Wroclaw University of Science and Technology

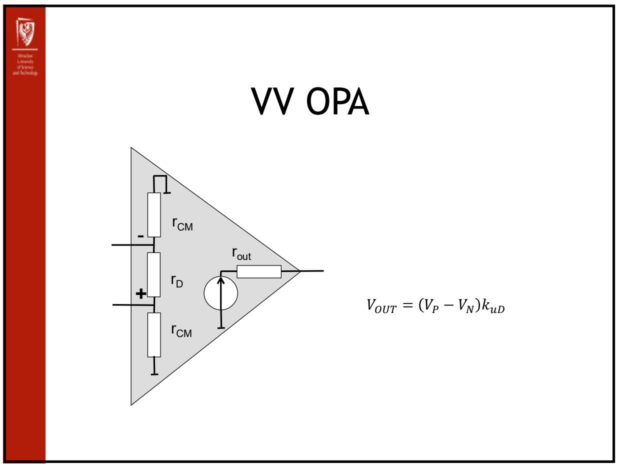
Front-end circuits

References:

- U. Tietze, Ch.Schenk, Electronics Circuits – Handbook for Design and Applications, Springer, 2008
- J.P. Bentley, Principles of mesurement system, Pearsosn Education, 4th ed.
- Application notes of:
  - Analog Devices,
  - Linear Technology (now AD)
  - Texas Instruments,
  - National Semiconductors (now TI)
  - Burr-Brown (now TI)
  - ON Semi (now with Fairchild Semiconductor)

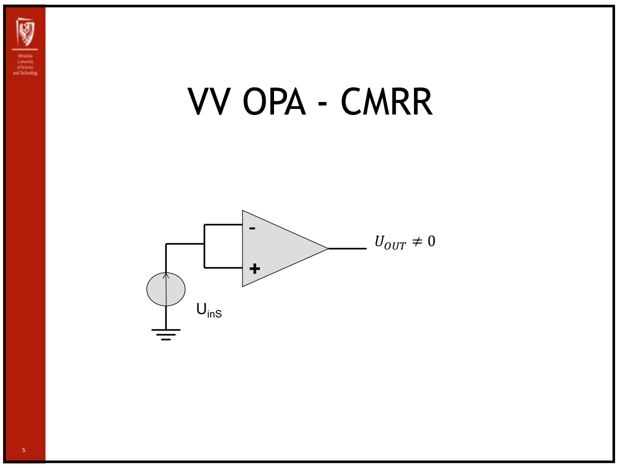
Outline:

- operational amplifier
  - VV- voltage/voltage amp – review
  - CV – current/voltage
  - VC – voltage/current
  - CC – current/current
- electrometer
- charge amplifier
- choppered amp and parametric modulation amp
- auto-zero amp



