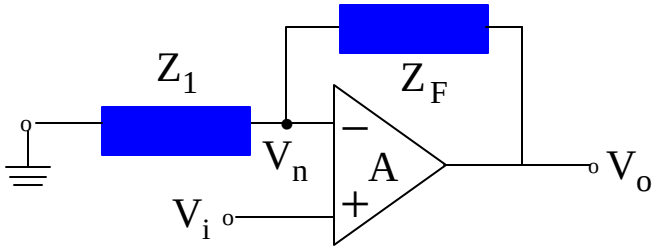
Fully Balanced, Fully Differential Circuits

Fully Differential Fully Balanced Circuits

What is the problem with single-input / single-output?



$$V_n = \frac{V_o Z_1}{Z_1 + Z_F}$$

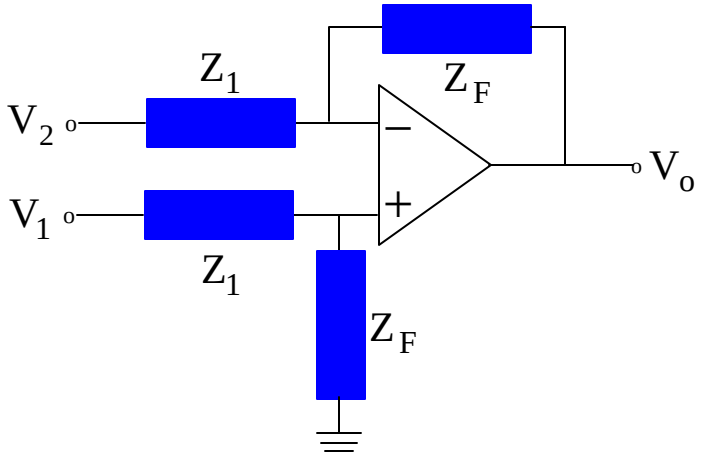
$$V_1 - V_n = \frac{V_o}{A}\Bigg|_{A \to \infty} = 0$$

For $V_i = V_{id} + V_{icm}$

$$V_o = \left(1 + \frac{Z_F}{Z_1}\right)(V_{id} + V_{icm})$$

No elimination of common-mode signal.

How to solve this problem?



For $V_i = V_{id} + V_{icm} = (V_1 - V_2) + \frac{(V_1 + V_2)}{2}$

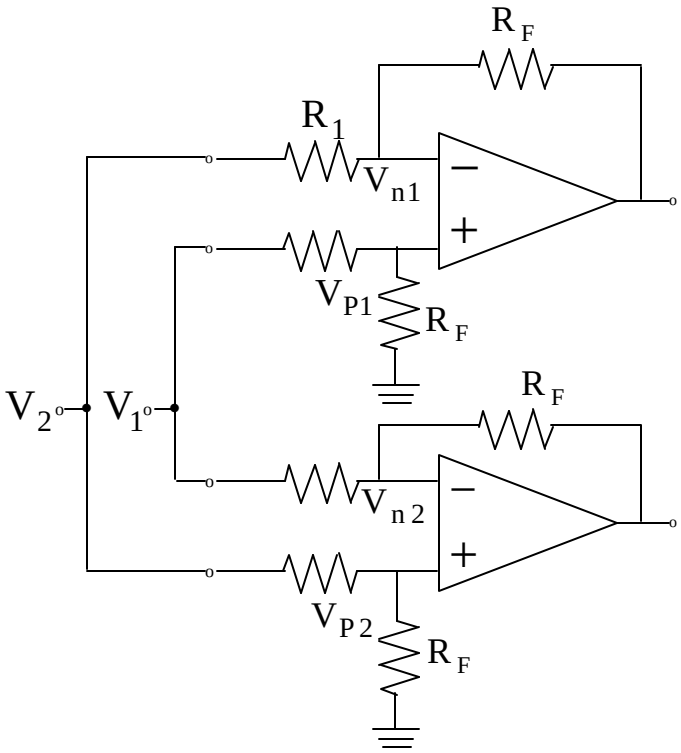
$$V_o = \frac{Z_F}{Z_1}(V_1 - V_2)$$

No common-mode output.

