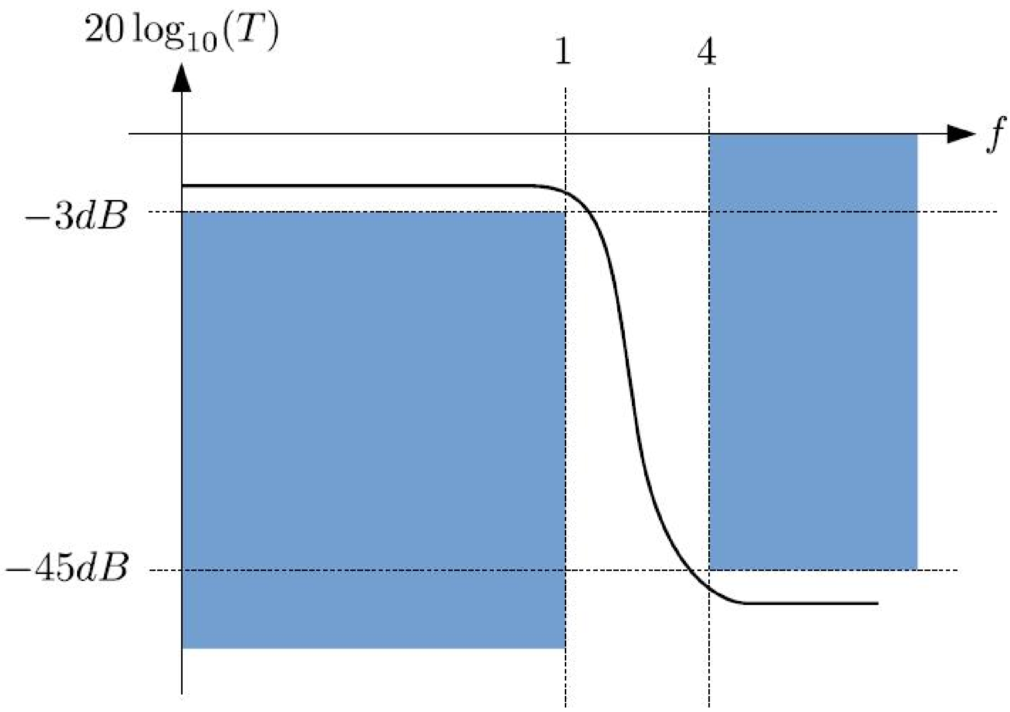
Q1

| | |
|---|---|
| **Type de filtre** | Passe bas |
| **Fréquence de coupure** | 1 kHz |
| **Fréquence de début de la bande d'arrêt** | 4 kHz |
| **Atténuation minimale dans la bande d'arrêt** | 45 dB |
| **Contrainte** | Amplitude aussi plate que possible |

