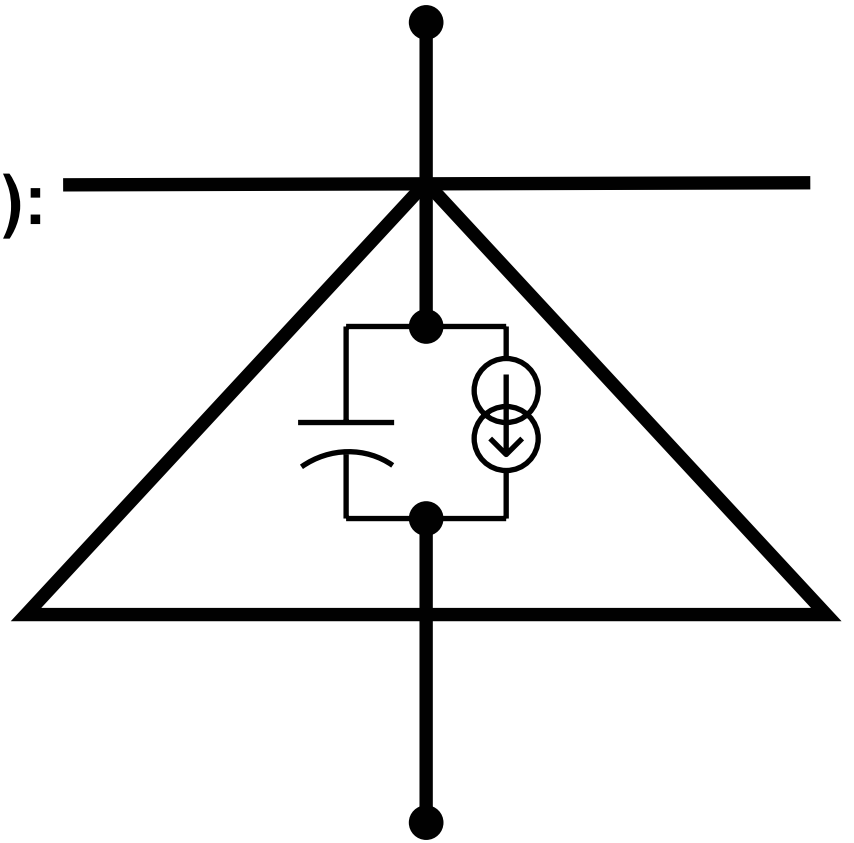
Biasing the Photodiode:

- 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?



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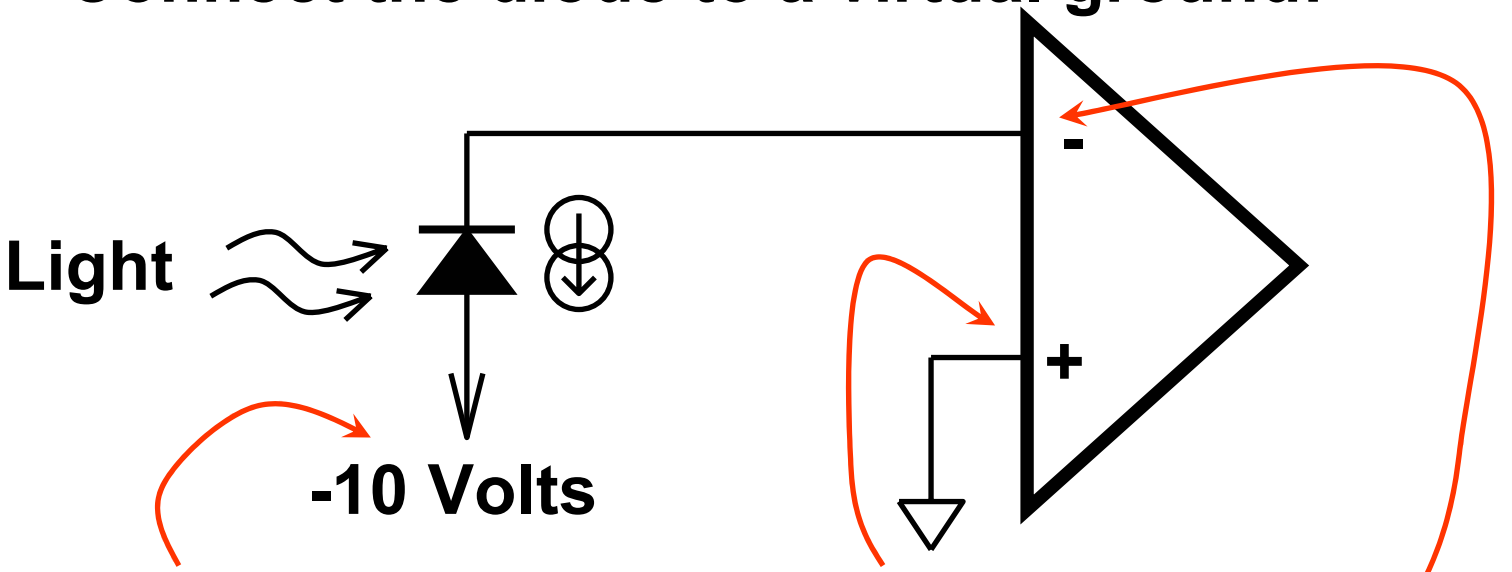
The Photodiode Amplifier:

- 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.

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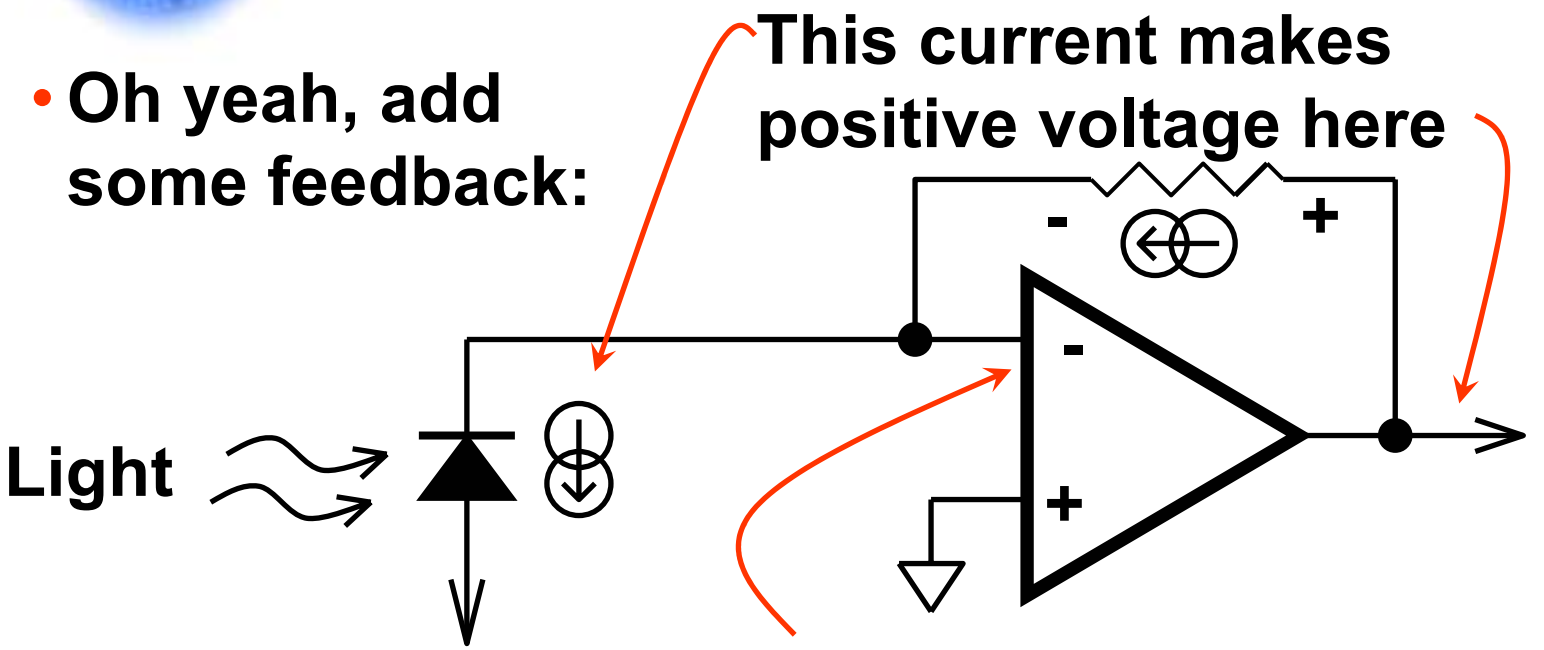
The Photodiode Amplifier:

- Oh yeah, add some feedback:



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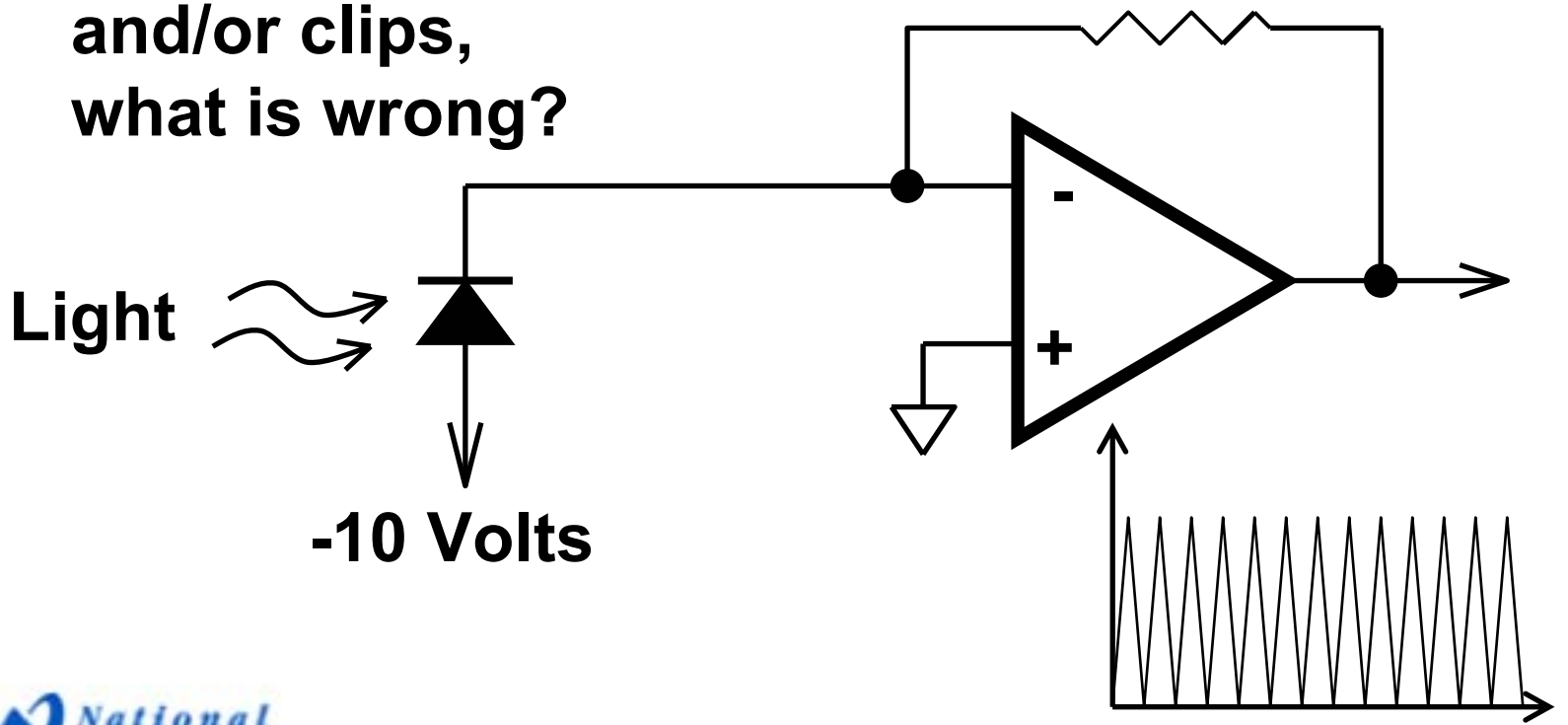
The Photodiode Amplifier:

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



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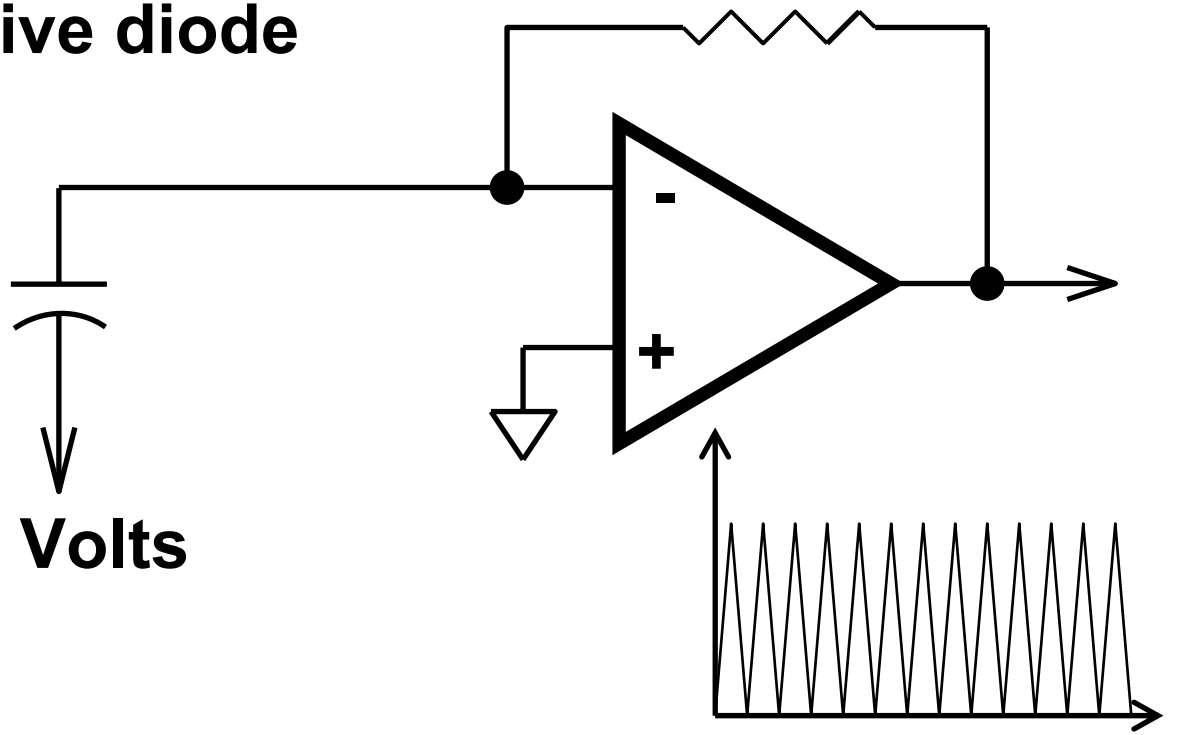
Amplifier Stability:

- Oscillations caused by capacitive diode on input.