How to obtain a fully differential circuit?

We will discuss two potential approaches

Approach 1



$$V_{o1} = -\frac{R_F}{R_1}(V_2 - V_1)$$

$$= \frac{R_F}{R_1}(V_1 - V_2)$$

$$V_{o2} = +\frac{R_F}{R_1}(V_2 - V_1)$$

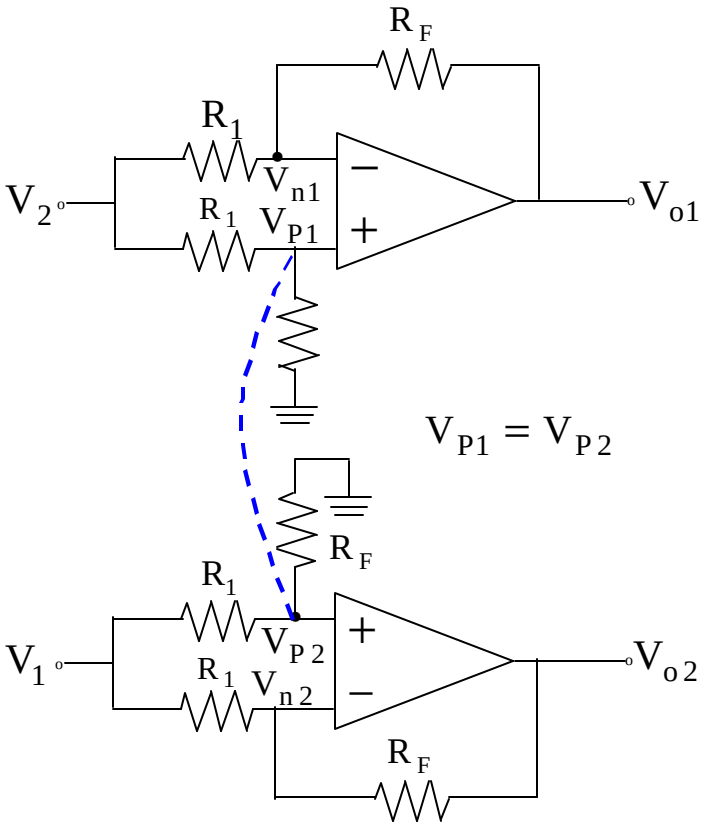
$$V_{o1} - V_{o2} = \frac{R_F}{R_1}(V_1 - V_2 - V_2 + V_1) =$$