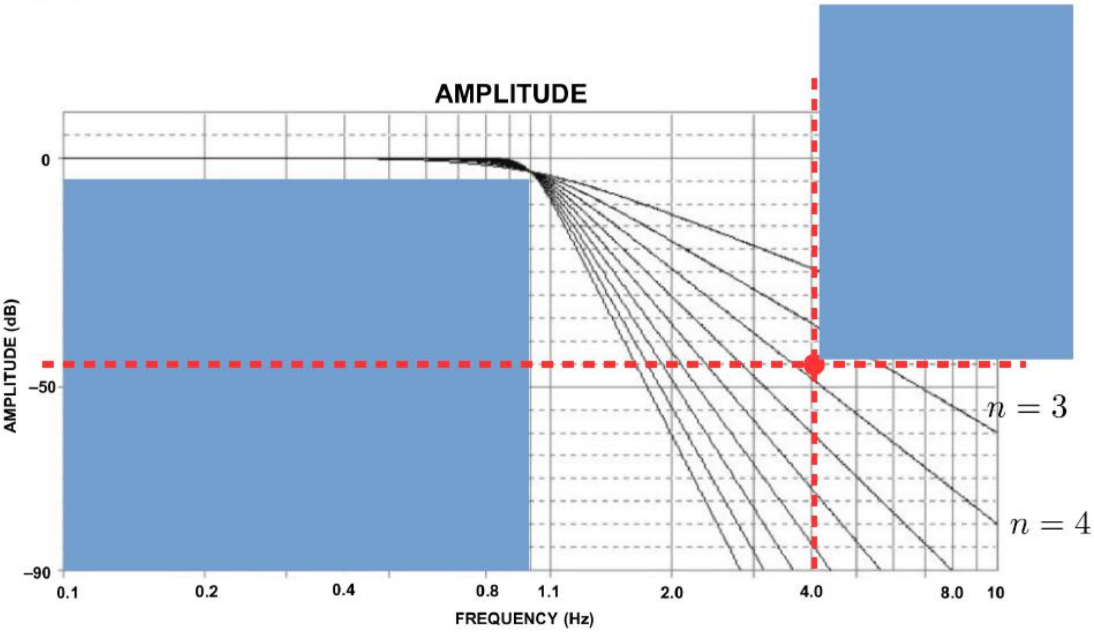
1 Filtre de Butterworth

2 $X_1 = f_1/f_0 = 4\ \text{kHz}/1\ \text{kHz} = 4$

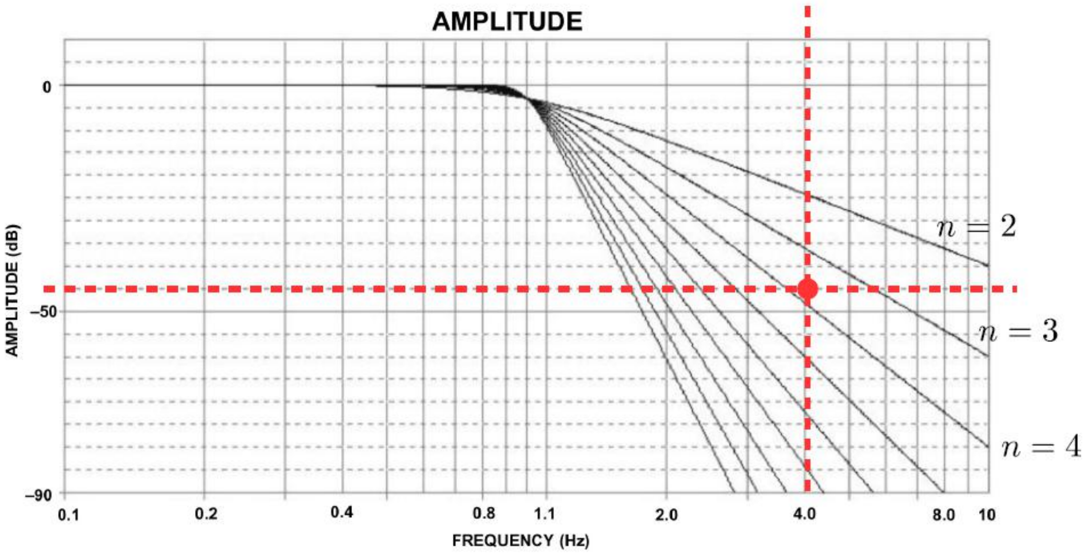
**Passe bas normalisé :**



## 3 Sélection de l'ordre du filtre en utilisant les abaques




## 3 Sélection de l'ordre du filtre en utilisant les abaques




→ On utilise un **filtre d'ordre 4** → 2 x Filtre d'ordre 2 emple

## 4 Racines du polynôme en utilisant les tables

| ORDER | SECTION | REAL PART | IMAGINARY PART | $F_0$ | $\alpha$ | Q | -3 dB FREQUENCY | PEAKING FREQUENCY | PEAKING LEVEL |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 0.7071 | 0.7071 | 1.0000 | 1.4142 | 0.7071 | 1.0000 | | |
| | | | | | | | | | |
| 3 | 1 | 0.5000 | 0.8660 | 1.0000 | 1.0000 | 1.0000 | | 0.7071 | 1.2493 |
| | 2 | 1.0000 | | 1.0000 | | | 1.0000 | | |
| | | | | | | | | | |
| 4 | 1 | 0.9239 | 0.3827 | 1.0000 | 1.8478 | 0.5412 | 0.7195 | | |
| | 2 | 0.3827 | 0.9239 | 1.0000 | 0.7654 | 1.3065 | | 0.8409 | 3.0102 |
| | | | | | | | | | |
| 5 | 1 | 0.8090 | 0.5878 | 1.0000 | 1.6180 | 0.6180 | 0.8588 | | |
| | 2 | 0.3090 | 0.9511 | 1.0000 | 0.6180 | 1.6182 | | 0.8995 | 4.6163 |
| | 3 | 1.0000 | | 1.0000 | | | 1.0000 | | |
| | | | | | | | | | |
| 6 | 1 | 0.9659 | 0.2588 | 1.0000 | 1.9319 | 0.5176 | 0.6758 | | |
| | 2 | 0.7071 | 0.7071 | 1.0000 | 1.4142 | 0.7071 | 1.0000 | | |
| | 3 | 0.2588 | 0.9659 | 1.0000 | 0.5176 | 1.9319 | | 0.9306 | 6.0210 |
| | | | | | | | | | |
| 7 | 1 | 0.9010 | 0.4339 | 1.0000 | 1.8019 | 0.5550 | 0.7449 | | |
| | 2 | 0.6235 | 0.7818 | 1.0000 | 1.2470 | 0.8019 | | 0.4717 | 0.2204 |
| | 3 | 0.2225 | 0.9749 | 1.0000 | 0.4450 | 2.2471 | | 0.9492 | 7.2530 |
| | 4 | 1.0000 | | 1.0000 | | | 1.0000 | | |
| | | | | | | | | | |