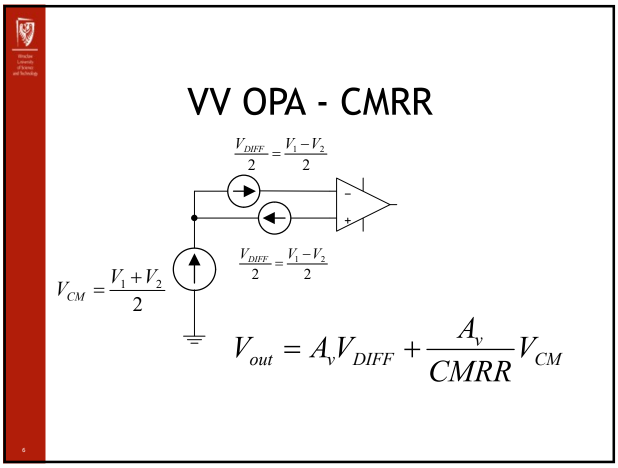
VV OPA

$$V_{OUT} = (V_P - V_N)k_{uD}$$



VV OPA - CMRR

$$U_{OUT} \neq 0$$



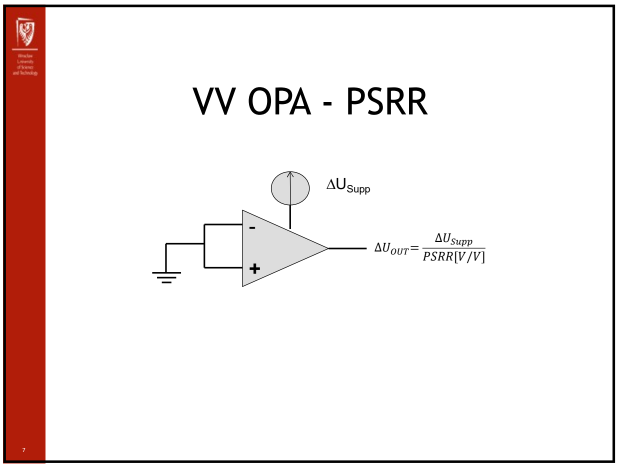
VV OPA - CMRR

$$\frac{V_{DIFF}}{2} = \frac{V_1 - V_2}{2}$$

$$\frac{V_{DIFF}}{2} = \frac{V_1 - V_2}{2}$$

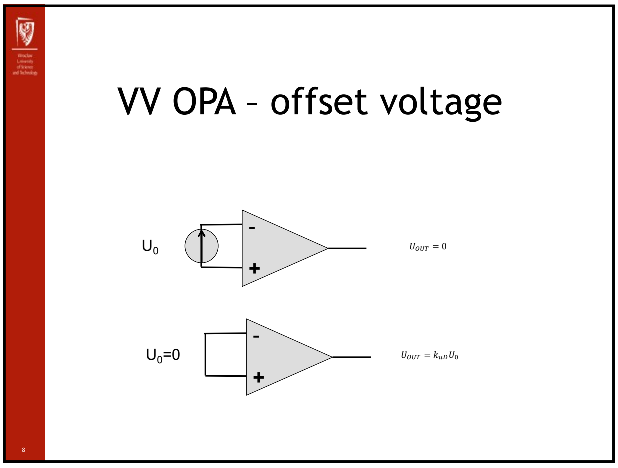
$$V_{CM} = \frac{V_1 + V_2}{2}$$

$$V_{out} = A_v V_{DIFF} + \frac{A_v}{CMRR} V_{CM}$$



VV OPA - PSRR

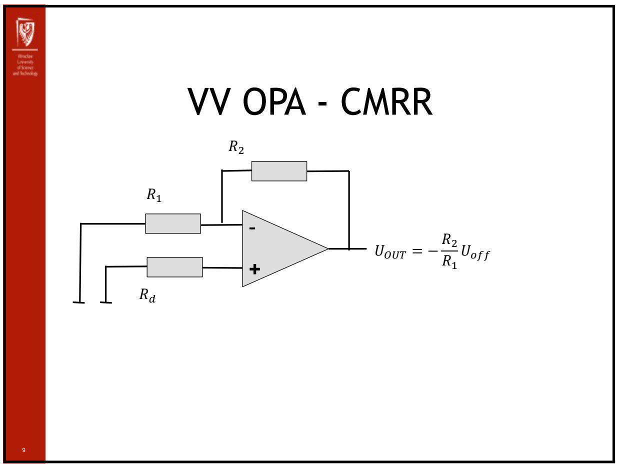
$$\Delta U_{OUT} = \frac{\Delta U_{Supp}}{PSRR[V/V]}$$



VV OPA – offset voltage

$U_{OUT} = 0$

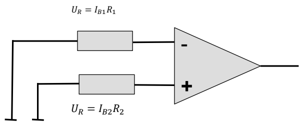
$U_{OUT} = k_{uD} U_0$



VV OPA - CMRR

$$U_{OUT} = -\frac{R_2}{R_1} U_{off}$$

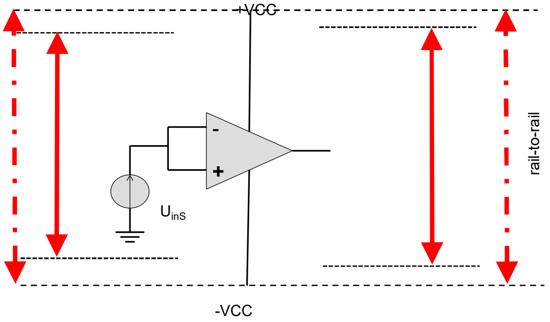
VV OPA – polarization/offset current

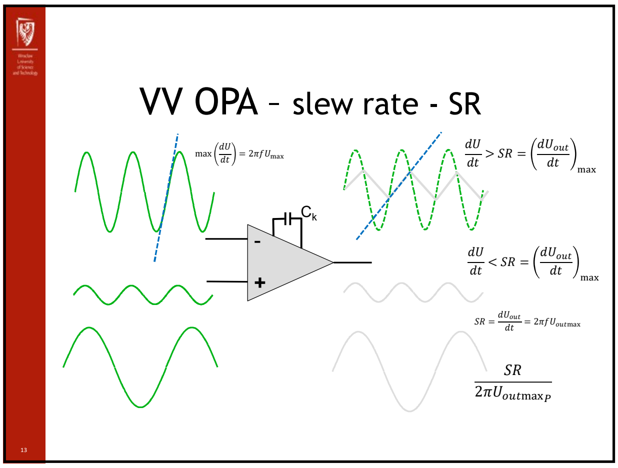


$$U_{off} = \frac{U_{OUT}}{k_{uD}} = (I_{B1}R_1 - I_{B2}R_2) \approx I_{Boff}R_{av} + I_B\Delta R$$

Offset of a system
Chalkboard

VV OPA – input/output voltage swing





VV OPA – slew rate - SR

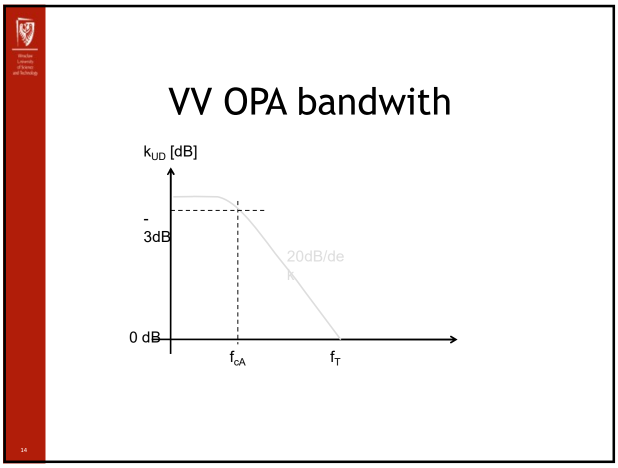
$\max\left(\frac{dU}{dt}\right) = 2\pi f U_{\max}$

$\frac{dU}{dt} > SR = \left(\frac{dU_{out}}{dt}\right)_{\max}$

$\frac{dU}{dt} < SR = \left(\frac{dU_{out}}{dt}\right)_{\max}$

$SR = \frac{dU_{out}}{dt} = 2\pi f U_{out\max}$

$\frac{SR}{2\pi U_{out\max_P}}$

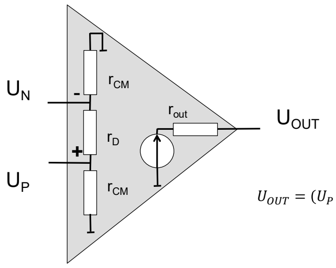


VV OPA bandwith

Basic parameters:

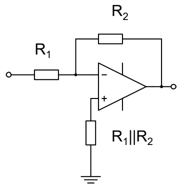
1. Offset
2. CMRR
3. PSRR
4. Output & Input swing
5. Bandwith

VV OPA



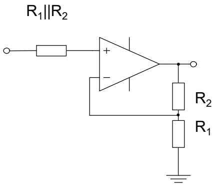
$U_{OUT} = (U_P - U_N)k_{uD}$

inverting amplifier



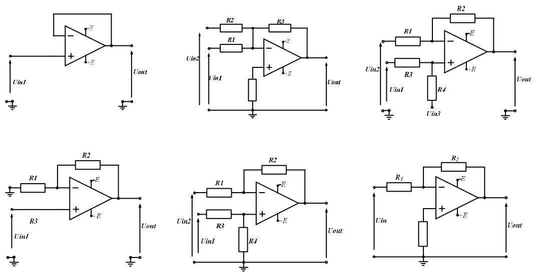
$K_u = \frac{U_{out}}{U_{in}} = -\frac{R_2}{R_1}$