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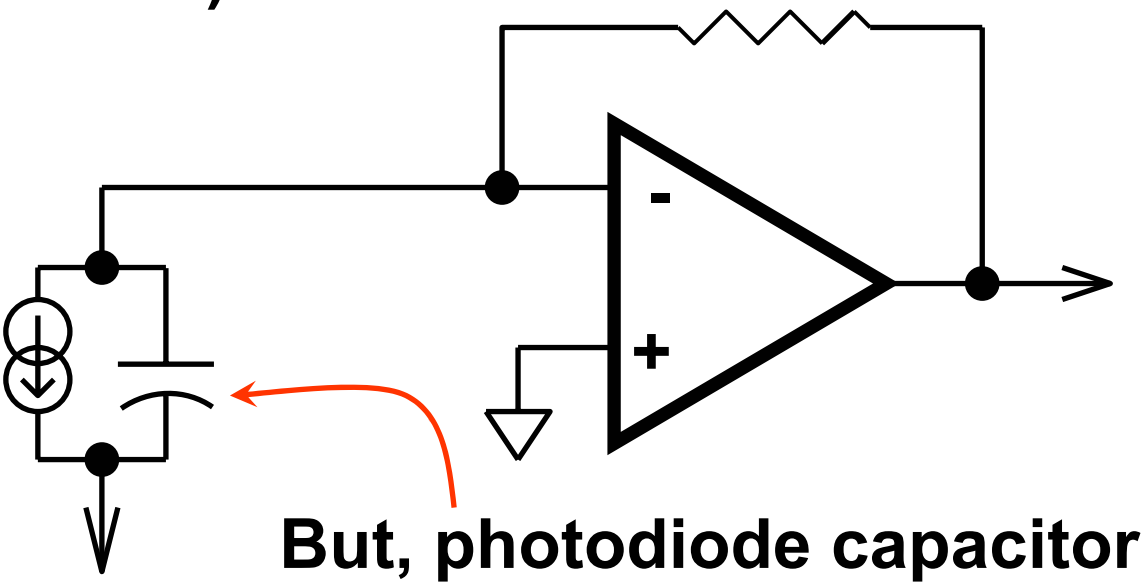
Amplifier Stability:

- 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.

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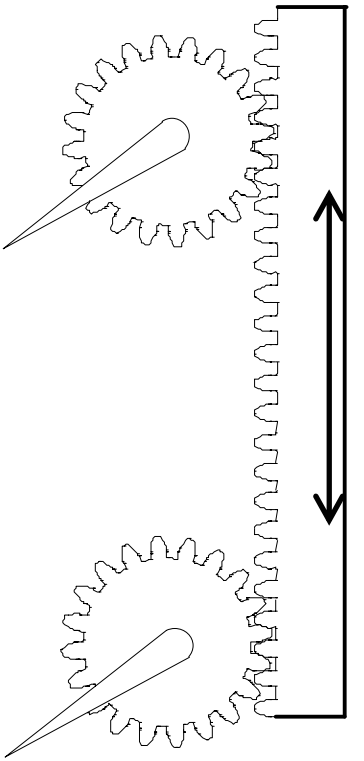
Mechanical Analogy:

- 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.

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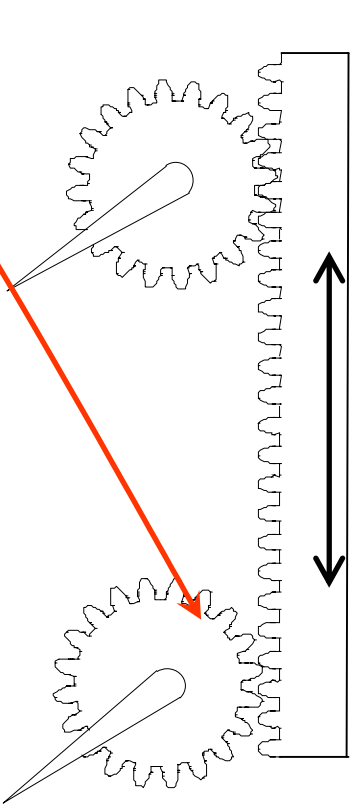
Mechanical Analogy:

- 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.



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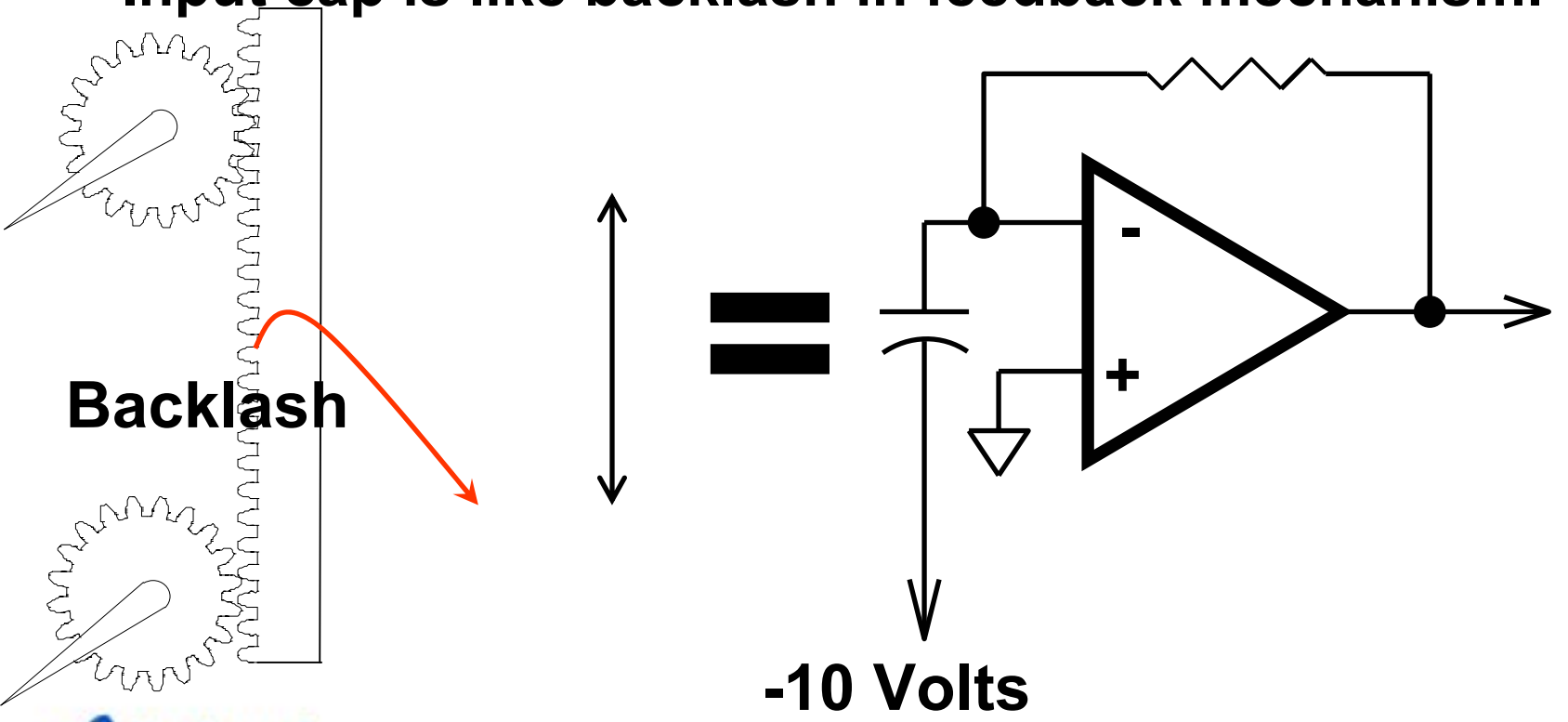
Mechanical Analogy:

- Input cap is like backlash in feedback mechanism.



