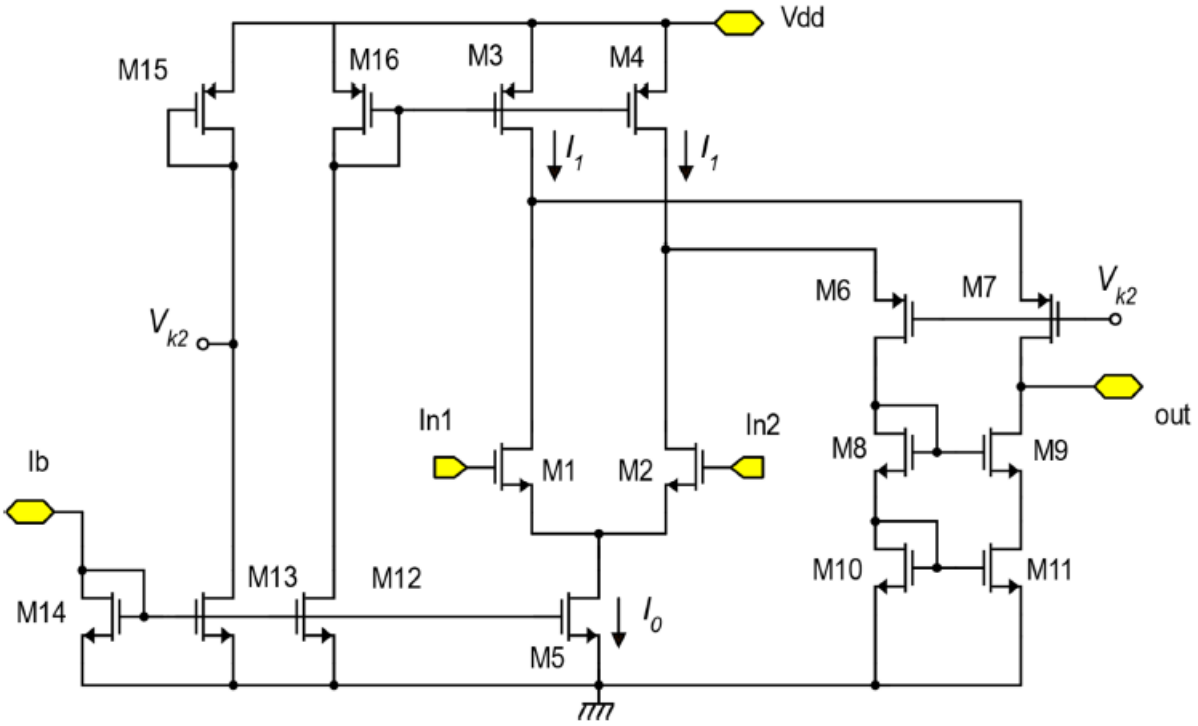
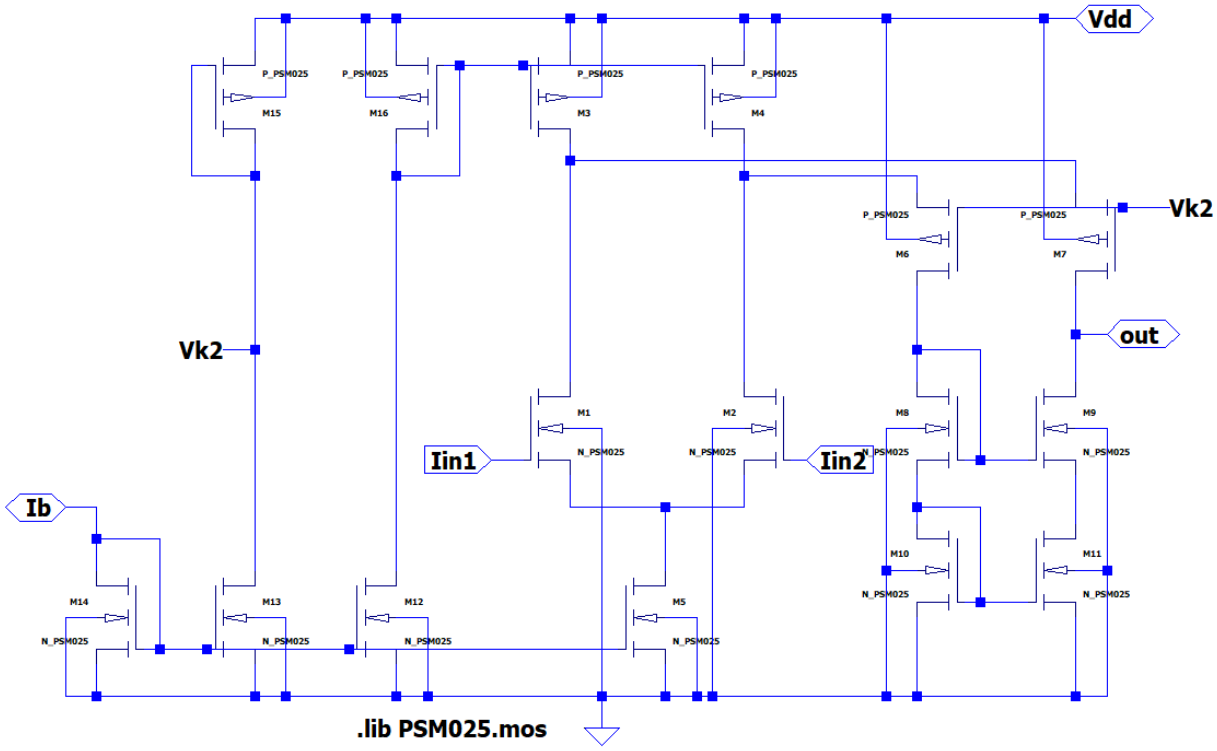
# Folded Cascode CMOS con ingresso n