$$V_{oD} = \frac{2R_F}{R_1}(V_1 - V_2)$$

conditions $V_{n2} = V_{P2}$; $V_{n1} = V_{P1}$

Remark: sensitive to CM signals

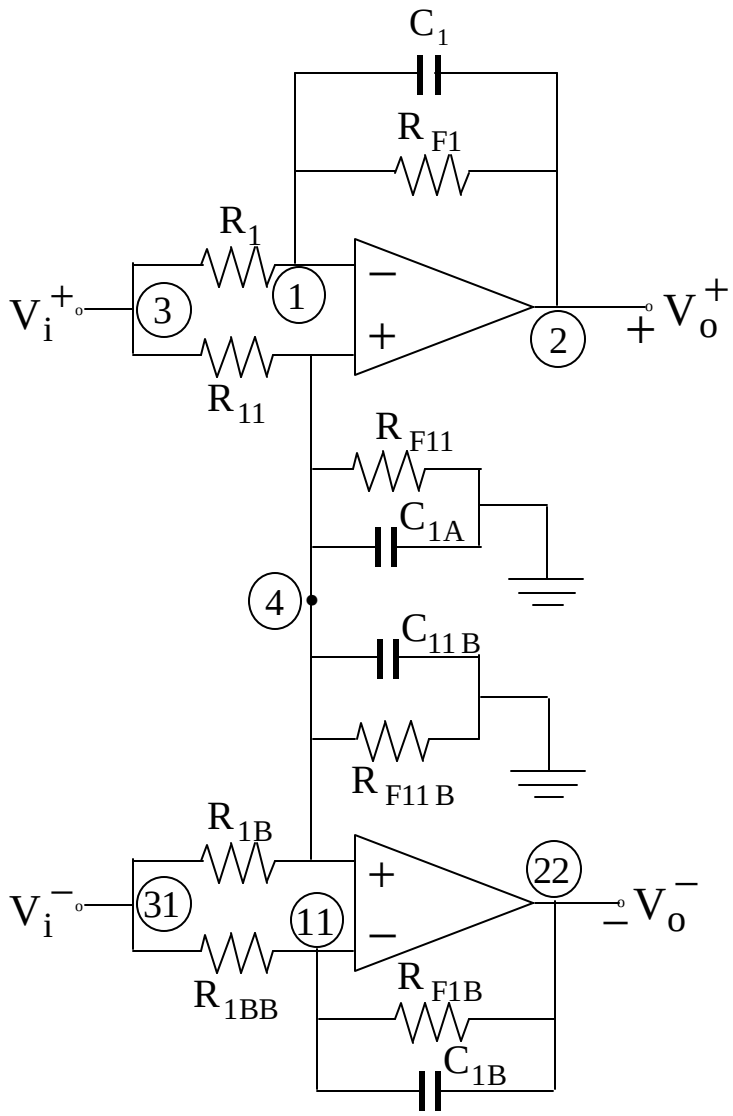
Approach 2



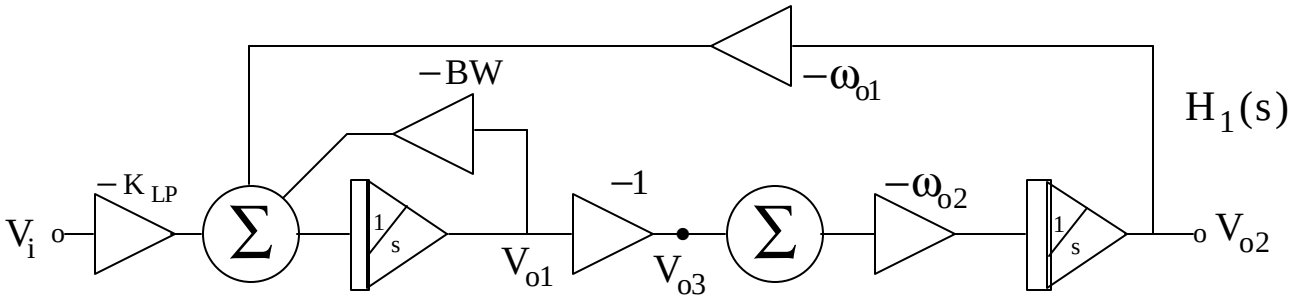
Remark:

More robust to reject common-mode signals

```
First-Order FB Low Pass with Op Amp
*
.subckt opamp non inv out
rin non inv 100K
egain      1      0      (non, inv)    200K
ropen      1      2      2K
copen  2   0      15.9155u
eout   3   0      (2, 0)   1
rout   3    out   50
.ends
*vin        3     31     ac     1.0
vin     31  0   ac   1.0
x1      4       1       2      opamp
x2      4       11      22     opamp
R1      3       1       1K
R11     3       4       1K
R1B     31      4       1K
R1BB 31      11      1K
RF1     2       1       1K
RF1B 22      11     1K
RF11  4       0       1K
RF11B         4       0       1K
C1      2       1       0.159155u
C1B   22       11      0.159155u
C1A   4        0       0.159155u
C11B 4         0       0.159155u
rdummy  3     31     1
.ac   dec   10    10Hz   10KHz
.probe
.end
```