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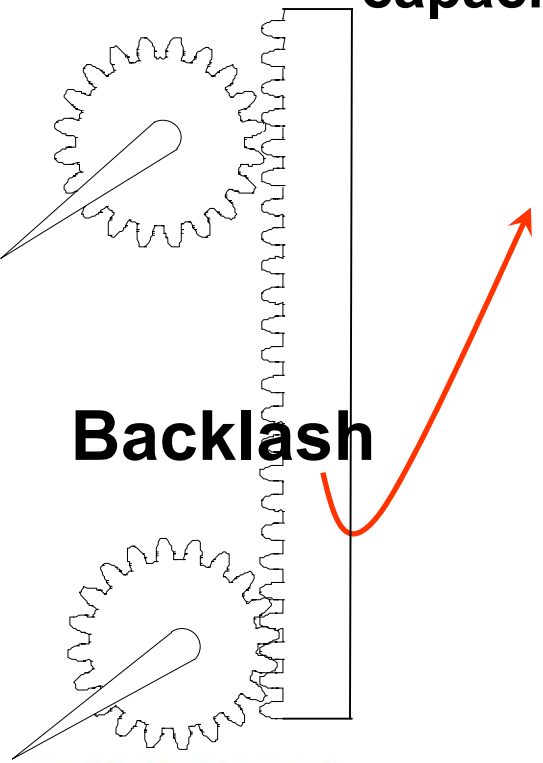
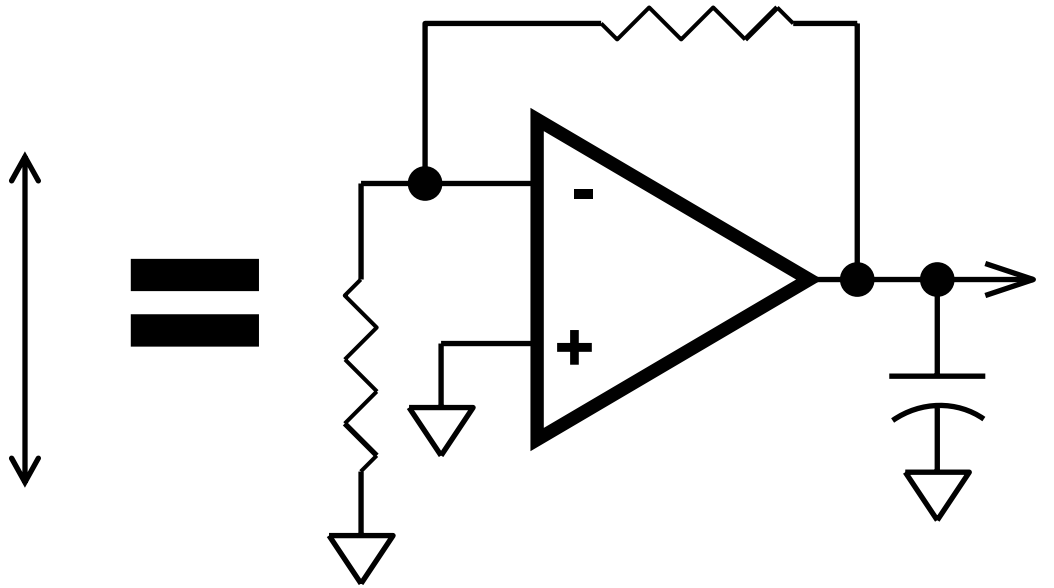
Mechanical Analogy:

- Interesting note: Driver backlash is like output capacitance.





Without compensation either cap will cause oscillations.

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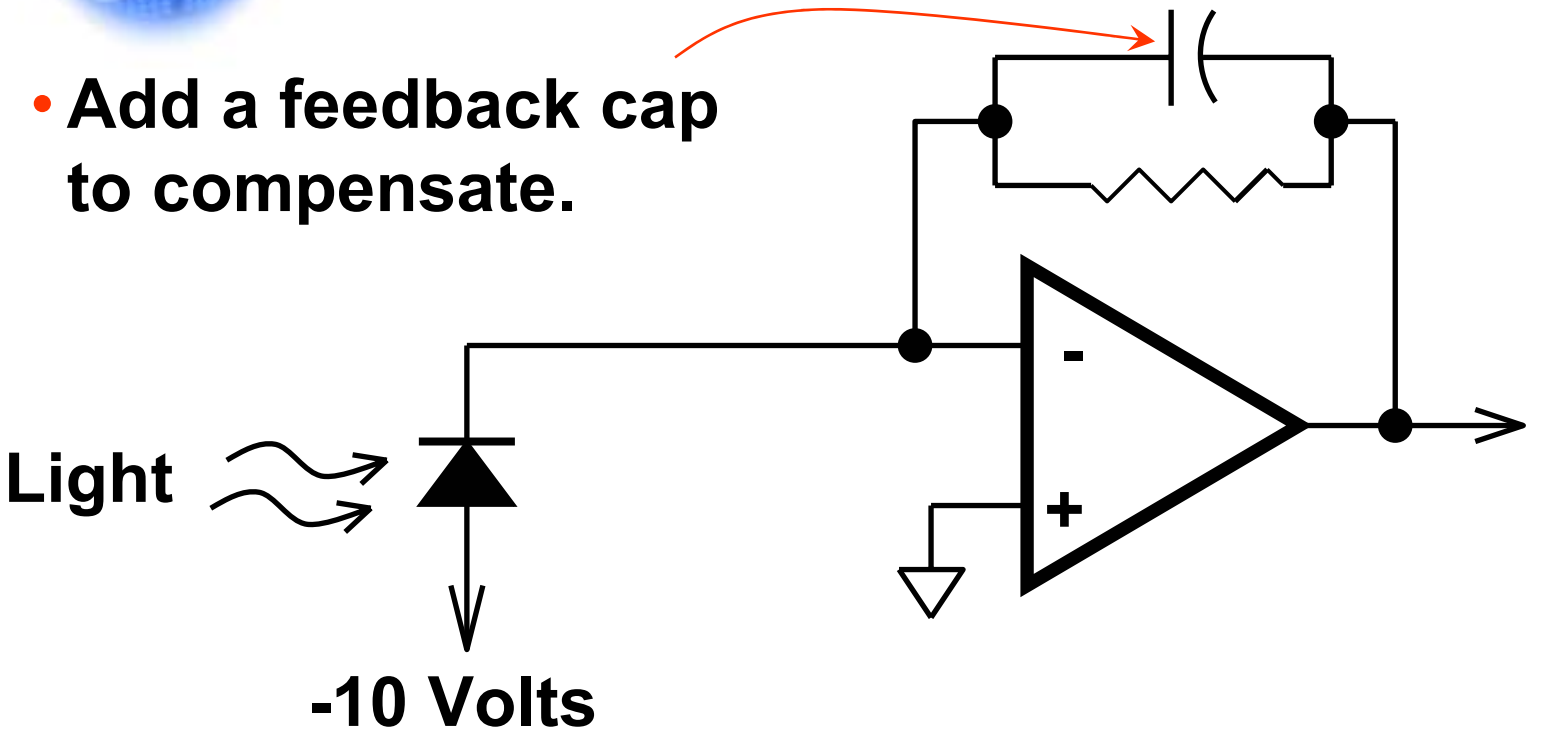
Compensated Amplifier:

- Add a feedback cap to compensate.