Noninverted amplifier



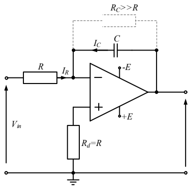
$K_u = \frac{U_{out}}{U_{in}} = 1 + \frac{R_2}{R_1}$

Numerical solutions



Calculations on the board

Integrator

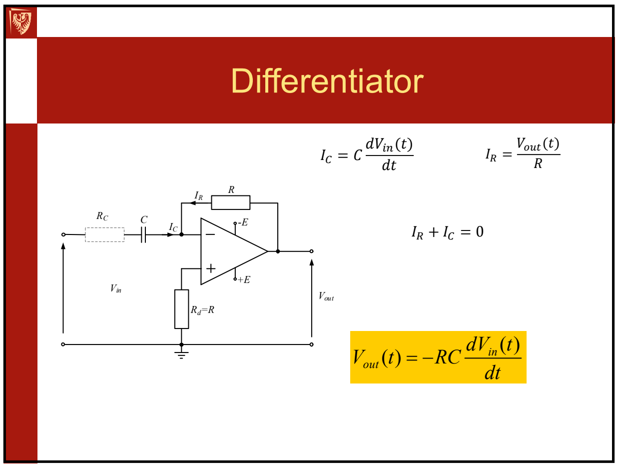


$$I_R = \frac{V_{in}(t)}{R} \qquad I_C = C\frac{dV_{out}(t)}{dt}$$

$$I_R + I_C = 0$$

$$V_{out}(t) = -\frac{1}{RC}\int V_{in}(t)dt + U_0$$

$$V_{out} = -\frac{V_{in}}{R_1 C}t + U_0$$

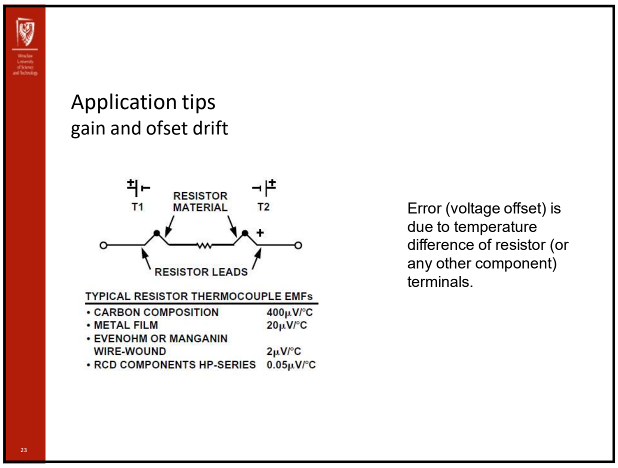


Differentiator

$$I_C = C\frac{dV_{in}(t)}{dt} \qquad I_R = \frac{V_{out}(t)}{R}$$

$$I_R + I_C = 0$$

$$V_{out}(t) = -RC\frac{dV_{in}(t)}{dt}$$

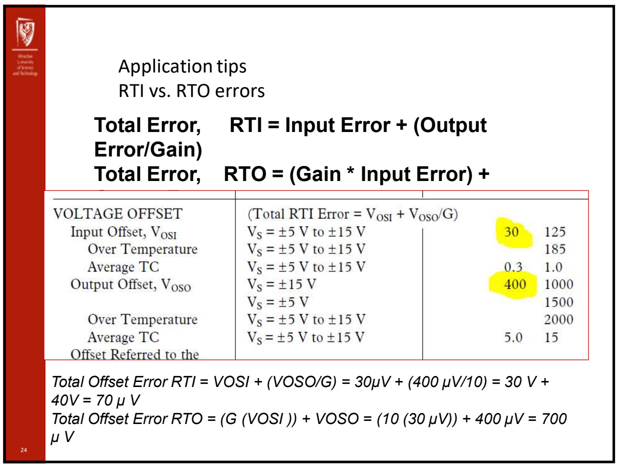


Application tips
gain and ofset drift

TYPICAL RESISTOR THERMOCOUPLE EMFs

• CARBON COMPOSITION	400µV/°C
• METAL FILM	20µV/°C
• EVENOHM OR MANGANIN WIRE-WOUND	2µV/°C
• RCD COMPONENTS HP-SERIES	0.05µV/°C

Error (voltage offset) is due to temperature difference of resistor (or any other component) terminals.



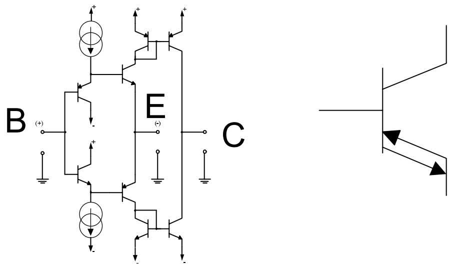
Application tips
RTI vs. RTO errors

Total Error, RTI = Input Error + (Output Error/Gain)
Total Error, RTO = (Gain * Input Error) +

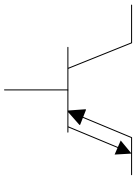
VOLTAGE OFFSET	(Total RTI Error = $V_{OSI} + V_{OSO}/G$)		
Input Offset, V_{OSI}	$V_S = \pm5$ V to ±15 V	30	125
Over Temperature	$V_S = \pm5$ V to ±15 V		185
Average TC	$V_S = \pm5$ V to ±15 V	0.3	1.0
Output Offset, V_{OSO}	$V_S = \pm15$ V	400	1000
	$V_S = \pm5$ V		1500
Over Temperature	$V_S = \pm5$ V to ±15 V		2000
Average TC	$V_S = \pm5$ V to ±15 V	5.0	15
Offset Referred to the			

Total Offset Error RTI = VOSI + (VOSO/G) = 30µV + (400 µV/10) = 30 V + 40V = 70 µ V
Total Offset Error RTO = (G (VOSI)) + VOSO = (10 (30 µV)) + 400 µV = 700 µ V