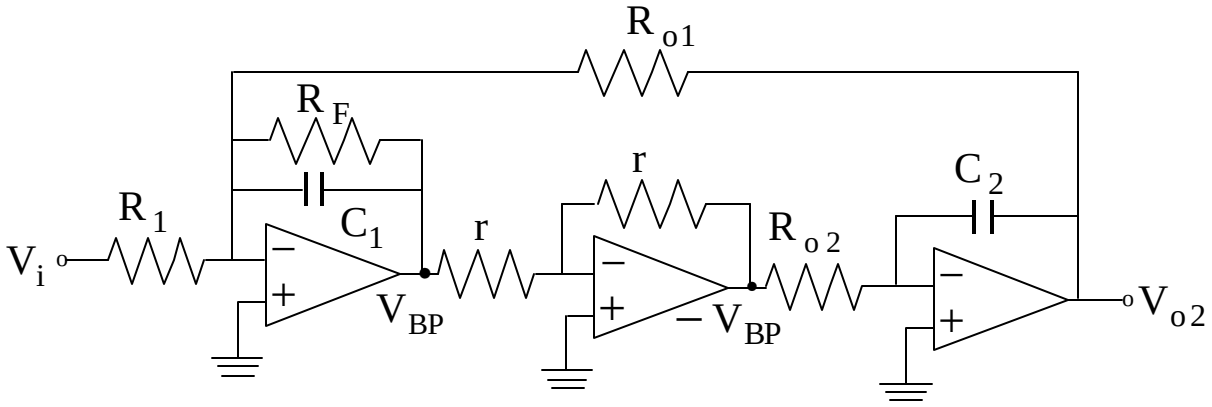


A Two-Integrator Active-RC Filter

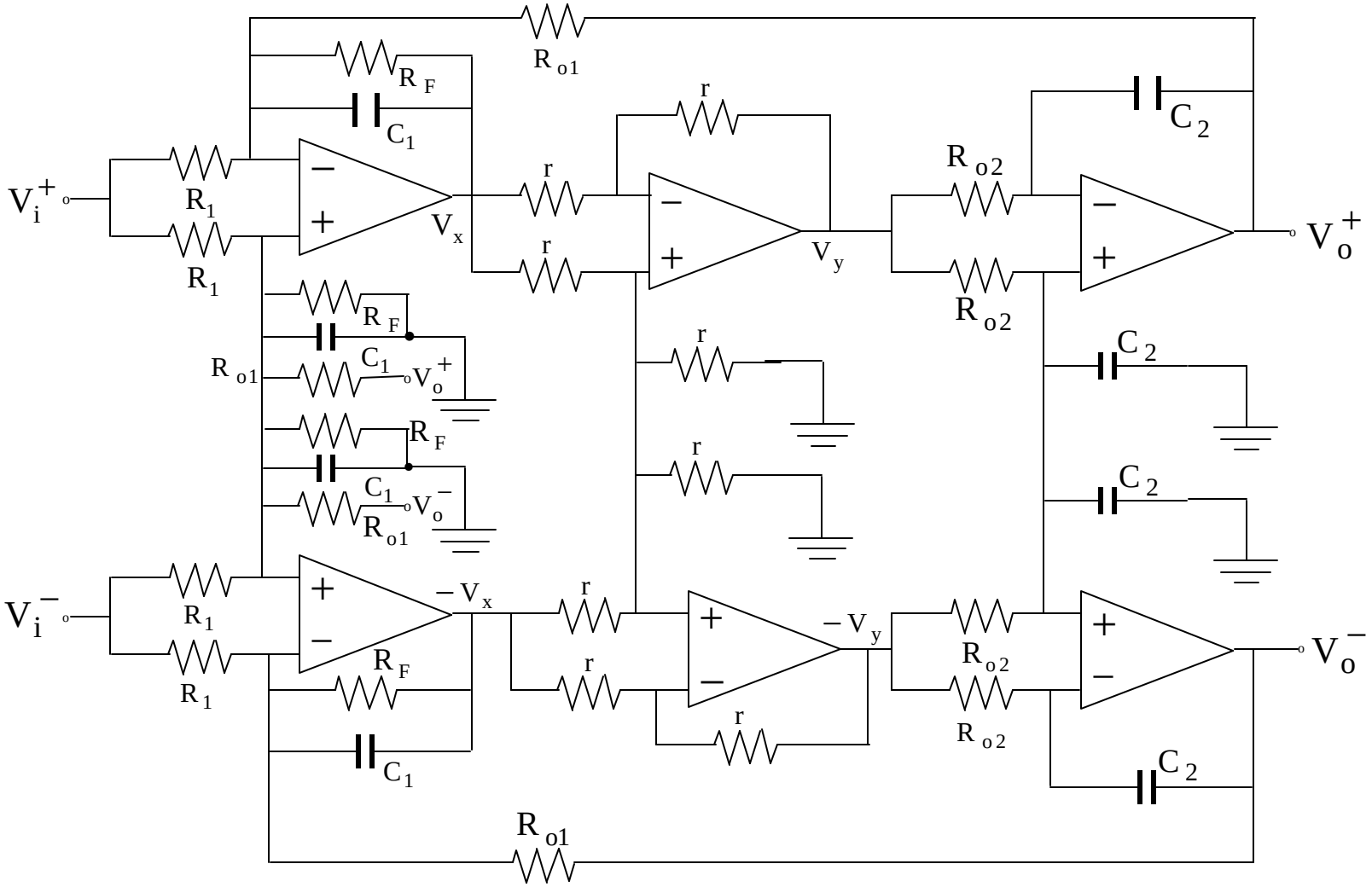


$$H_1(s) = \frac{V_{o2}}{V_i} = \frac{-K_{LP}\omega_{o2}}{s^2 + BWS + \omega_{o1}\omega_{o2}}$$