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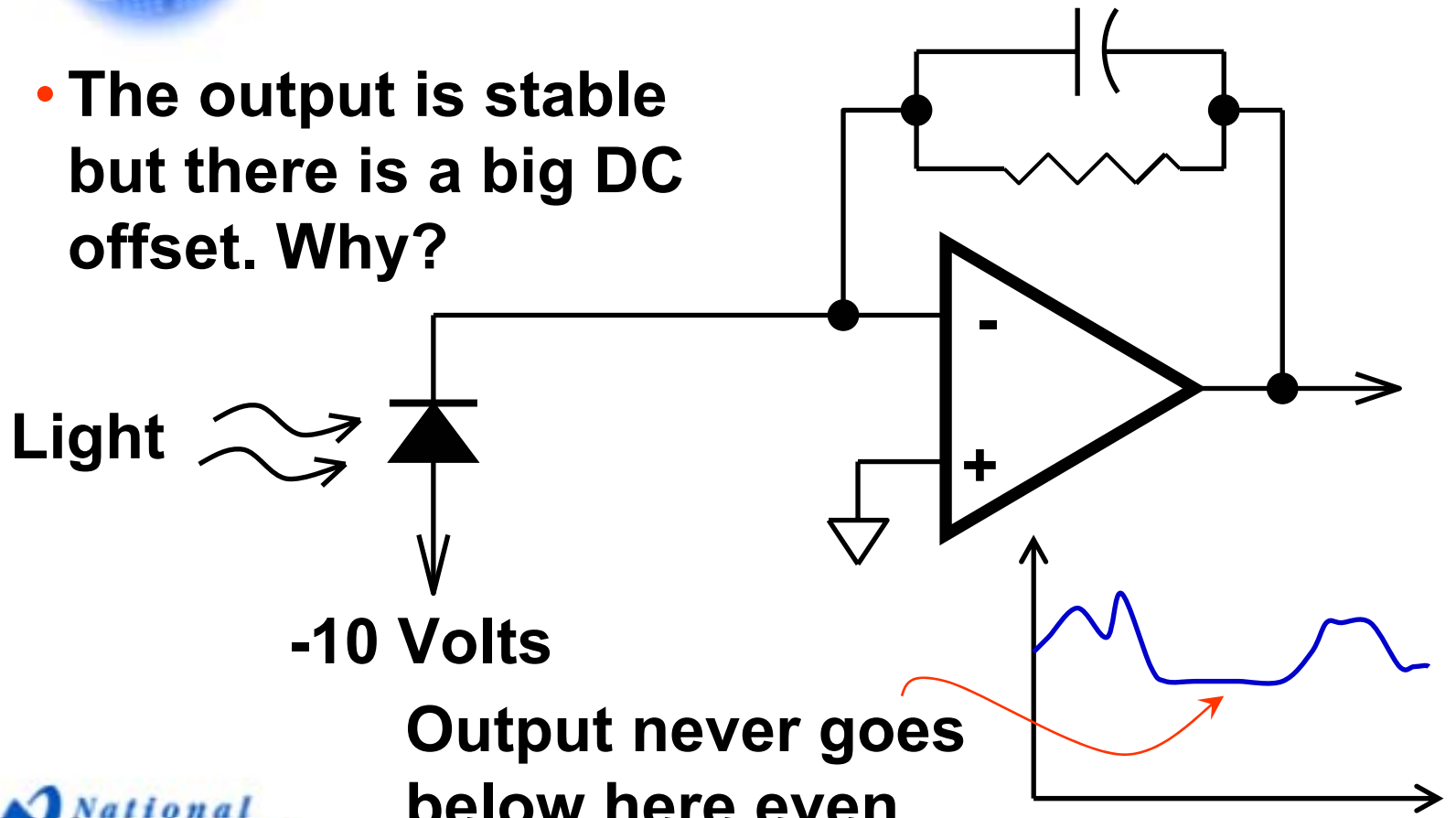
Biasing the Amplifier:

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



Output never goes below here even with no light.

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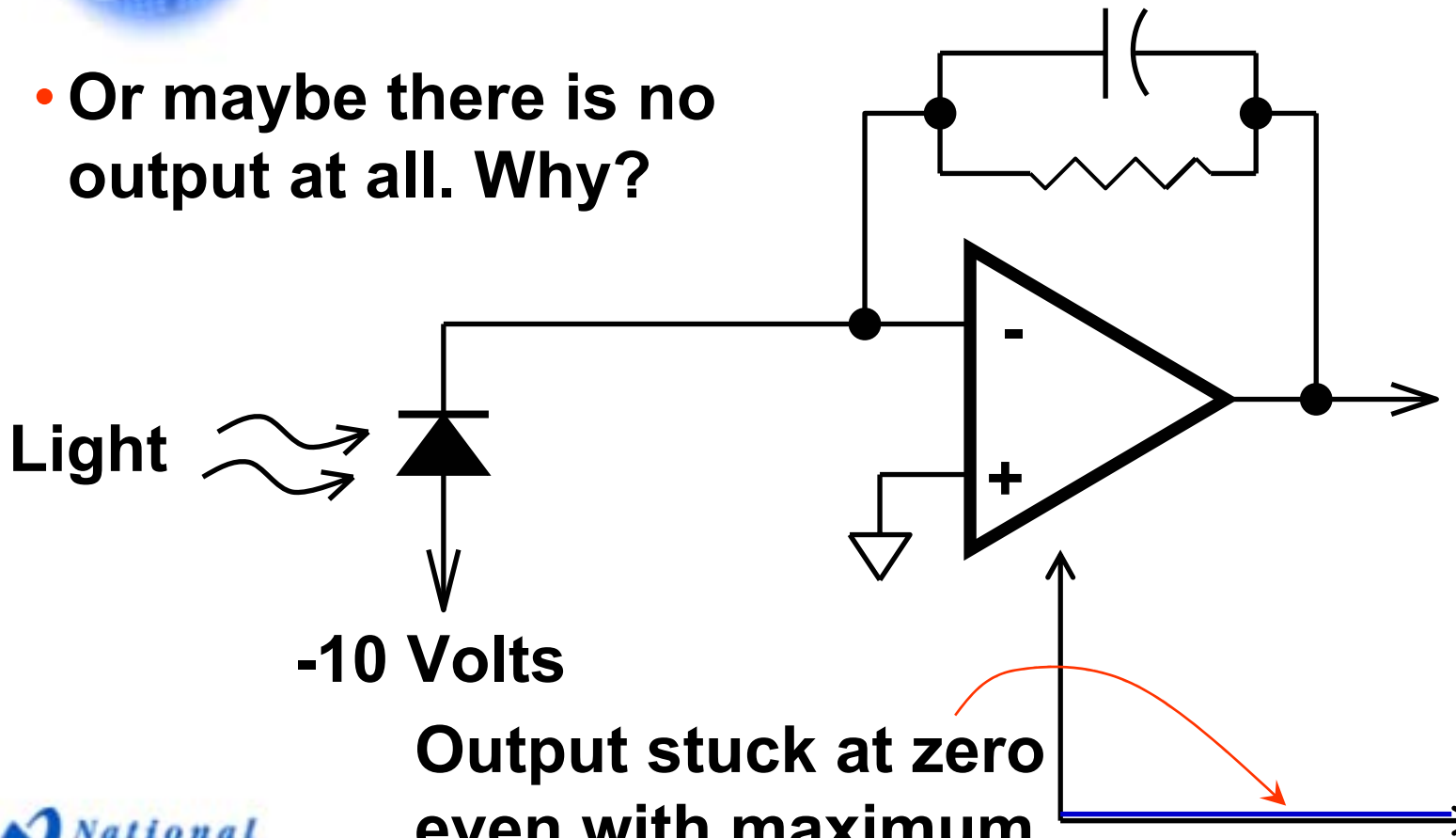
Biasing the Amplifier:

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



Output stuck at zero even with maximum light.

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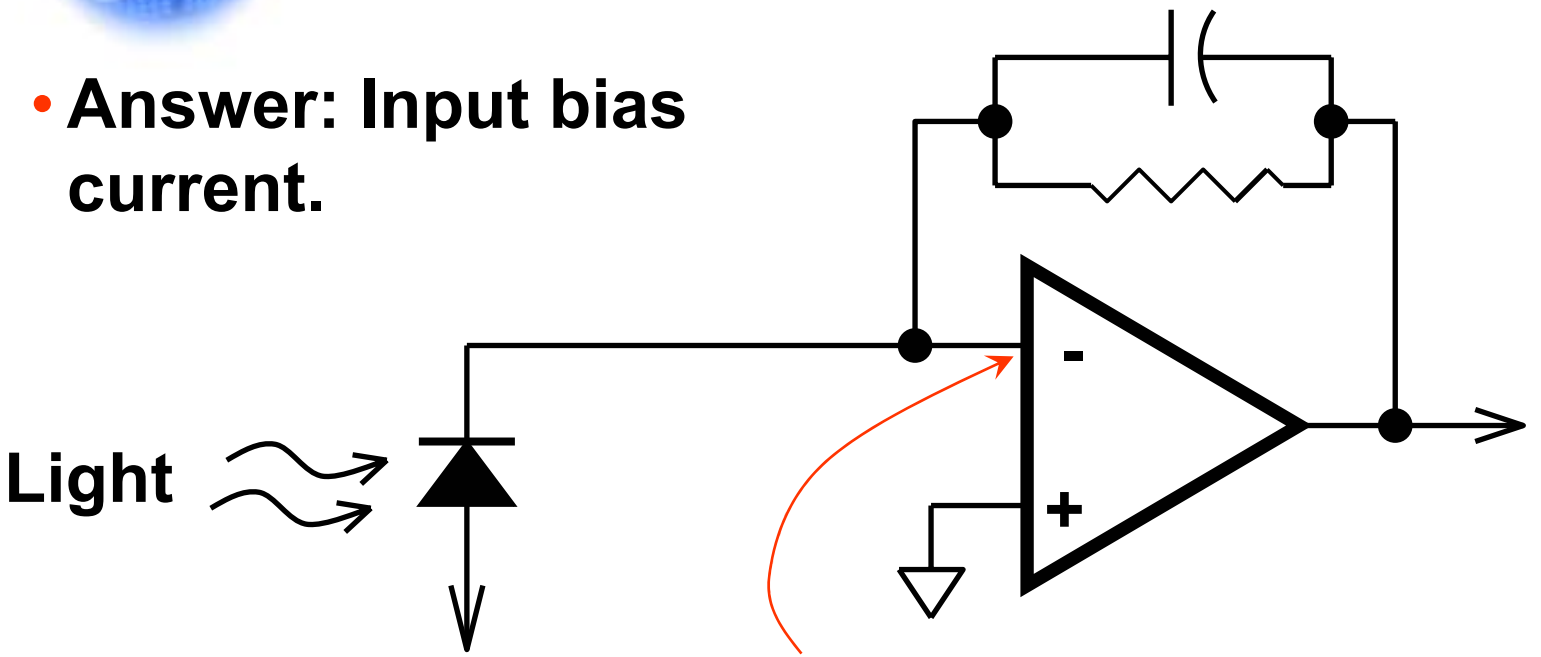
Biasing the Amplifier:

- Answer: Input bias current.



Input pins will have small currents in or out of the pin (bias current).

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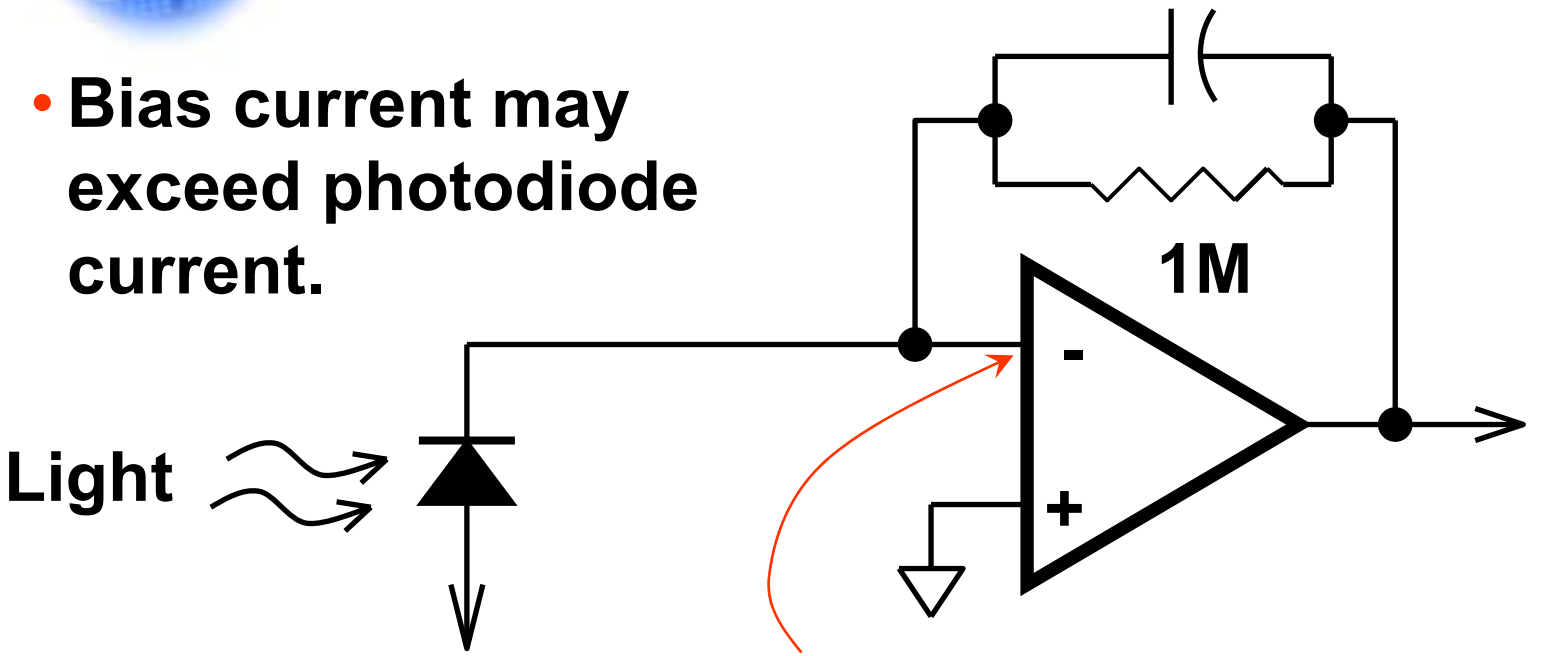
Biasing the Amplifier:

- Bias current may exceed photodiode current.



15uA out of this pin reacts against 1M feedback to try and put -15 volts on output.

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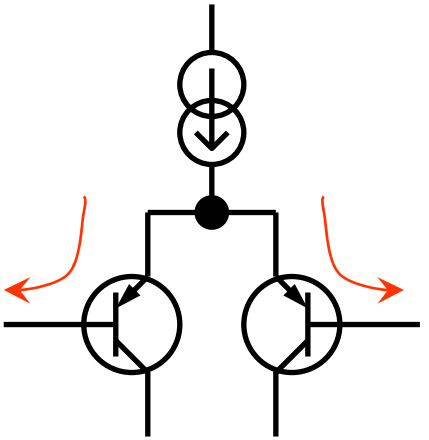
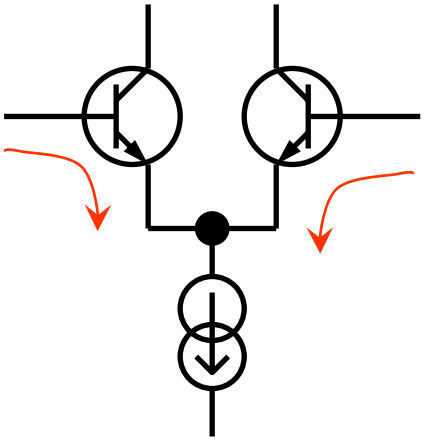
Amplifier Input Stage:

- 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

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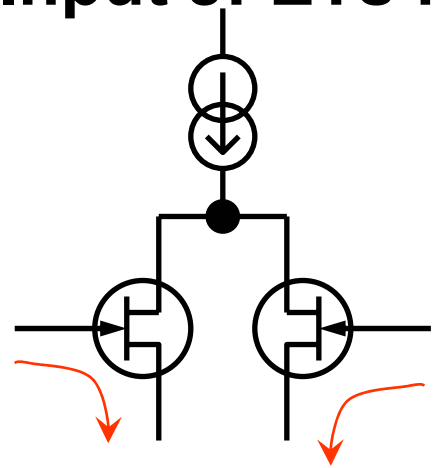
Amplifier Input Stage:

- Input JFETs have large drift.