*Report Preliminare*

Si riporta il circuito da progettare




Di seguito si riporta lo schematico su LTSpice

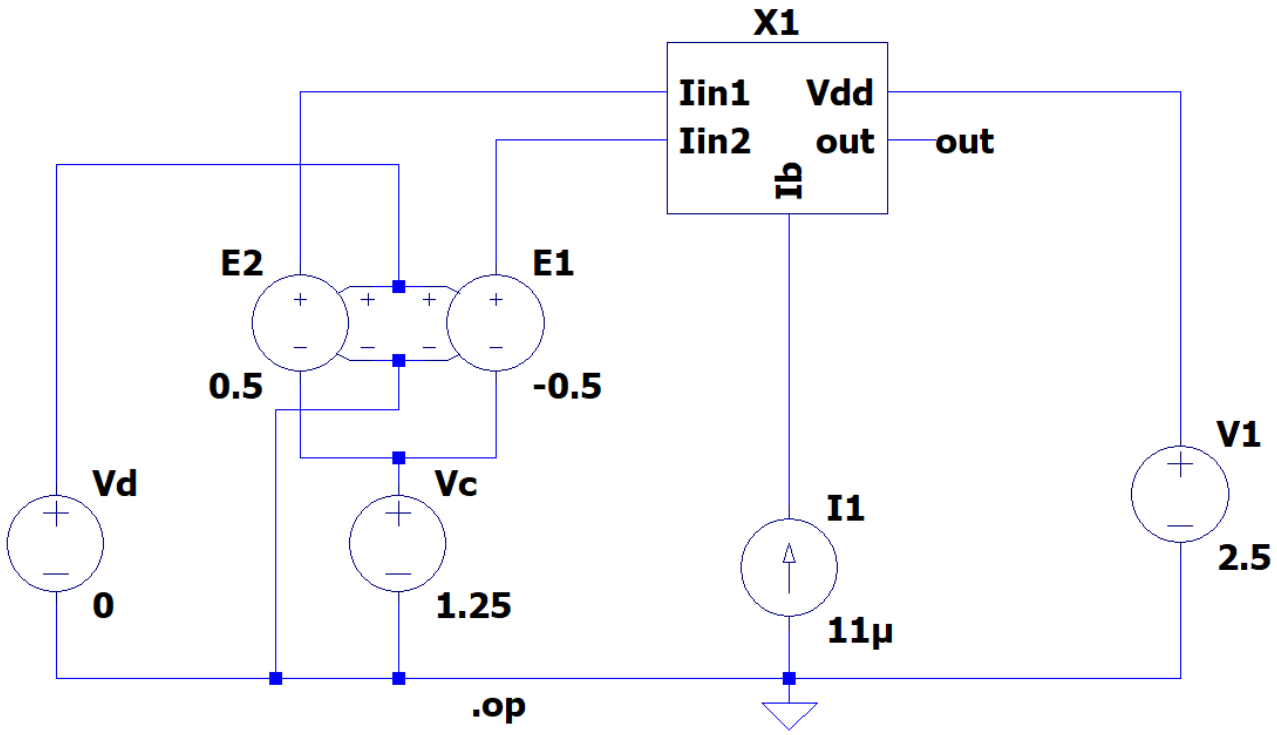



Le condizioni per il progetto sono:

Vdd=2.5 V

$I_b$ =11 µA , $I_0$= 22 µA, $I_1$=22 µA, $I_{D12}$= $I_b$, $I_{D13}$=3 $I_b$

Facendo riferimento al seguente test-bench




Si effettua una preliminare analisi del punto di riposo (.op) e si verifica che i transistori siano in saturazione e che le $V_{GS}$-$V_t$ siano vicine a quelle richieste.

