# Front-end circuits

*Choose yourself and new technologies*

HUMAN CAPITAL

Wrocław University of Technology

Project co-financed from the EU European Social Fund

Wrocław University of Technology

Master programmes in English
at Wrocław University of Technology

## 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:
  - Linear Technology,
  - Analog Devices,
  - Texas Instruments,
  - National Semiconductors

HUMAN CAPITAL

Wrocław University of Technology

Project co-financed from the EU European Social Fund

Wrocław University of Technology

Master programmes in English
at Wrocław University of Technology

## outline

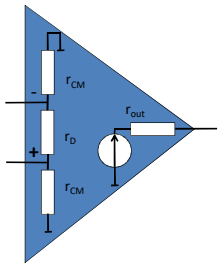
- operational amplifier
  - VV- voltage/voltage amp – review
  - CV – current/voltage
  - VC – voltage/current
  - CC – curent/current
- electrometer
- charge amplifier
- choppered amp and parametric modulation amp
- auto-zero amp

HUMAN CAPITAL

Wrocław University of Technology

Project co-financed from the EU European Social Fund

## VV OPA

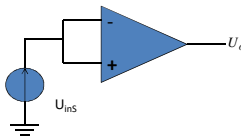



$$V_{OUT}=(V_P-V_N)k_{uD}$$





## VV OPA - CMRR

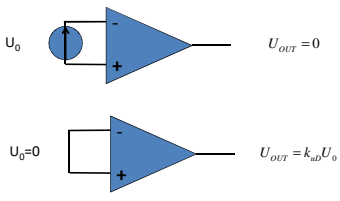



$$U_{OUT}=\frac{U_{inS}}{CMRR[V/V]}$$





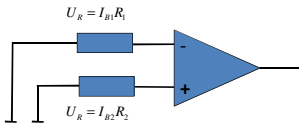
## VV OPA – offset voltage




$$U_{OUT}=0$$

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

## VV OPA – polarization/offset current




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



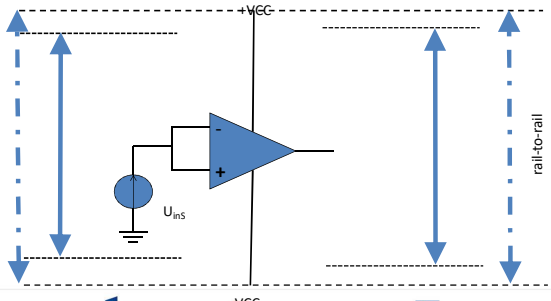
Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