| 8 | 1 | 0.9808 | 0.1951 | 1.0000 | 1.9616 | 0.5098 | 0.6615 | | |
| | 2 | 0.8315 | 0.5556 | 1.0000 | 1.6629 | 0.6013 | 0.8295 | | |
| | 3 | 0.5556 | 0.8315 | 1.0000 | 1.1112 | 0.9000 | | 0.6186 | 0.6876 |
| | 4 | 0.1951 | 0.9808 | 1.0000 | 0.3902 | 2.5628 | | 0.9612 | 8.3429 |
| | | | | | | | | | |
| 9 | 1 | 0.9397 | 0.3420 | 1.0000 | 1.8794 | 0.5321 | 0.7026 | | |
| | 2 | 0.7660 | 0.6428 | 1.0000 | 1.5320 | 0.6527 | 0.9172 | | |
| | 3 | 0.5000 | 0.8660 | 1.0000 | 1.0000 | 1.0000 | | 0.7071 | 1.2493 |
| | 4 | 0.1737 | 0.9848 | 1.0000 | 0.3474 | 2.8785 | | 0.9694 | 9.3165 |
| | 5 | 1.0000 | | 1.0000 | | | 1.0000 | | |
| | | | | | | | | | |
| 10 | 1 | 0.9877 | 0.1564 | 1.0000 | 1.9754 | 0.5062 | 0.6549 | | |
| | 2 | 0.8910 | 0.4540 | 1.0000 | 1.7820 | 0.5612 | 0.7564 | | |
| | 3 | 0.7071 | 0.7071 | 1.0000 | 1.4142 | 0.7071 | 1.0000 | | |
| | 4 | 0.4540 | 0.8910 | 1.0000 | 0.9080 | 1.1013 | | 0.7667 | 1.8407 |
| | 5 | 0.1564 | 0.9877 | 1.0000 | 0.3128 | 3.1970 | | 0.9752 | 10.2023 |

Ordre 2 → 4 racines

$$s_1 = 0.9239 + 0.3827i$$
$$\bar{s_1} = 0.9239 - 0.3827i$$
$$s_2 = 0.3827 + 0.9239i$$
$$\bar{s_2} = 0.3827 - 0.9239i$$

## 5 Polynôme du passe-bas normalisé

$$H_{PBN}(S) = \prod_i \frac{|s_i|^2}{(S-s_i)(S-\bar{s_i})} = \left(\frac{\Omega_{PBN,1}^2}{S^2 + \frac{\Omega_{PBN,1}}{Q_{PBN,1}} S + \Omega_{PBN,1}^2}\right)\left(\frac{\Omega_{PBN,2}^2}{S^2 + \frac{\Omega_{PBN,2}}{Q_{PBN,2}} S + \Omega_{PBN,2}^2}\right)$$

$$\Omega_{PBN,1} = |s_1| \qquad \Omega_{PBN,2} = |s_2|$$

$$Q_{PBN,1} = -\frac{\Omega_{PBN,1}}{2s_{r1}} \qquad Q_{PBN,1} = -\frac{\Omega_{PBN,2}}{2s_{r2}}$$

Dans l'exemple :

$$\Omega_{PBN,1} = \Omega_{PBN,2} = 1$$
$$Q_{PBN,1} = 1.3065$$
$$Q_{PBN,2} = 0.541196$$