CC amplifier



CC – transistor like amplifier



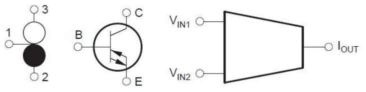
Transistor like:

- $I_C=I_E$
- R_{in} = very high (base)
- R_{out}= very high(collector)

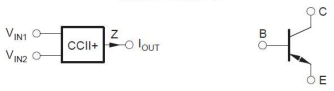
Differences:

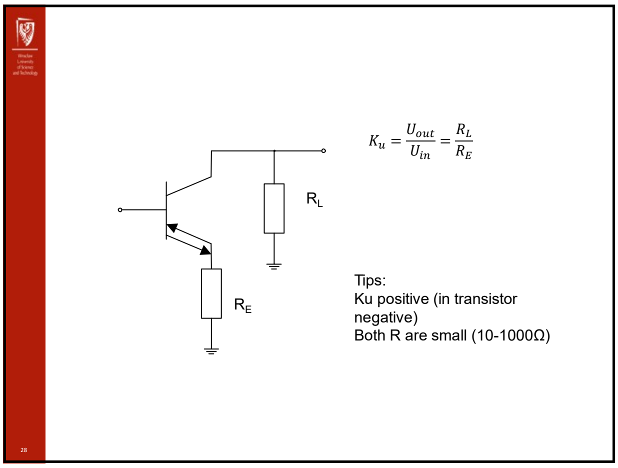
- quiescent point is set internally
- I_C is positive (source)
- $U_{BEQ}=0$ (and not 0.6V)
- I_C and I_B can be +/-

CC – alternative symbols and names



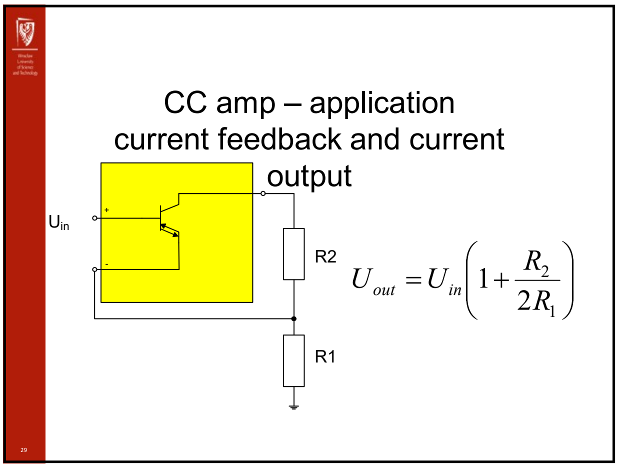
Diamond Transistor
Voltage−Controlled Current Source
Transconductor
Macro Transistor
Current Conveyor II+





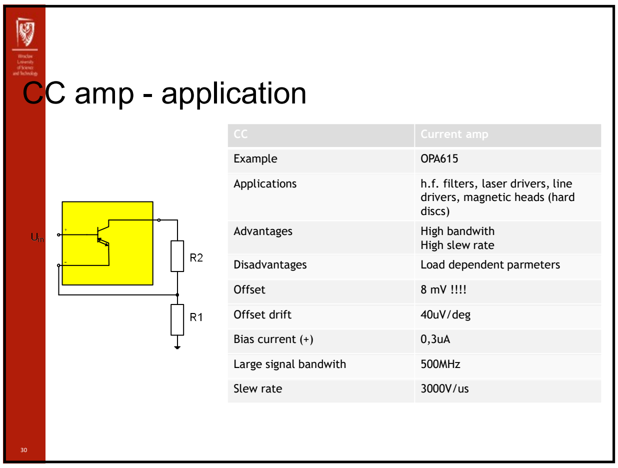
$$K_u = \frac{U_{out}}{U_{in}} = \frac{R_L}{R_E}$$

Tips:
Ku positive (in transistor negative)
Both R are small (10-1000Ω)



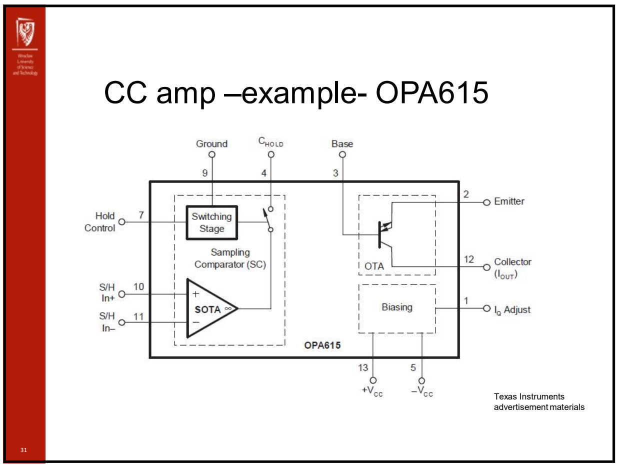
CC amp – application current feedback and current output

$$U_{out} = U_{in}\left(1 + \frac{R_2}{2R_1}\right)$$



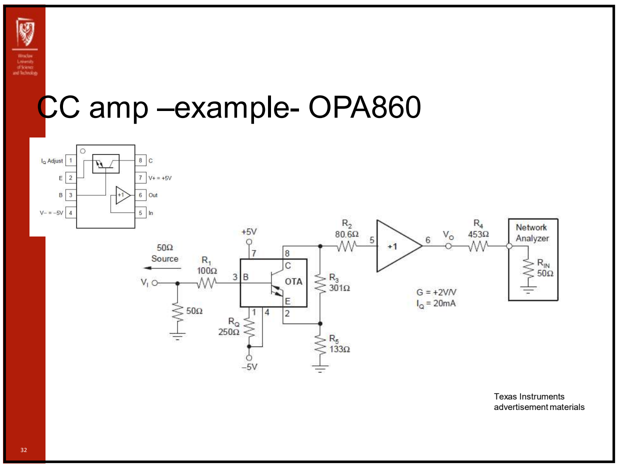
CC amp - application

CC	Current amp
Example	OPA615
Applications	h.f. filters, laser drivers, line drivers, magnetic heads (hard discs)
Advantages	High bandwith High slew rate
Disadvantages	Load dependent parmeters
Offset	8 mV !!!!
Offset drift	40uV/deg
Bias current (+)	0,3uA
Large signal bandwith	500MHz
Slew rate	3000V/us