## Offset of a system
## Chalkboard

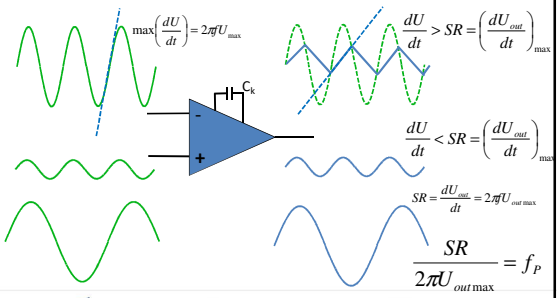


Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

## VV OPA – input/output voltage swing



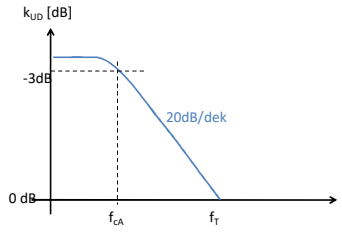
## VV OPA – slew rate - SR







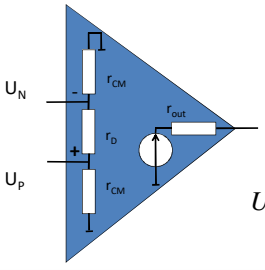

## VV OPA bandwith





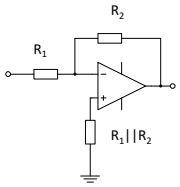



## VV OPA




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

## inverting amplifier

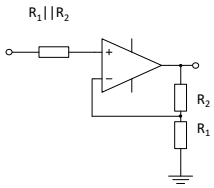



$$K_u = \frac{U_{out}}{U_{in}} = -\frac{R_2}{R_1}$$





## Noninverted amplifier

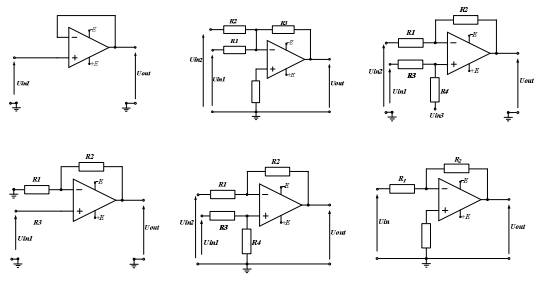



$$K_u = \frac{U_{out}}{U_{in}} = 1 + \frac{R_2}{R_1}$$





## Numerical solutions



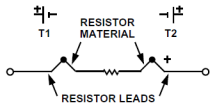
Calculations on the board



Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

## 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.

HUMAN CAPITAL
Wrocław University of Technology
Project co-financed from the EU European Social Fund

Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

### Application tips
### RTI vs. RTO errors

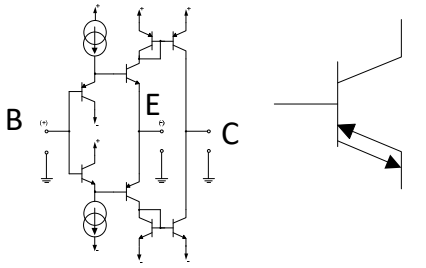
**Total Error, RTI = Input Error + (Output Error/Gain)**
**Total Error, RTO = (Gain * Input Error) + Output Error**

| | | | |
|---|---|---|---|
| VOLTAGE OFFSET | (Total RTI Error = $V_{OSI}$ + $V_{OSO}$/G) | | |
| Input Offset, $V_{OSI}$ | $V_S$ = ±5 V to ±15 V | 30 | 125 |
| Over Temperature | $V_S$ = ±5 V to ±15 V | | 185 |
| Average TC | $V_S$ = ±5 V to ±15 V | 0.3 | 1.0 |
| Output Offset, $V_{OSO}$ | $V_S$ = ±15 V | 400 | 1000 |
| | $V_S$ = ±5 V | | 1500 |
| Over Temperature | $V_S$ = ±5 V to ±15 V | | 2000 |
| Average TC | $V_S$ = ±5 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*

HUMAN CAPITAL
Wrocław University of Technology
Project co-financed from the EU European Social Fund

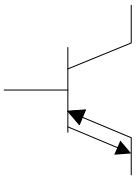
# CC amplifier








# CC – transistor like amplifier



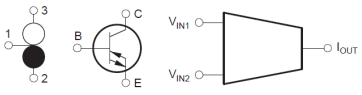
Transistor like:
- $I_C=I_E$
- $R_{in}$ = very high (base)
- $R_{out}$= very high(collector)

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 +/-

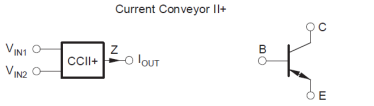


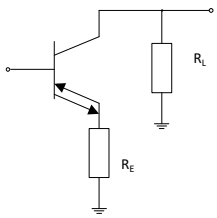


# CC – alternative symbols and names




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





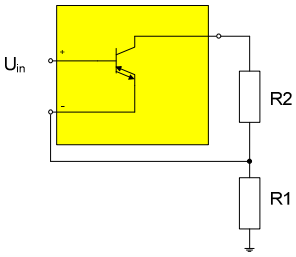

$$K_u = \frac{U_{out}}{U_{in}} = \frac{R_L}{R_E}$$

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





## CC amp – application current feedback and current output

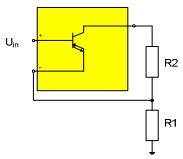



$$U_{out} = U_{in}\left(1 + \frac{R_2}{2R_1}\right)$$



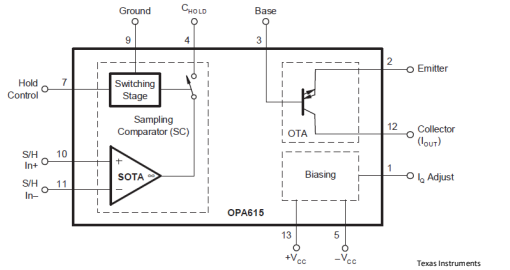


## CC amp - application




| CC | Current amp |
|---|---|
| Example | OPA615 |
| Applications | h.f. filters, laser drivers, line drivers, magnetic heads (hard discs) |
| Advantages | High bandwith<br>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