Tramite lo “Spice Error Log” si ottiene

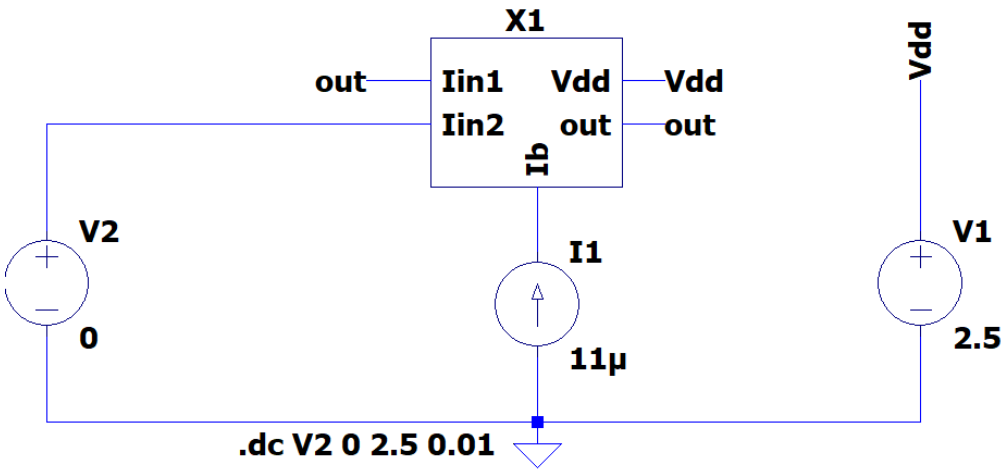
| Name: | m:x1:5 | m:x1:8 | m:x1:9 | m:x1:10 | m:x1:11 |
|---|---|---|---|---|---|
| Model: | x1:n_psm025 | x1:n_psm025 | x1:n_psm025 | x1:n_psm025 | x1:n_psm025 |
| Id: | 2.12e-05 | 1.27e-05 | 1.27e-05 | 1.27e-05 | 1.27e-05 |
| Vgs: | 6.51e-01 | 7.92e-01 | 7.92e-01 | 6.69e-01 | 6.69e-01 |
| Vds: | 5.16e-01 | 7.92e-01 | 7.92e-01 | 6.69e-01 | 6.69e-01 |
| Vbs: | 0.00e+00 | -6.69e-01 | -6.69e-01 | 0.00e+00 | 0.00e+00 |
| Vth: | 4.24e-01 | 5.58e-01 | 5.58e-01 | 4.20e-01 | 4.20e-01 |
| Vdsat: | 1.89e-01 | 2.11e-01 | 2.11e-01 | 2.04e-01 | 2.04e-01 |
| Gm: | 1.78e-04 | 1.00e-04 | 1.00e-04 | 9.82e-05 | 9.82e-05 |
| Gds: | 2.81e-06 | 1.20e-06 | 1.20e-06 | 1.33e-06 | 1.33e-06 |
| Gmb | 3.79e-05 | 1.67e-05 | 1.67e-05 | 2.06e-05 | 2.06e-05 |
| Cbd: | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 |
| Cbs: | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 |
| Cgsov: | 2.46e-15 | 1.23e-15 | 1.23e-15 | 1.23e-15 | 1.23e-15 |
| Cgdov: | 2.46e-15 | 1.23e-15 | 1.23e-15 | 1.23e-15 | 1.23e-15 |
| Cgbov: | 1.00e-18 | 1.00e-18 | 1.00e-18 | 1.00e-18 | 1.00e-18 |
| dQgdVgb: | 2.65e-14 | 1.30e-14 | 1.30e-14 | 1.32e-14 | 1.32e-14 |
| dQgdVdb: | -2.37e-15 | -1.18e-15 | -1.18e-15 | -1.18e-15 | -1.18e-15 |
| dQgdVsb: | -2.30e-14 | -1.13e-14 | -1.13e-14 | -1.15e-14 | -1.15e-14 |
| dQddVgb: | -1.13e-14 | -5.65e-15 | -5.65e-15 | -5.65e-15 | -5.65e-15 |
| dQddVdb: | 2.42e-15 | 1.20e-15 | 1.20e-15 | 1.20e-15 | 1.20e-15 |
| dQddVsb: | 1.11e-14 | 5.24e-15 | 5.24e-15 | 5.52e-15 | 5.52e-15 |
| dQbdVgb: | -3.87e-15 | -1.68e-15 | -1.68e-15 | -1.94e-15 | -1.94e-15 |
| dQbdVdb: | -7.29e-18 | 7.45e-19 | 7.45e-19 | 1.10e-18 | 1.10e-18 |
| dQbdVsb: | -1.57e-15 | -4.04e-16 | -4.04e-16 | -7.76e-16 | -7.76e-16 |