(a) Block Diagram

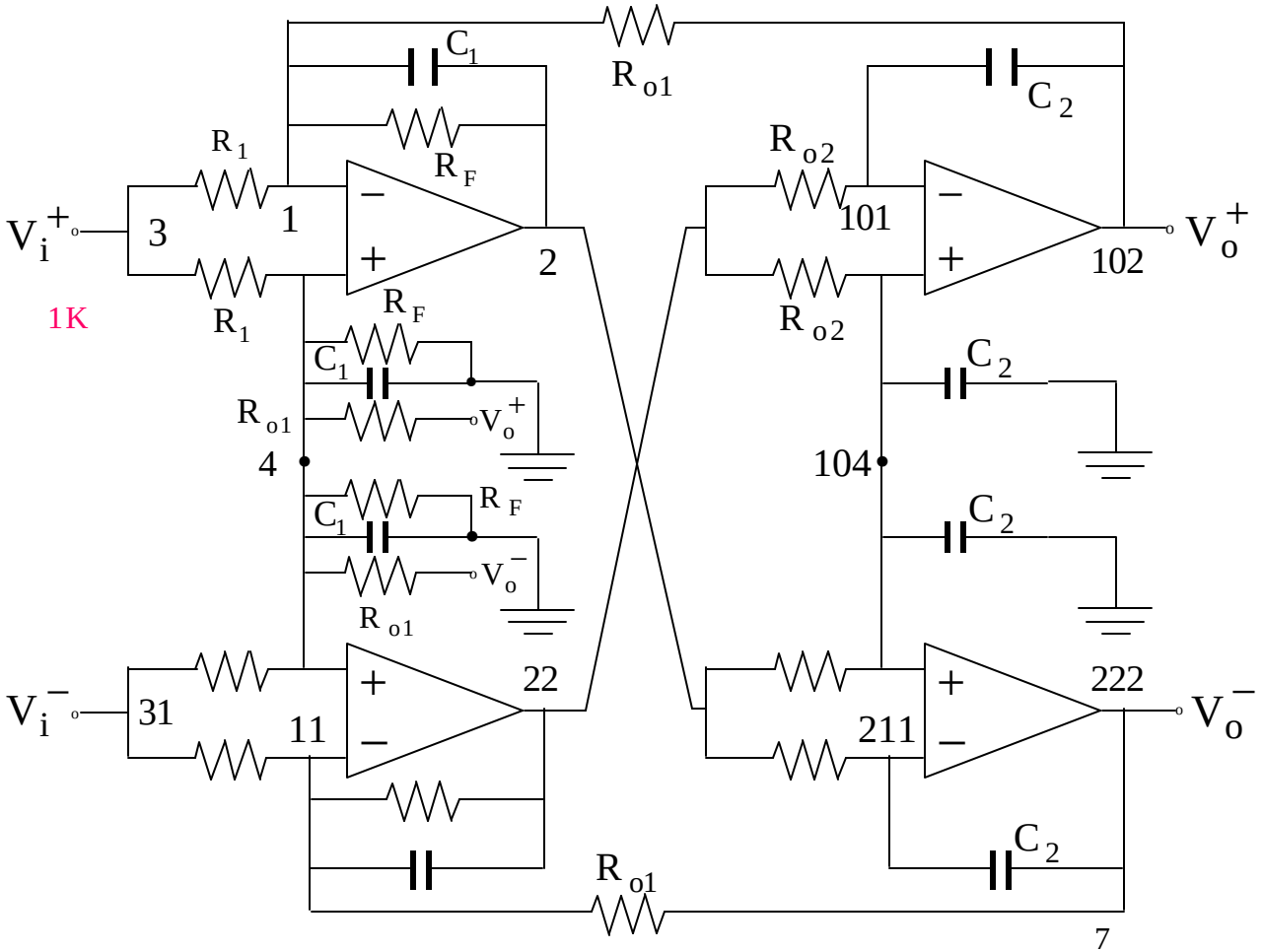


(b) Active RC Implementation (single-ended)



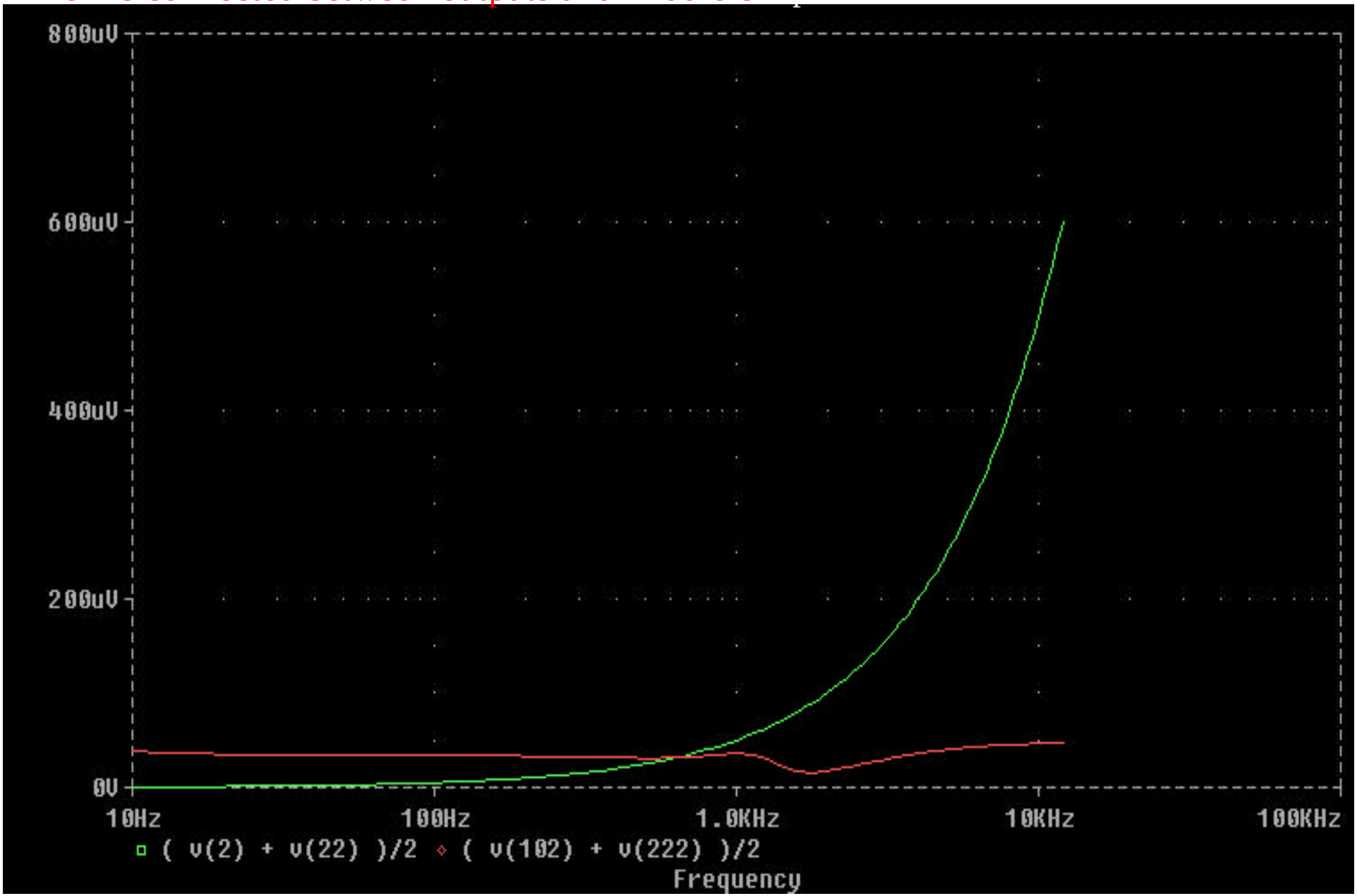
(c) Fully Balanced, Fully-Differential (not simplified)

```
Second-Order FB Low Pass with Op Amp
*
.subckt opamp non inv out
rin non inv 100K
egain     1     0     (non, inv)   200K
ropen     1     2     2K
copen  2  0     15.9155u
eout   3  0     (2, 0)  1
rout   3   out  50
.ends
vin     3     31    ac    1.0
*vin          0     31    ac   1.0
*ein       3  0     (31, 0)      1
x1      4     1     2     opamp
x2      4     11    22    opamp
R1      3     1     1K R11   3     4     1K
R1B    31     4     1K
R1BB 31     11    1K
RF1    2     1     1K
RF1B 22     11    1K
RF11  4     0     1K
RF11B       4     0       1K
C1      2     1     0.159155u
C1B   22     11    0.159155u
C1A   4      0     0.159155u
C11B 4      0     0.159155u
RO1A 4      0     1K
RO1B 4      0      1K
rdummy  3    31   1
Ro11    22     101    1K
Ro11a       22     104     1K
Ro11b       2      211     1K
Ro111       2      211     1K
C2     102     101     0.159155u
C2a    104     0       0.159155u
C2b    104     0       0.159155u
C2bb  222     211     0.159155u
* FEEDBACK RESISTORS
RO1   1       102     1K
RO2   11      222     1K
x3      104     211     222    opamp
x4      104     101     102    opamp
.ac   dec   50    10Hz   12KHz
.probe
.end
```