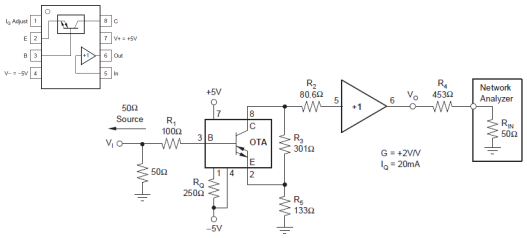



Texas Instruments advertisement materials





## CC amp –example- OPA860



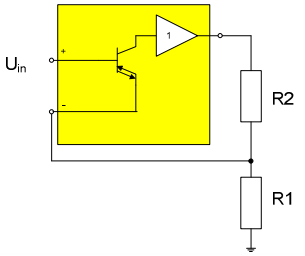

Texas Instruments advertisement materials





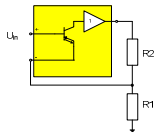
## CV – transimpedance amp

**<u>current feedback</u>**, voltage output amp




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

## CV amp



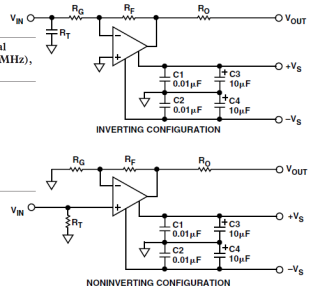

| CV | Transimpedance amp |
|---|---|
| Example | AD8024 |
| Applications | line drivers, LCD drivers, Sallen-Key active filter |
| Advantages | High bandwith<br>High slew rate |
| Disadvantages | Can be unstable with C or L load |
| Offset | 2 mV !!!! |
| Offset drift | 2uV/deg |
| Bias current (+)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





## AD8011 current feedback amp

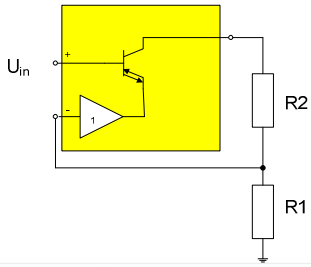
| Gain | $R_F$ (Ω) | $R_G$ (Ω) | $R_T$ (Ω) | Small Signal −3 dB BW (MHz), $V_S$ = ±5 V |
|---|---|---|---|---|
| −1 | 1000 | 1000 | 52.3 | 150 |
| −2 | 1000 | 499 | 54.9 | 130 |
| −10 | 499 | 49.9 | | 140 |
| +1 | 1000 | | 49.9 | 400 |
| +2 | 1000 | 1000 | 49.9 | 250 |
| +10 | 422 | 47.5 | 49.9 | 100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





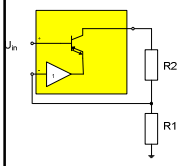



## VC – transconductance amp
## voltage feedback current output




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

## VC – transconductance amp

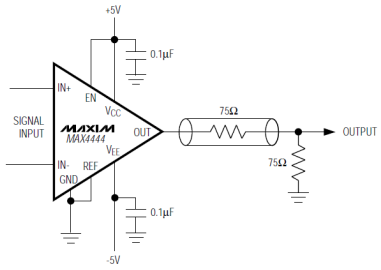



| VC | Transconductance amplifier |
|---|---|
| Example | MAX4445 |
| Applications | Capacitive load |
| Advantages | Low offset and drift<br>Stable with C load |
| Disadvantages | Load dependent gain |
| Offset | 15 mV !!!! |
| Offset drift | 12uV/deg |
| Bias current (+) | 10uA |
| Large signal bandwith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