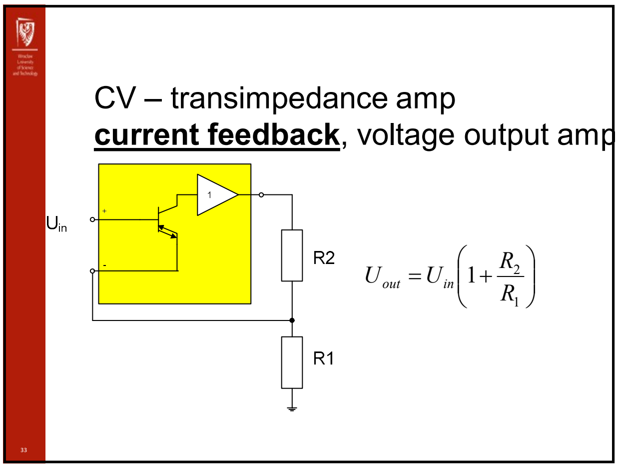
CC amp –example- OPA615

Texas Instruments advertisement materials



CC amp –example- OPA860

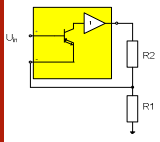
Texas Instruments advertisement materials



CV – transimpedance amp
current feedback, voltage output amp

$$U_{out} = U_{in}\left(1+\frac{R_2}{R_1}\right)$$

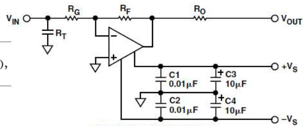
CV amp



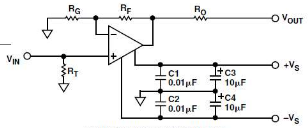
CV	Transimpedance amp
Example	AD8024
Applications	line drivers, LCD drivers, Sallen-Key active filter
Advantages	High bandwith High slew rate
Disadvantages	Can be unstable with C or L load
Offset	2 mV !!!!
Offset drift	2uV/deg
Bias current (+)	1uA
Large signal bandwith	350MHz
Slew rate	2400V/us

AD8011 current feedback amp

Gain	R_F (Ω)	R_G (Ω)	R_T (Ω)	Small Signal –3 dB BW (MHz), $V_S = \pm 5$ V
–1	1000	1000	52.3	150
–2	1000	499	54.9	130
–10	499	49.9		140
+1	1000		49.9	400
+2	1000	1000	49.9	250
+10	422	47.5	49.9	100
+6	1000	200	49.9	70
+6	500	100	49.9	170

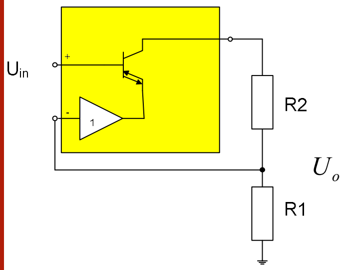


INVERTING CONFIGURATION



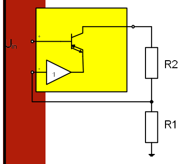
NONINVERTING CONFIGURATION

VC – transconductance amp voltage feedback current output



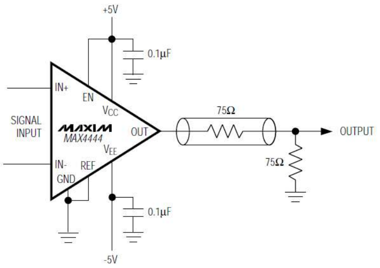
$$U_{out} = U_{in}\left(1+\frac{R_2}{R_1}\right)$$

VC – transconductance amp

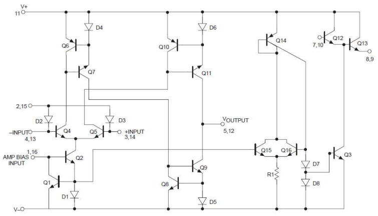


VC	Transconductance amplifier
Example	MAX4445
Applications	Capacitive load
Advantages	Low offset and drift Stable with C load
Disadvantages	Load dependent gain
Offset	15 mV !!!!
Offset drift	12uV/deg
Bias current (+)	10uA
Large signal bandwith	550MHz
Slew rate	5000V/us

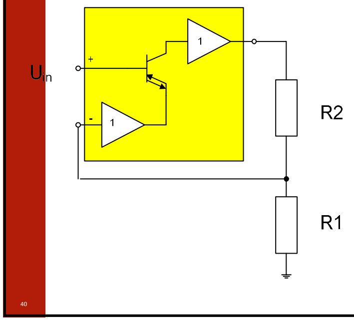
VC – transconductance amp



On the board explanation



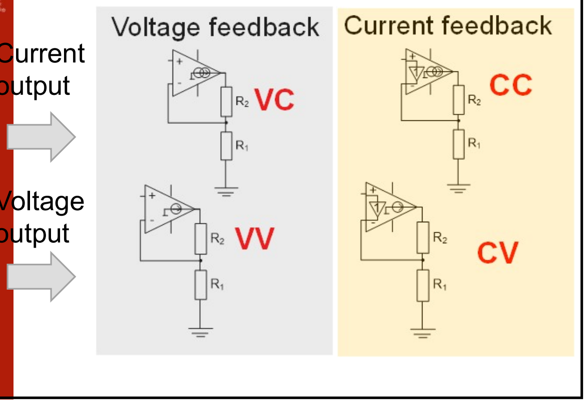
VV –traditional OPA



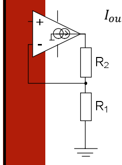
$$U_{out} = U_{in}\left(1 + \frac{R_2}{R_1}\right)$$

Current output

Voltage output

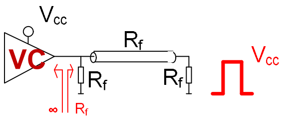


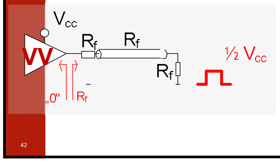
TRANSCONDUCTANCE AMP (VC)