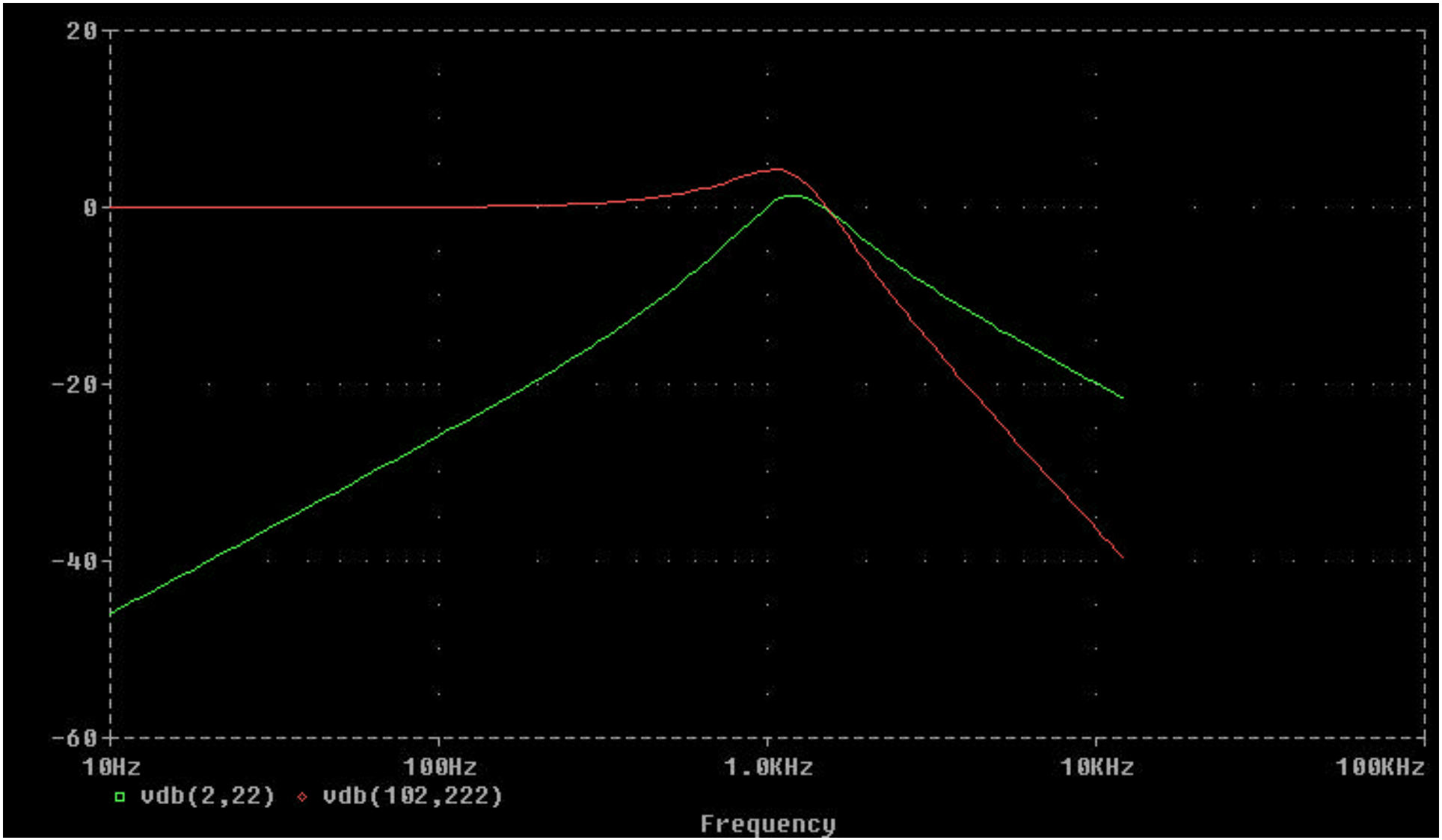
Fully Balanced Tow-Thomas Active RC: *CM output signals*