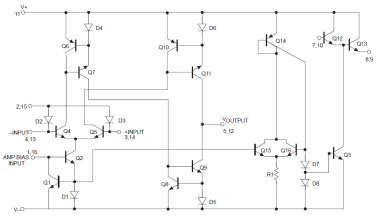
## VC – transconductance amp



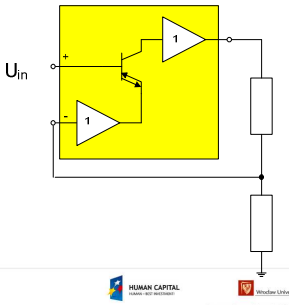





On the board explanation



## VV –traditional OPA



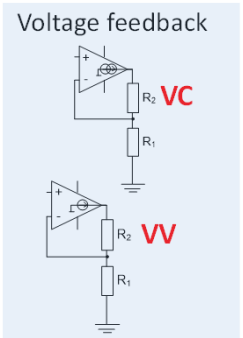

$$U_{out} = U_{in}\left(1+\frac{R_2}{R_1}\right)$$

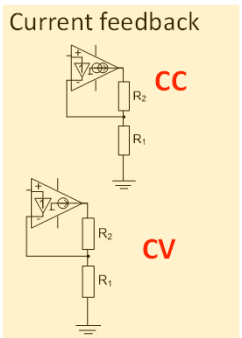




Current output

Voltage output

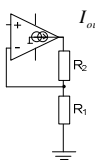




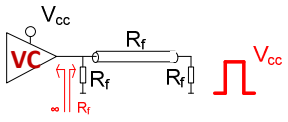


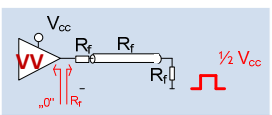

## TRANSCONDUCTANCE AMP (VC)



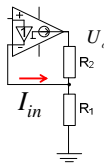

$$I_{out} = g_m\left(U_{in(+)} - U_{in(-)}\right)$$

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



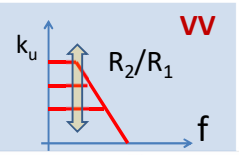
## TRANSIMPEDANCE AMP (CV)

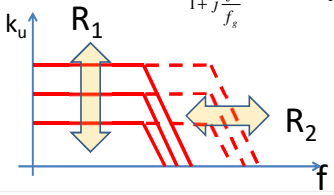



$$U_{out} = z_T I_{in}$$

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

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








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")



Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

## Electrometer problems:

Use of GΩ resistors (Vishay)

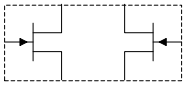
Surface leakage (PCB on teflon, glass, cleaning problems, drying),

Transistor/IC leakage,



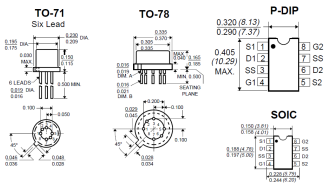
Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