JFET Input Stage

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

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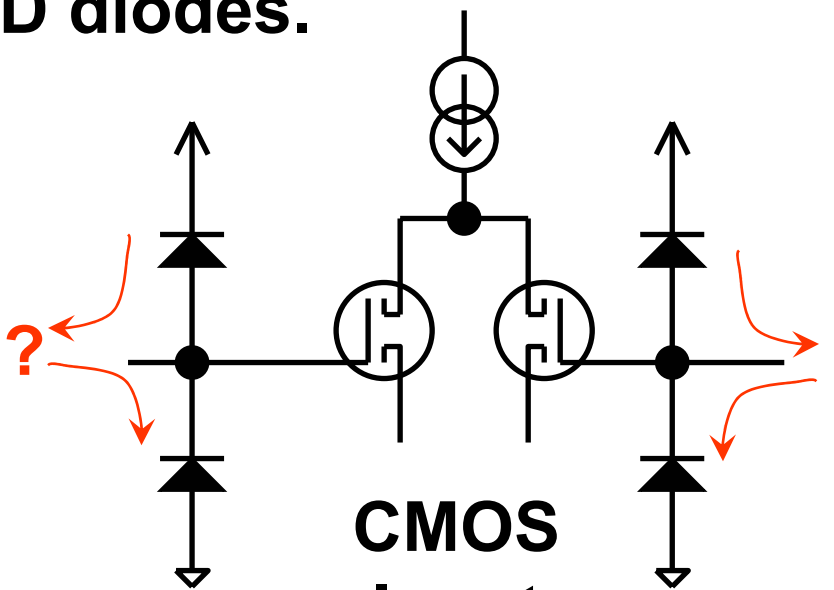
Amplifier Input Stage:

- 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.



CMOS Input Stage

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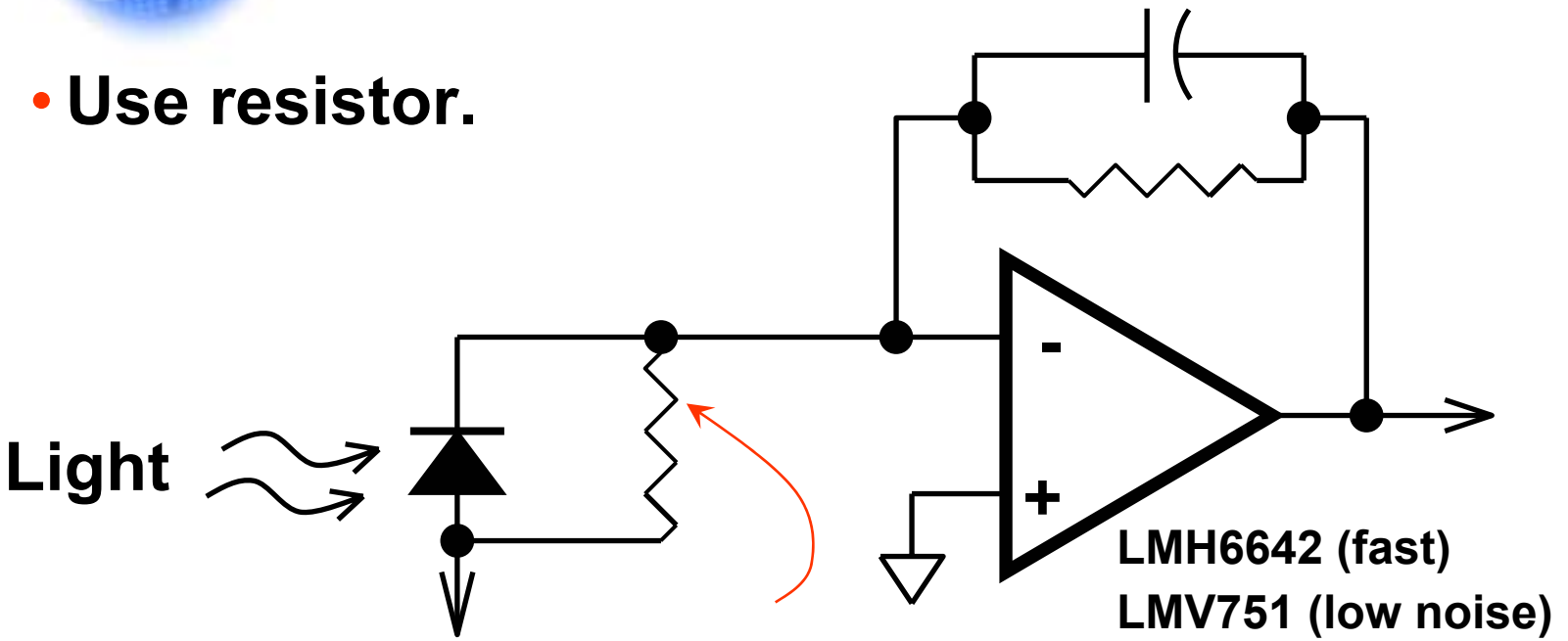
Correcting DC Bias

- Use resistor.



Add resistor to compensate for bias current.

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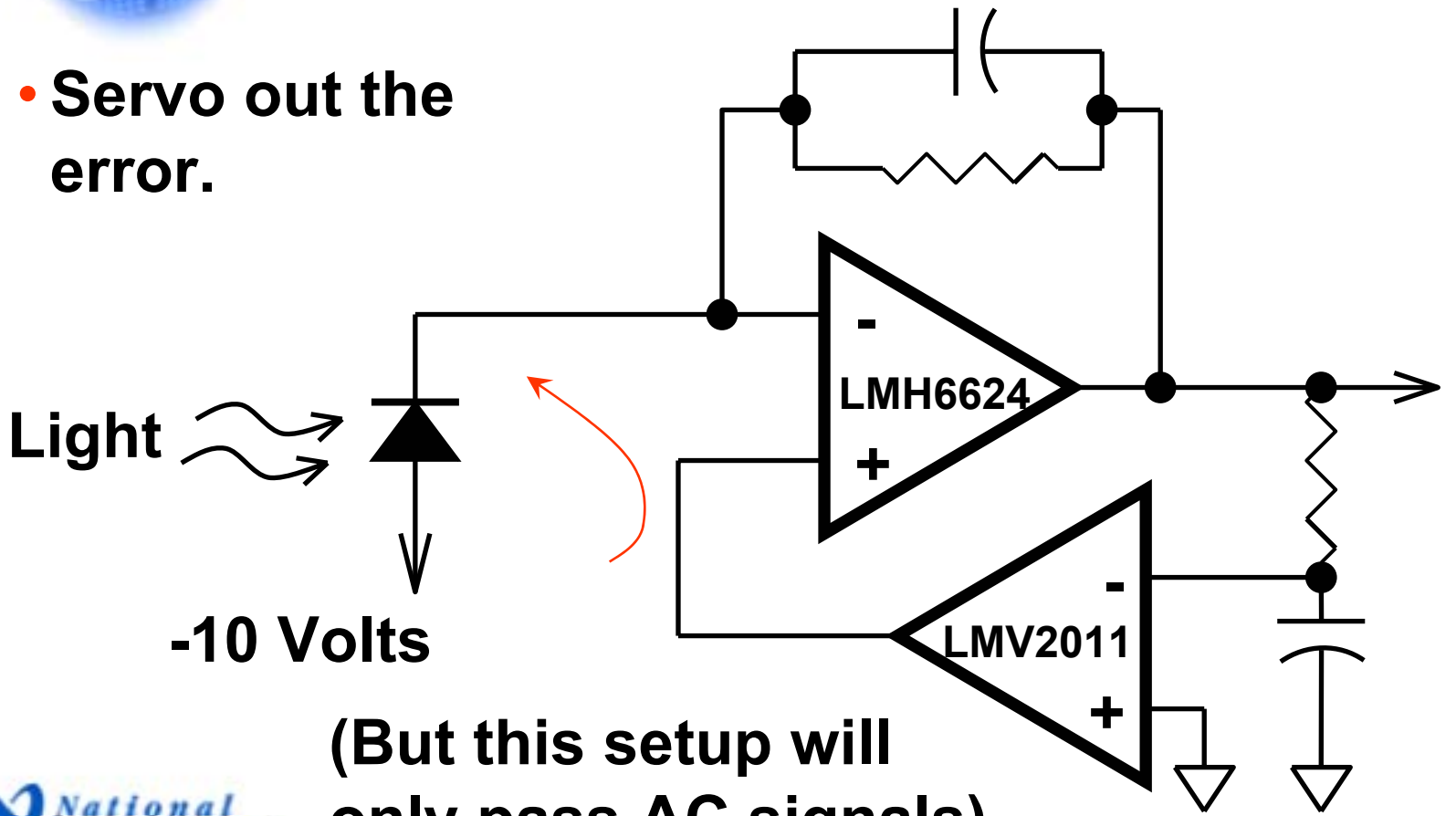
Correcting DC Bias

- Servo out the error.