Ro1 is connected between outputs and middle cm

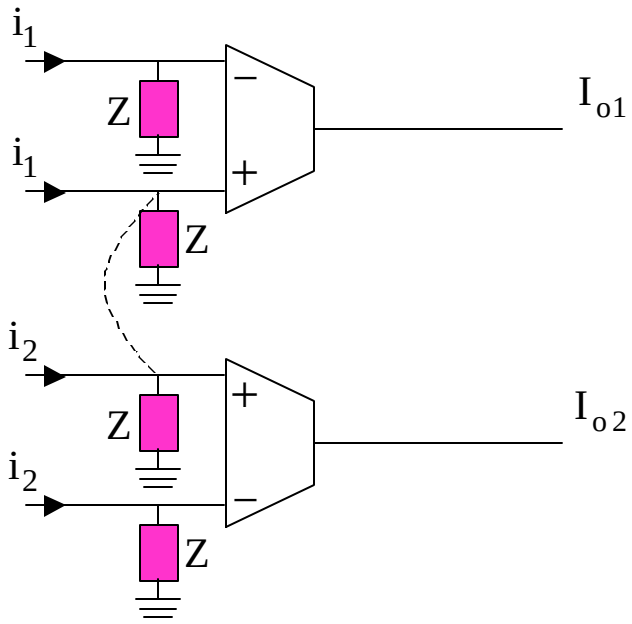


Fully Balanced Active RC Fully Differential, : *Differential outputs*

Ro1 connected to the outputs and middle point cm, + terminal of Op Amps



For OTA the solution becomes



Every input should be in pairs of signal.