| Name: | m:x1:14 | m:x1:13 | m:x1:12 | m:x1:1 | m:x1:2 |
|---|---|---|---|---|---|
| Model: | x1:n_psm025 | x1:n_psm025 | x1:n_psm025 | x1:n_psm025 | x1:n_psm025 |
| Id: | 1.10e-05 | 3.43e-05 | 1.21e-05 | 1.06e-05 | 1.06e-05 |
| Vgs: | 6.51e-01 | 6.51e-01 | 6.51e-01 | 7.34e-01 | 7.34e-01 |
| Vds: | 6.51e-01 | 1.42e+00 | 1.75e+00 | 1.74e+00 | 1.74e+00 |
| Vbs: | 0.00e+00 | 0.00e+00 | 0.00e+00 | -5.16e-01 | -5.16e-01 |
| Vth: | 4.21e-01 | 4.18e-01 | 4.12e-01 | 5.23e-01 | 5.23e-01 |
| Vdsat: | 1.92e-01 | 1.93e-01 | 1.97e-01 | 1.91e-01 | 1.91e-01 |
| Gm: | 9.15e-05 | 2.81e-04 | 9.69e-05 | 9.20e-05 | 9.20e-05 |
| Gds: | 1.21e-06 | 2.85e-06 | 9.61e-07 | 8.91e-07 | 8.91e-07 |
| Gmb | 1.92e-05 | 6.01e-05 | 2.04e-05 | 1.61e-05 | 1.61e-05 |
| Cbd: | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 |
| Cbs: | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 |
| Cgsov: | 1.23e-15 | 3.70e-15 | 1.23e-15 | 1.23e-15 | 1.23e-15 |
| Cgdov: | 1.23e-15 | 3.70e-15 | 1.23e-15 | 1.23e-15 | 1.23e-15 |
| Cgbov: | 1.00e-18 | 1.00e-18 | 1.00e-18 | 1.00e-18 | 1.00e-18 |
| dQgdVgb: | 1.32e-14 | 3.97e-14 | 1.32e-14 | 1.30e-14 | 1.30e-14 |
| dQgdVdb: | -1.18e-15 | -3.52e-15 | -1.17e-15 | -1.17e-15 | -1.17e-15 |
| dQgdVsb: | -1.15e-14 | -3.45e-14 | -1.15e-14 | -1.13e-14 | -1.13e-14 |
| dQddVgb: | -5.65e-15 | -1.69e-14 | -5.64e-15 | -5.64e-15 | -5.64e-15 |
| dQddVdb: | 1.20e-15 | 3.60e-15 | 1.20e-15 | 1.20e-15 | 1.20e-15 |
| dQddVsb: | 5.51e-15 | 1.66e-14 | 5.51e-15 | 5.28e-15 | 5.28e-15 |
| dQbdVgb: | -1.94e-15 | -5.85e-15 | -1.95e-15 | -1.73e-15 | -1.73e-15 |
| dQbdVdb: | 1.23e-18 | 1.48e-17 | 5.12e-18 | 2.99e-18 | 2.99e-18 |
| dQbdVsb: | -7.84e-16 | -2.34e-15 | -7.86e-16 | -4.73e-16 | -4.73e-16 |