(But this setup will only pass AC signals)

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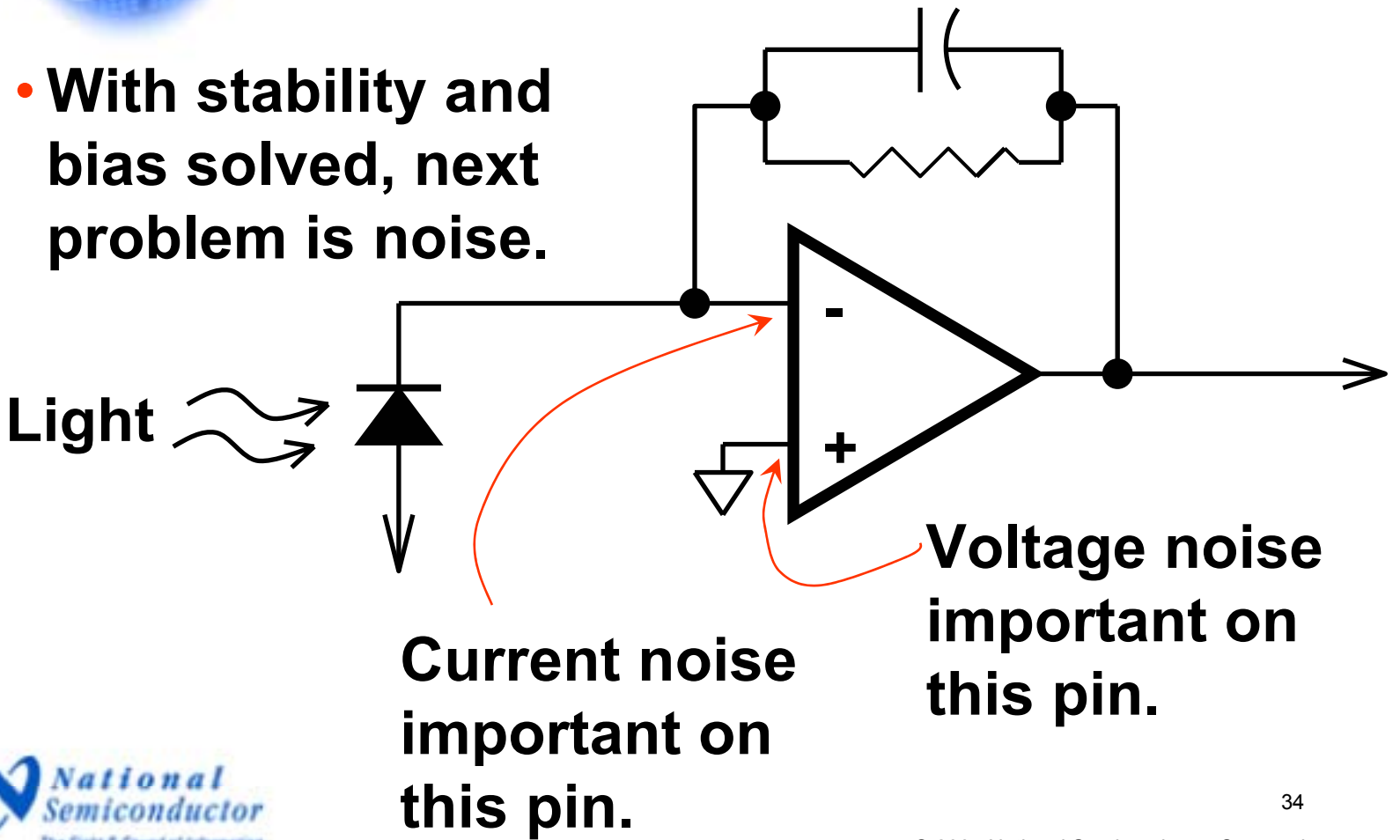
Amplifier noise:

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



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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.

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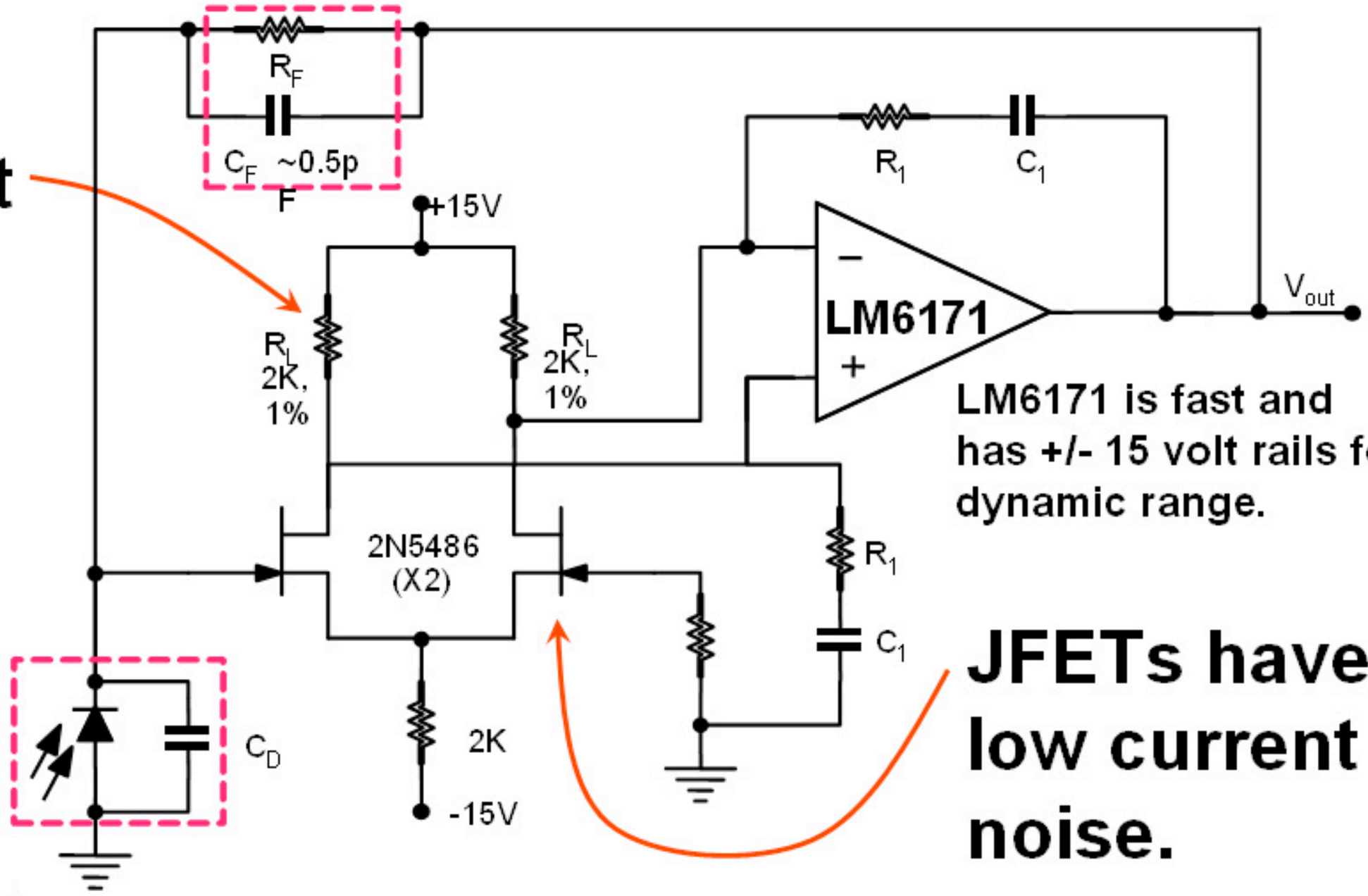
A Composite Amplifier:

- One solution: a compound amp.

Run a lot of current to reduce the voltage noise.



LM6171 is fast and has +/- 15 volt rails for dynamic range.

JFETs have low current noise.

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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

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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.

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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

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