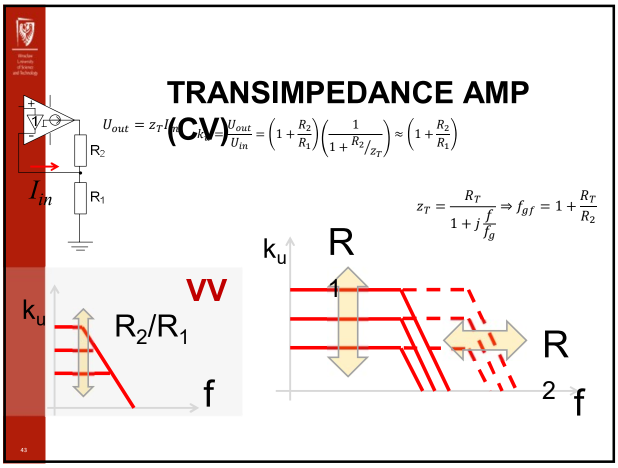


$$I_{out} = g_m\left(U_{in(+)} - U_{in(-)}\right)$$

$$k_u = \frac{U_{out}}{U_{in}} = \left(\frac{g_m R_L}{1 + g_m R_L \, {}^{R_1}/_{(R_1 + R_2)}}\right) \approx \left(1 + \frac{R_2}{R_1}\right)$$





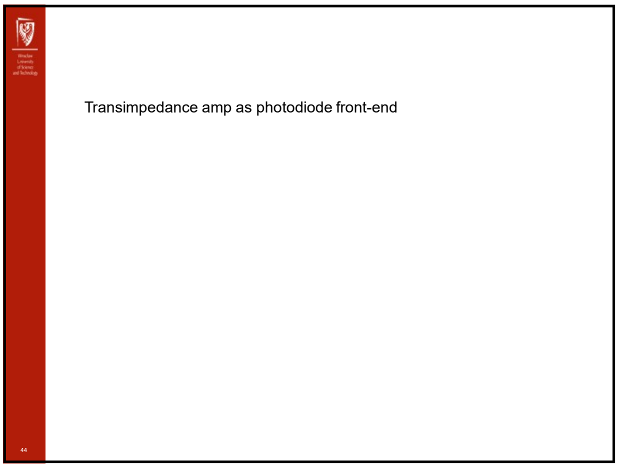


TRANSIMPEDANCE AMP (CV)

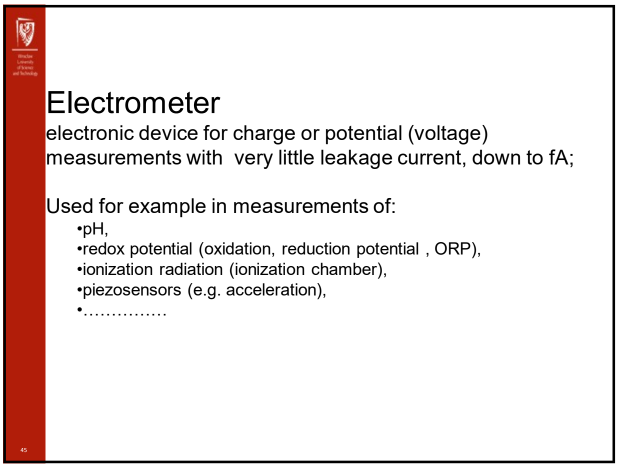
$$U_{out} = z_T I_{in}$$

$$k_u = \frac{U_{out}}{U_{in}} = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{1}{1 + {R_2}/{z_T}}\right) \approx \left(1 + \frac{R_2}{R_1}\right)$$

$$z_T = \frac{R_T}{1 + j\frac{f}{f_g}} \Rightarrow f_{gf} = 1 + \frac{R_T}{R_2}$$



Transimpedance amp as photodiode front-end



Electrometer

electronic device for charge or potential (voltage) measurements with very little leakage current, down to fA;

Used for example in measurements of:

- pH,
- redox potential (oxidation, reduction potential , ORP),
- ionization radiation (ionization chamber),
- piezosensors (e.g. acceleration),
- ……………

Types of electrometers:

Valve electrometer – use a special tube of leakage of fA;

Solid state – with FET/MOSFET transistors;

Vibrating capacitor –(„parametric modulation”)

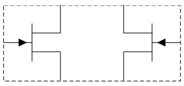
Electrometer problems:

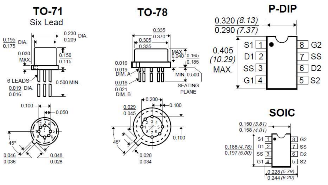
Use of GΩ resistors (Vishay)

Surface leakage (PCB on teflon, glass, cleaning problems, drying),

Transistor/IC leakage,

High input inpedance

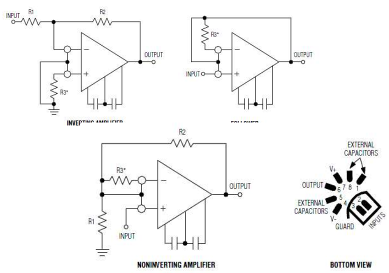




LS830 2 FET in common case:
I_G<80fA,En<70nV/Hz$^{1/2,}$ C<3pF

Single FET:
BF862 (3pA)
2N4416 (C<1pF)

Surface leakage solutions



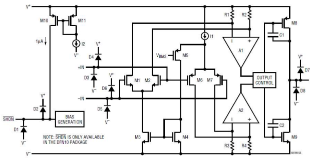
Intersil
advertisement materials

LTC6078/LTC6079 by Linear Technology

Maximum Offset Voltage of 25µV (25°C)
- Maximum Offset Drift of 0.7µV/°C
- Maximum Input Bias:

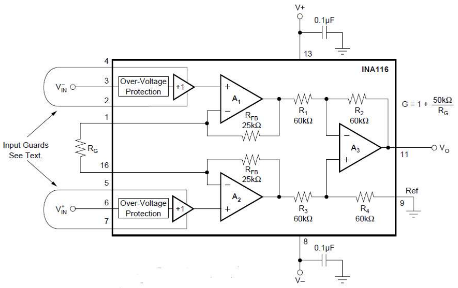
1pA (25°C)
50pA (≤85°C)
- Micropower: 54µA per Amp
- 95dB CMRR (Min)
- 100dB PSRR (Min)
- Input Noise Voltage Density: 16nV/√Hz
- Rail-to-Rail Inputs and Outputs
- 2.7V to 5.5V Operation Voltage
- LTC6078 Available in 8-Lead MSOP and 10-Lead DFN

Packages; LTC6079 Available in 16-Lead SSOP and
DFN Packages

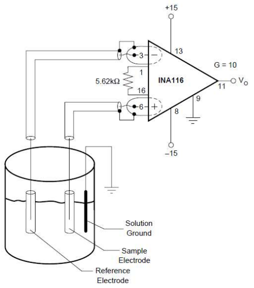


Linear Technology
advertisement materials

Driven Shield Inputs - example

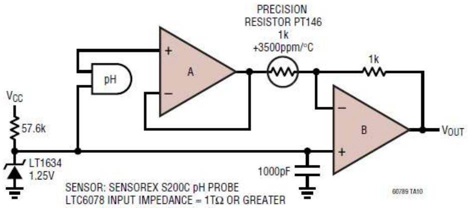


pH transducer



LTC6078/LTC6079 appllication example

pH Probe Amplifier



SENSOR: SENSOREX S200C pH PROBE
LTC6078 INPUT IMPEDANCE = 1TΩ OR GREATER
$V_{OUT} = 1.25V + 59.2mV \cdot (pH - 7)$
A, B: LTC6078

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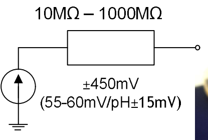
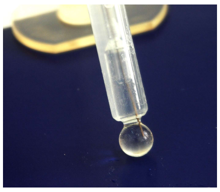
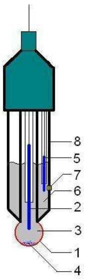
pH glass electrode construction

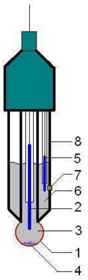




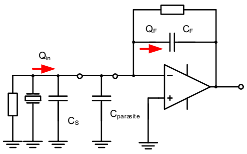


pH glass electrode construction

1.a sensing part of electrode, a bulb made from a specific glass
2.internal electrode, usually silver chloride electrode or calomel electrode
3.internal solution, usually a pH=7 buffered solution of 0.1 mol/L KCl for pH electrodes or 0.1 mol/L MeCl for pMe electrodes
4.when using the silver chloride electrode, a small amount of AgCl can precipitate inside the glass electrode
5.reference electrode, usually the same type as 2
6.reference internal solution, usually 0.1 mol/L KCl
7.junction with studied solution, usually made from ceramics or capillary with asbestos or quartz fiber.
8.body of electrode, made from non-conductive glass or plastics.



An idea of „charge amplifier”

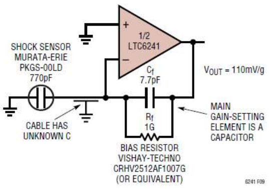


$$Q_{in} = Q_F$$
$$as\ V_+ = V_-$$

$$U_{out} = U_{CF} = \frac{Q_F}{C_F}$$

U_{out} is not depend on C_S nor $C_{parasite}$

LTC6241 „charge amplifier” (integrating amplifier)



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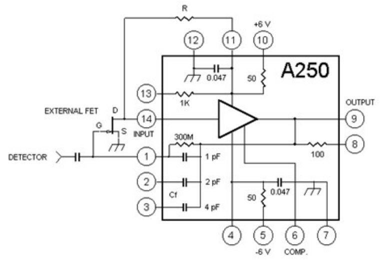
A250 Amptek charge amp



AMPTEC
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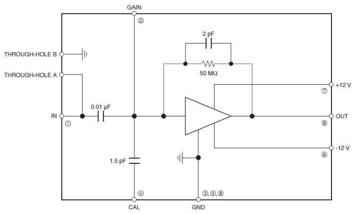
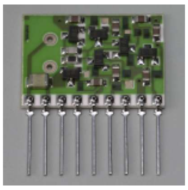
Hybrid charge amplifier





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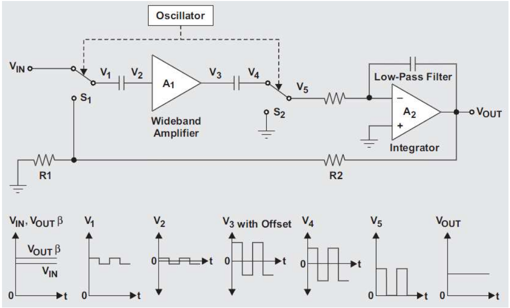
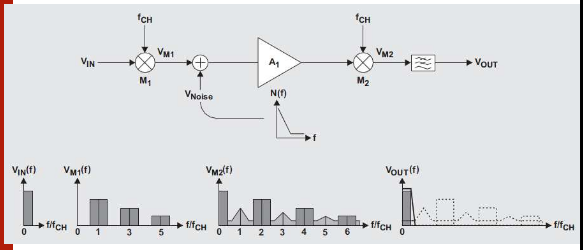
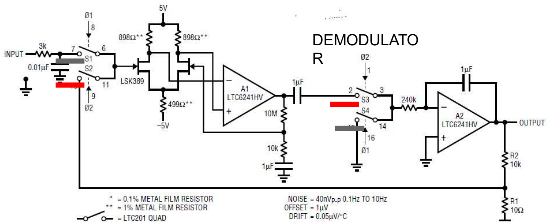
Example of charge amps

An idea of chopper amp



An idea of chopper amp in frequency domain





DEMODULATOR

* = 0.1% METAL FILM RESISTOR
** = 1% METAL FILM RESISTOR
= LTC201 QUAD
= LSK389
= LINEAR INTEGRATED SYSTEMS FREMONT, CA

NOISE = $40nV_{P-P}$ 0.1Hz TO 10Hz
OFFSET = 1µV
DRIFT = 0.05µV/°C
GAIN = $\frac{R2}{10}+1$
OPEN-LOOP GAIN = 10^9
I_{BIAS} = 500pA

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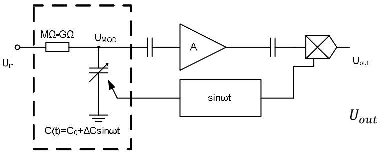
chopper amp drawbacks

- the amplifier has a single-ended, noninverting input and cannot accept differential signals without additional circuitry at the front end,
- the carrier-based approach constitutes a sampled data system, and overall amplifier bandwidth is limited to a small fraction of the chopper frequency,
- the chopper frequency is restricted by ac amplifier gain-phase limitations and errors induced by switch response time,
- keeping the effects of these considerations small the chopper frequencies are therefore in the low-kilohertz range, dictating low overall bandwidth.