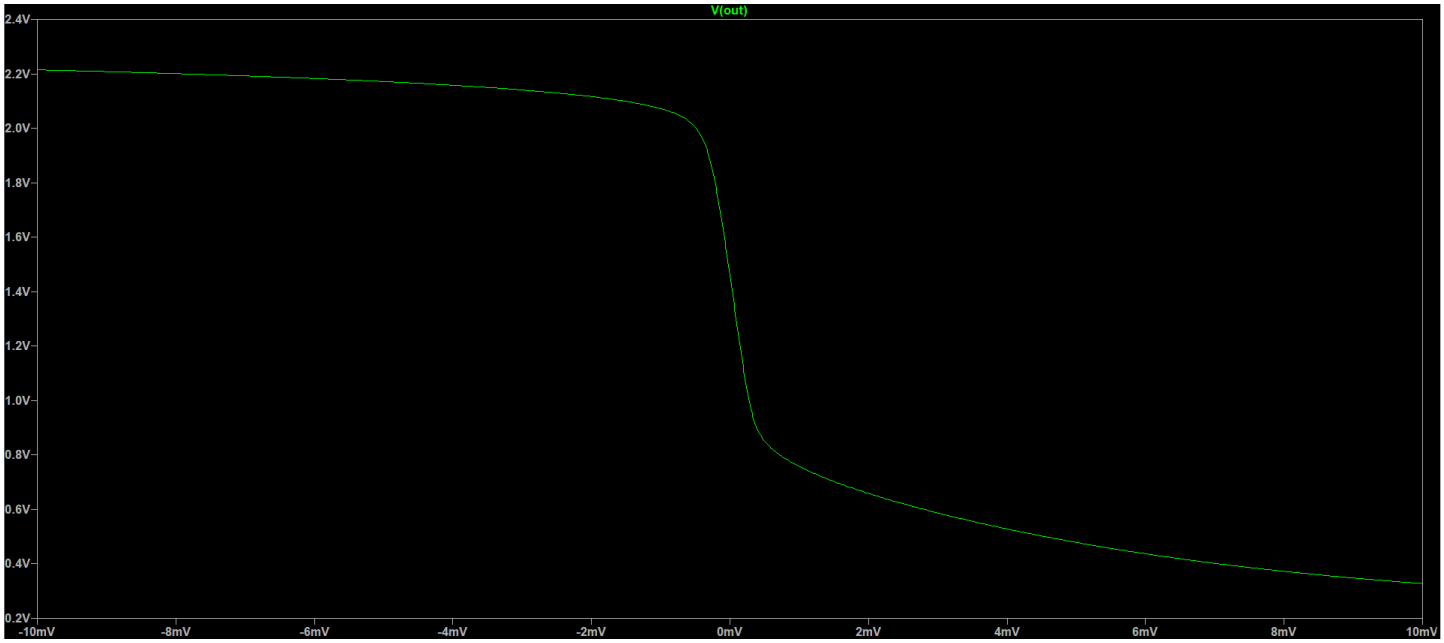
| Name: | m:x1:15 | m:x1:16 | m:x1:3 | m:x1:4 | m:x1:6 | m:x1:7 |
|---|---|---|---|---|---|---|
| Model: | x1:p_psm025 | x1:p_psm025 | x1:p_psm025 | x1:p_psm025 | x1:p_psm025 | x1:p_psm025 |
| Id: | -3.43e-05 | -1.21e-05 | -2.33e-05 | -2.33e-05 | -1.27e-05 | -1.27e-05 |
| Vgs: | -1.08e+00 | -7.54e-01 | -7.54e-01 | -7.54e-01 | -8.35e-01 | -8.35e-01 |
| Vds: | -1.08e+00 | -7.54e-01 | -2.46e-01 | -2.46e-01 | -7.93e-01 | -7.93e-01 |
| Vbs: | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 2.46e-01 | 2.46e-01 |
| Vth: | -5.67e-01 | -5.67e-01 | -5.67e-01 | -5.67e-01 | -6.41e-01 | -6.41e-01 |
| Vdsat: | -4.34e-01 | -1.89e-01 | -1.90e-01 | -1.90e-01 | -1.98e-01 | -1.98e-01 |
| Gm: | 1.19e-04 | 1.06e-04 | 2.00e-04 | 2.00e-04 | 1.09e-04 | 1.09e-04 |
| Gds: | 1.12e-06 | 6.03e-07 | 7.90e-06 | 7.90e-06 | 6.07e-07 | 6.07e-07 |
| Gmb | 3.85e-05 | 3.43e-05 | 6.54e-05 | 6.54e-05 | 3.14e-05 | 3.14e-05 |
| Cbd: | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 |
| Cbs: | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 | 0.00e+00 |
| Cgsov: | 3.64e-15 | 7.57e-15 | 1.51e-14 | 1.51e-14 | 7.57e-15 | 7.57e-15 |
| Cgdov: | 3.64e-15 | 7.57e-15 | 1.51e-14 | 1.51e-14 | 7.57e-15 | 7.57e-15 |
| Cgbov: | 9.36e-19 | 9.36e-19 | 9.36e-19 | 9.36e-19 | 9.36e-19 | 9.36e-19 |
| dQgdVgb: | 3.26e-14 | 6.76e-14 | 1.36e-13 | 1.36e-13 | 6.72e-14 | 6.72e-14 |
| dQgdVdb: | -3.65e-15 | -7.58e-15 | -1.66e-14 | -1.66e-14 | -7.58e-15 | -7.58e-15 |
| dQgdVsb: | -2.72e-14 | -5.57e-14 | -1.12e-13 | -1.12e-13 | -5.57e-14 | -5.57e-14 |
| dQddVgb: | -1.42e-14 | -2.95e-14 | -6.02e-14 | -6.02e-14 | -2.95e-14 | -2.95e-14 |
| dQddVdb: | 3.64e-15 | 7.58e-15 | 1.63e-14 | 1.63e-14 | 7.58e-15 | 7.58e-15 |
| dQddVsb: | 1.39e-14 | 2.89e-14 | 5.84e-14 | 5.84e-14 | 2.82e-14 | 2.82e-14 |
| dQbdVgb: | -4.14e-15 | -8.56e-15 | -1.60e-14 | -1.60e-14 | -8.12e-15 | -8.12e-15 |
| dQbdVdb: | -6.40e-18 | -8.12e-18 | -8.66e-16 | -8.66e-16 | -7.02e-18 | -7.02e-18 |
| dQbdVsb: | -4.31e-15 | -9.74e-15 | -2.02e-14 | -2.02e-14 | -8.18e-15 | -8.18e-15 |