## High input inpedance

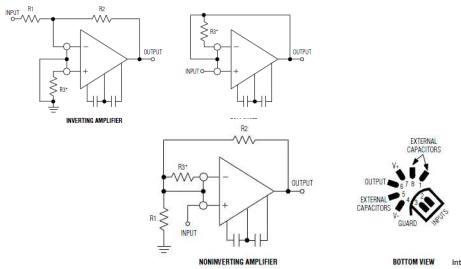


LS830 2 FET in common case:
$I_G$<80fA,En<70nV/Hz$^{1/2}$, C<3pF

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



## Surface leakage solutions



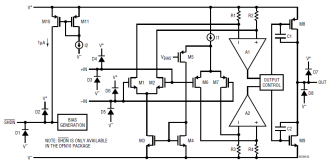

Intersil advertisement materials





## 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/√H:
■ 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

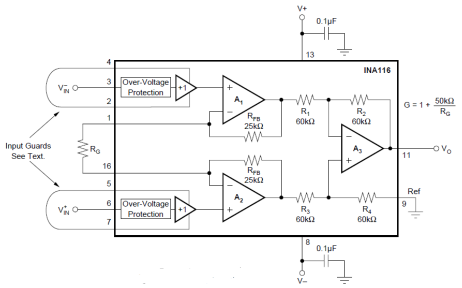


Linear Technology advertisement materials

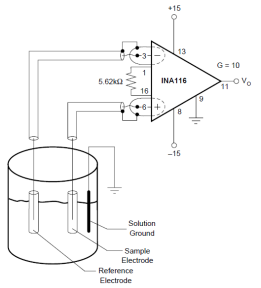




## Driven Shield Inputs - example



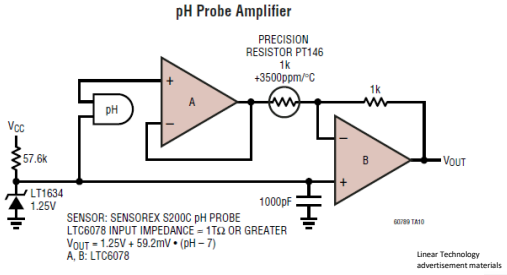
## pH transducer








## LTC6078/LTC6079 appllication example

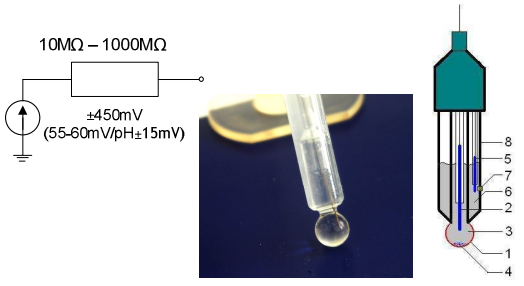



Linear Technology advertisement materials



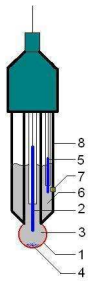


## pH glass electrode construction



## pH glass electrode construction

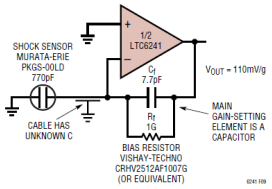
1.a sensing part of electrode, a bulb made from a specific glass
2.internal electrode, usually silver chloride electrode or calomel electrode
3.internal solution, usually a pH=7 buffered solution of 0.1 mol/L KCl for pH electrodes or 0.1 mol/L MeCl for pMe electrodes
4.when using the silver chloride 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.