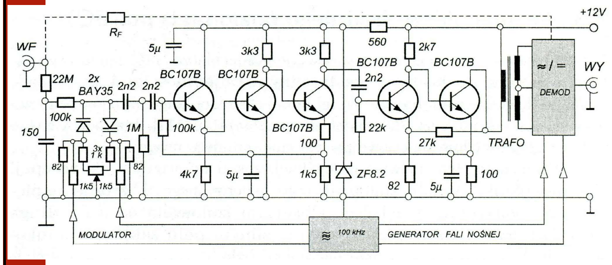
Parametric modulation



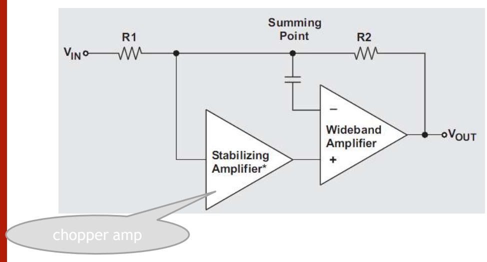
$$U_{out} \propto AU_{in}\frac{\Delta C}{C_0}$$

$$U_{MOD} = \frac{Q}{C} \approx \frac{C_0 U_{in}}{C_0 + \Delta C \sin\omega\, t} \approx \underbrace{U_{in}}_{DC} - \underbrace{U_{in}\frac{\Delta C}{C_0}\sin\omega\, t}_{AC}$$

Electrometer with parametric modulation



chopper -stabilized amp



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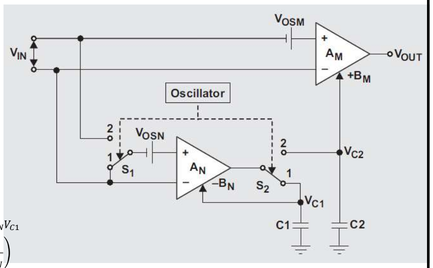
auto-zero amp



phase 1

$$V_{C1} = V_{OSN}\left(\frac{A_N}{1+B_N}\right)$$

phase 2

$$V_{C2} = A_N(V_{IN} + V_{OSN}) - B_N V_{C1}$$

$$V_{C2} = A_N\left(V_{IN} + \frac{V_{OSN}}{1+B_N}\right)$$

$$V_{OUT} = A_M(V_{IN} + V_{OSM}) + B_M V_{C2}$$

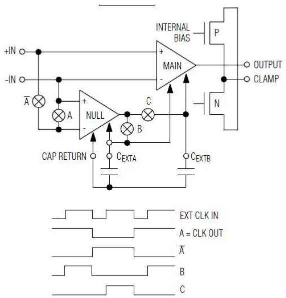
$$V_{OUT} = V_{IN}(A_M + A_N B_M) + V_{OSM}A_M + V_{OSN}\left(\frac{A_N B_M}{1+B_N}\right) = V_{IN}A_N B_M\left(1 + \frac{A_M}{A_N B_M} + V_{OSM}\frac{A_M}{A_N B_M} + V_{OSN}\frac{1}{1+B_N}\right)$$

$$V_{OUT} = V_{IN}(A_M + A_N B_M) + V_{OSM}A_M + V_{OSN}\left(\frac{A_N B_M}{1+B_N}\right) =$$

$$= V_{IN}A_N B_M\left(1 + \frac{A_M}{A_N B_M} + V_{OSM}\frac{A_M}{A_N B_M} + V_{OSN}\frac{1}{1+B_N}\right) \approx$$

$$= V_{IN}AB + A(V_{OSM} + V_{OSN}) = AB\left(V_{IN} + \frac{V_{OSM} + V_{OSN}}{B}\right)$$

ICL7650



Intersil (Maxim)
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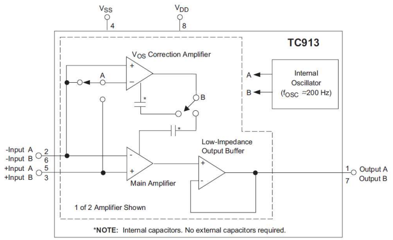
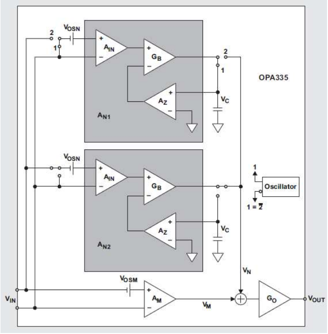
TC913



OPA335 wide band amp



Summary

- operational amplifier
  - ✓VV- voltage/voltage amp – review
  - ✓CV
  - ✓VC
  - ✓CC
- auto-zero amp
- electrometer
- charge amplifier
- choppered prametric modulation

Test questions:

1. The amplifier was designed for video signal using “current feedback amplifier”. What is wrong with it ? (fig.b) ?
2. What are the VV, CC, CV, VC op-amp ?
3. Name the main parametres of a OpAmp.
4. What are the main features of a transconductance and a transimpedance amplifier?
5. What is the concept of a charge amplifier ?
6. What is the concept of a chopper amplifier ?
7. What is the idea of a parametric modulation amp ?

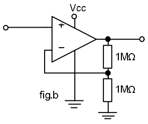


fig.b