Si può notare che le $V_{GS}$-$V_t$ dei transistor rientrano nel range richiesto 200mV ±20mV, mentre per quanto riguarda il transistor M15, che dovrebbe avere $V_{GS}$-$V_t$ = 500mV, si ottiene un valore di 434mV.

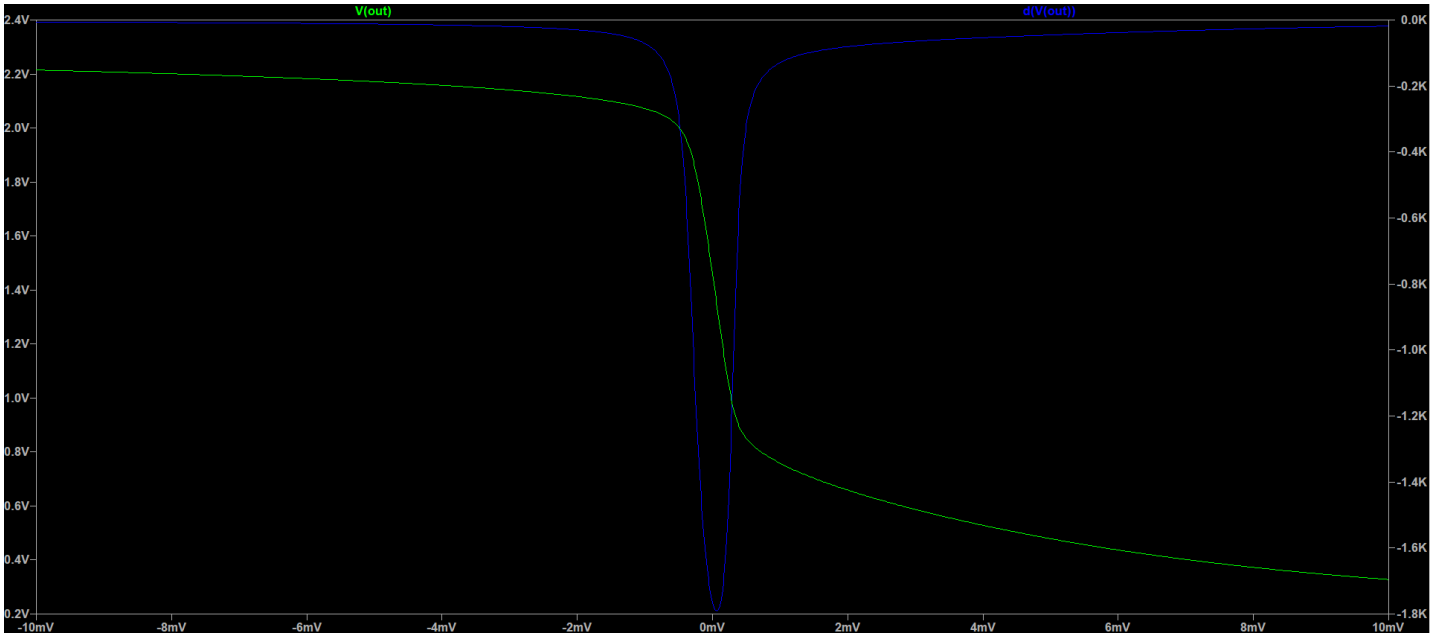
La seconda simulazione da effettuare è stata realizzata con la stessa test-bench, ma realizzando un dc sweep della tensione Vd tra −10mV e +10mV con un passo di 10 µV mantenendo VC a 1.25 V (.dc Vd -10m 10m 10u)