## LTC6241 „charge amplifier” (integrating amplifier)

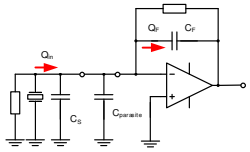



Linear Technology advertisement materials





## An idea of „charge amplifier”



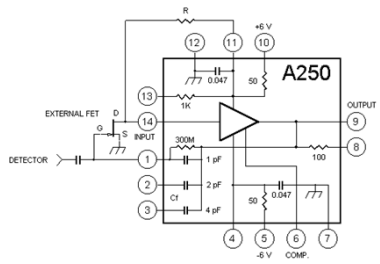

$$Q_{in} = Q_F$$

$$as\ V_+ = V_-$$

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

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

## A250 Amptek charge amp

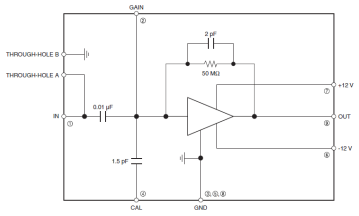


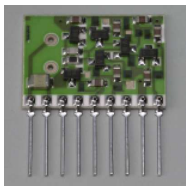

AMPTEC advertisement materials





## Hybrid charge amplifier



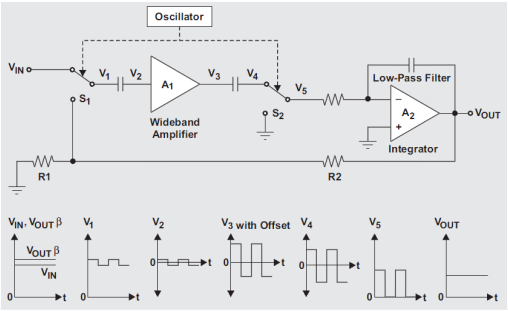
Hamamatsu advertisement materials





## Example of charge amps

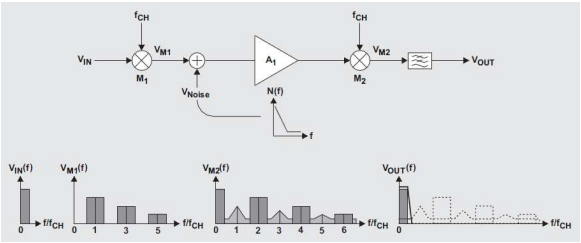

## An idea of chopper amp





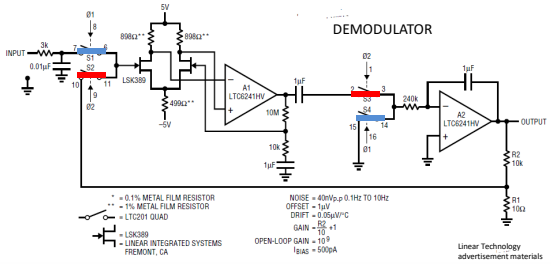

Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

## An idea of chopper amp in frequency domain






Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology



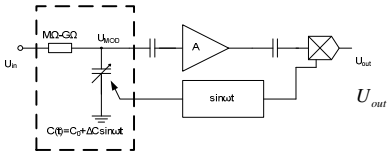
## chopper amp drawbacks

- 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



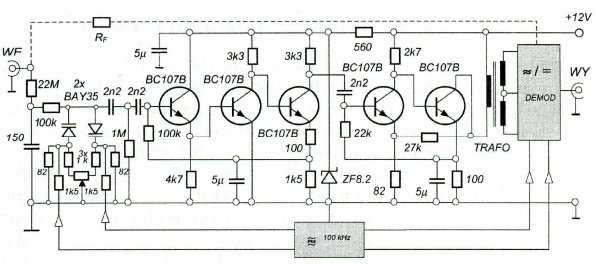

$$U_{out} \propto AU_{in}\frac{\Delta C}{C_0}\sin \omega t$$

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

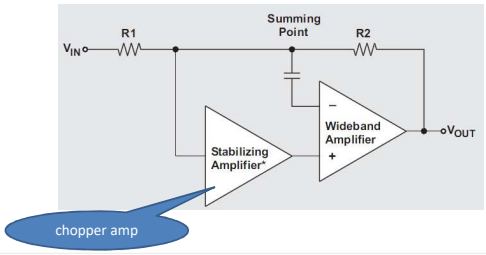




## Electrometer with parametric modulation



## chopper -stabilized amp








## auto-zero amp

phase 1

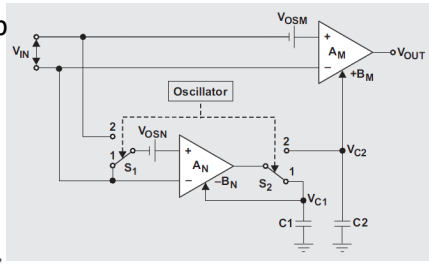
$$V_{C1} = V_{OSN}\left(\frac{A_N}{1+B_N}\right)$$

phase 2

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

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

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




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



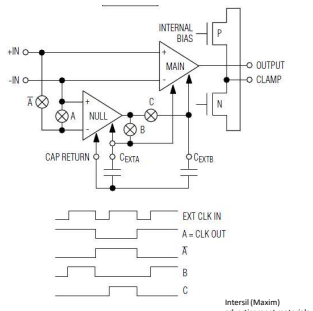


$$V_{OUT} = V_{IN}(A_M + A_N B_M) + V_{OSM} A_M + V_{OSN}\left(\frac{A_N B_M}{1+B_N}\right) =$$

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

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

ICL7650

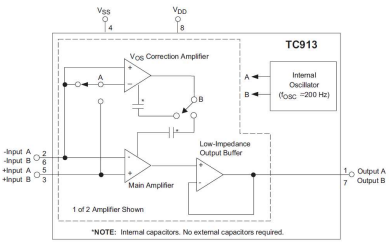



Intersil (Maxim) advertisement materials



Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

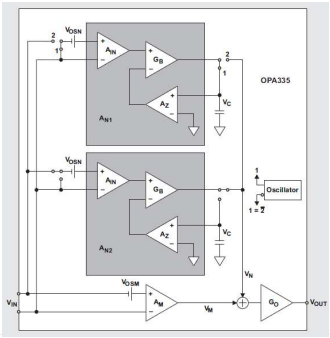
TC913




HUMAN CAPITAL
Wrocław University of Technology
Project co-financed from the EU European Social Fund

Wrocław University of Technology
Master programmes in English
at Wrocław University of Technology

OPA335 wide band amp




HUMAN CAPITAL
Wrocław University of Technology
Project co-financed from the EU European Social Fund

## Summary

- operational amplifier
  - ✓VV- voltage/voltage amp – review
  - ✓CV
  - ✓VC
  - ✓CC
- electrometer
- charge amplifier
- choppered and auto-zero amp
- 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. What are the main features of a transconductance and a transimpedance amplifier?
4. What is the idea of a charge amplifier ?
5. What is the idea of a chopper amplifier ?
6. What is the idea of a parametric modulation amp ?

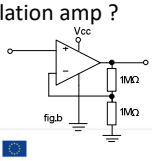


fig.b