Di seguito riporta il grafico della corrispondente tensione di uscita



Per una stima dell'amplificazione si riporta il grafico di d(V(out))/d(Vd)




| Cursor 1 | d(V(out)) | | |
|---|---|---|---|
| Horz: | 0V | Vert: | -1.7687201K |
| **Cursor 2** | | | |
| Horz: | -- N/A-- | Vert: | -- N/A-- |
| **Diff (Cursor2 - Cursor1)** | | | |
| Horz: | -- N/A-- | Vert: | -- N/A-- |
| | | Slope: | -- N/A-- |

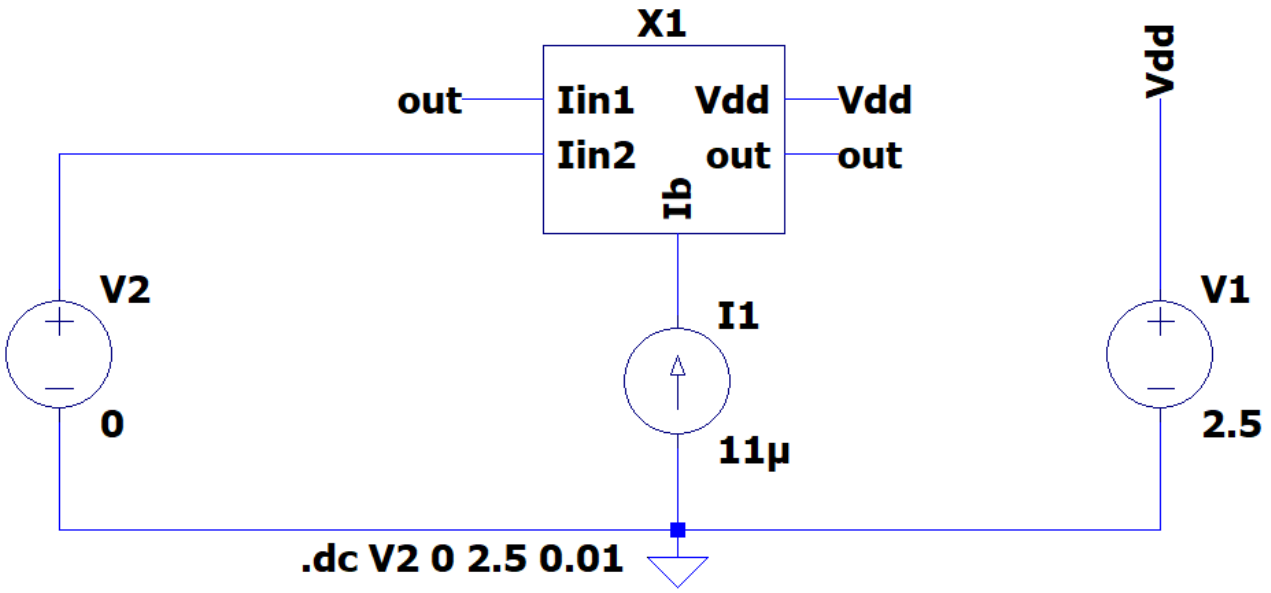
Grazie al cursore si ha un guadagno Ad ≈ 1768, valore che rientra nelle specifiche (>1000).

La seconda stima da effettuare è quella relativa alla tensione di offset sistematica dello stadio, un secondo cursore fornisce

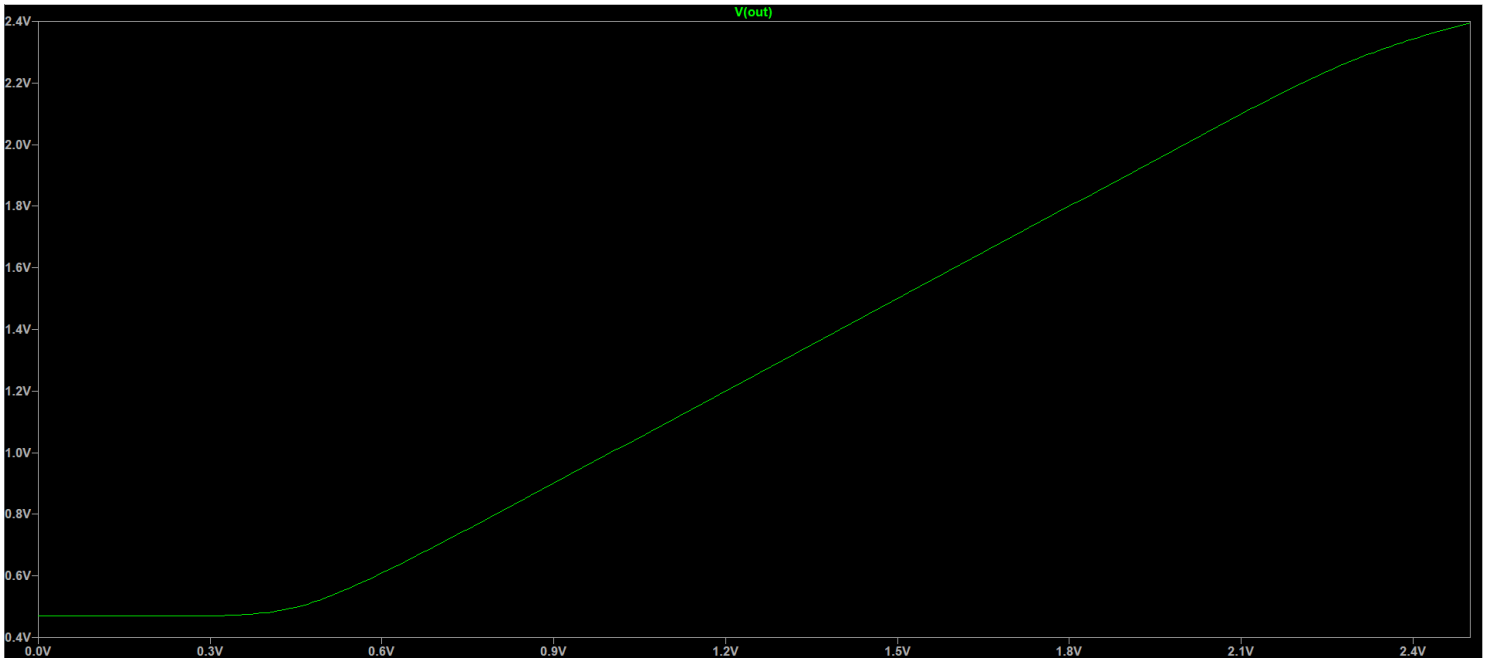
| Cursor 1 | V(out) | | |
|---|---|---|---|
| Horz: | 120µV | Vert: | 1.2464658V |
| **Cursor 2** | | | |
| Horz: | -- N/A-- | Vert: | -- N/A-- |
| **Diff (Cursor2 - Cursor1)** | | | |
| Horz: | -- N/A-- | Vert: | -- N/A-- |
| | | Slope: | -- N/A-- |

Si ha un offset sistematico pari a 120 µV, valore che non rientra nelle specifiche richieste (<100 µV). Tale risultato è frutto di alcuni tentativi di dimensionamento per cercare di avvicinarsi alle specifiche richieste e rappresenta il miglior risultato che si è riusciti ad ottenere.

Come simulazione finale si chiede si collegare l'amplificatore operazionale a formare un buffer ed effettuare un dc sweep della tensione da 0 a Vdd con step 0.01V (.dc V2 0 2.5 0.01).
Si riporta la test-bench utilizzata




Il risultato della simulazione è il seguente




| | | | |
|---|---|---|---|
| Cursor 1 | | | |
| | V(out) | | |
| Horz: | 2.29V | Vert: | 2.2692878V |
| Cursor 2 | | | |
| | V(out) | | |
| Horz: | 600mV | Vert: | 609.31259mV |
| Diff (Cursor2 - Cursor1) | | | |
| Horz: | -1.69V | Vert: | -1.6599752V |
| | | Slope: | 0.982234 |

Il range di linearità misurato risulta pari a:

$$600\ mV < Vin < 2.29\ V$$