## 6 Transformation de la fonction de transfert du PBN vers la fonction de transfert réelle

Pour une section **unique** :

$$H_{PBN}(S) = \frac{\Omega_{PBN}^2}{S^2 + \frac{\Omega_{PBN}}{Q_{PBN}} S + \Omega_{PBN}^2} \xrightarrow{S = s/\omega_0} H_{PB}(s) = \frac{(\omega_0 \Omega_{PBN})^2}{s^2 + \frac{\Omega_{PBN}\omega_0}{Q_{PBN}} s + (\Omega_{PBN}\omega_0)^2}$$

$$= \frac{\Omega_{PB}^2}{s^2 + \frac{\Omega_{PB}}{Q} s + \Omega_{PB}^2}$$

Dans l'exemple :

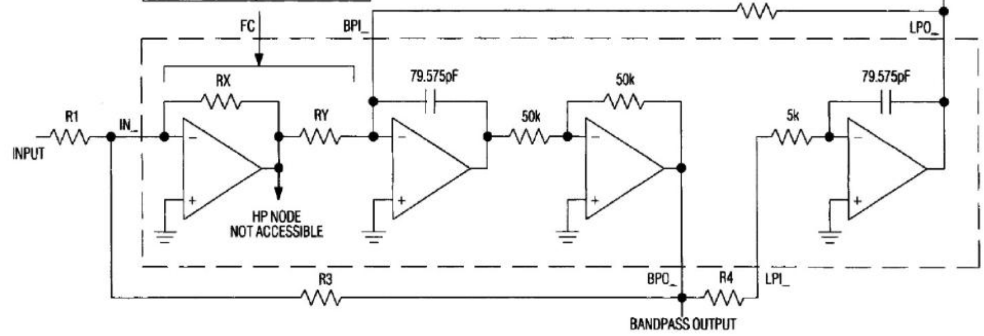
$$\Omega_{PB} = \omega_0 \Omega_{PBN} \quad Q = Q_{PBN}$$

$$f_{PB,1} = f_{PB,2} = 1 \text{ kHz}$$
$$Q_{PB,1} = 1.3065$$
$$Q_{PB,2} = 0.541196$$

MAX274.asc

# Exemple : Structure Biquad (MAX274)

| CONNECT FC TO: | RY/RX* (kΩ) |
|---|---|
| V+ | 13/52 |
| GND | 65/13 |
| V- | 325/13 |




$$H_{LP}(s) = K\frac{\omega_0^2}{s^2 + s\frac{\omega_0}{Q} + \omega_0^2} \qquad \omega_0 = \frac{1}{C\sqrt{R_2(R_4 + 5\ \text{k}\Omega)}} \qquad K = -\frac{R_2}{R_1}\left(\frac{R_X}{R_Y}\right)$$

$$H_{BP}(s) = K'\frac{s\frac{\omega_0}{Q}}{s^2 + s\frac{\omega_0}{Q} + \omega_0^2} \qquad Q = \frac{R_3}{\sqrt{R_2(R_4 + 5\ \text{k}\Omega)}}\left(\frac{R_Y}{R_X}\right) \qquad K' = -\frac{R_3}{R_1}$$

## 8 Égalisation des parametres

On suppose que

$$R_4 + 5\ \text{k}\Omega = R_2$$

FC = GND

**Section 1 :**

$$R_2 = \frac{2\times 10^9}{f_0} \approx 2\ \text{M}\Omega$$

$$R_4 = R_2 - 5\ \text{k}\Omega \approx 1.995\ \text{M}\Omega$$

$$R_3 = Q_{LP,1}R_2\left(\frac{R_X}{R_Y}\right) \approx 522.6\ \text{k}\Omega$$

$$R_1 = \frac{R_2}{H_{OLP}}\left(\frac{R_X}{R_Y}\right) \approx 400\ \text{k}\Omega$$

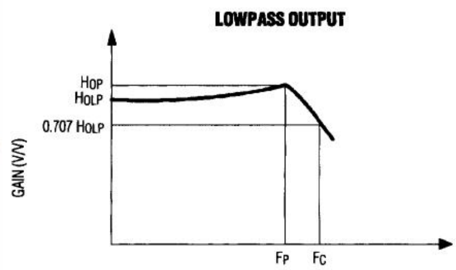
**Section 2 :**

$$R_2 = \frac{2\times 10^9}{f_0} \approx 2\ \text{M}\Omega$$

$$R_4 = R_2 - 5\ \text{k}\Omega \approx 1.995\ \text{M}\Omega$$

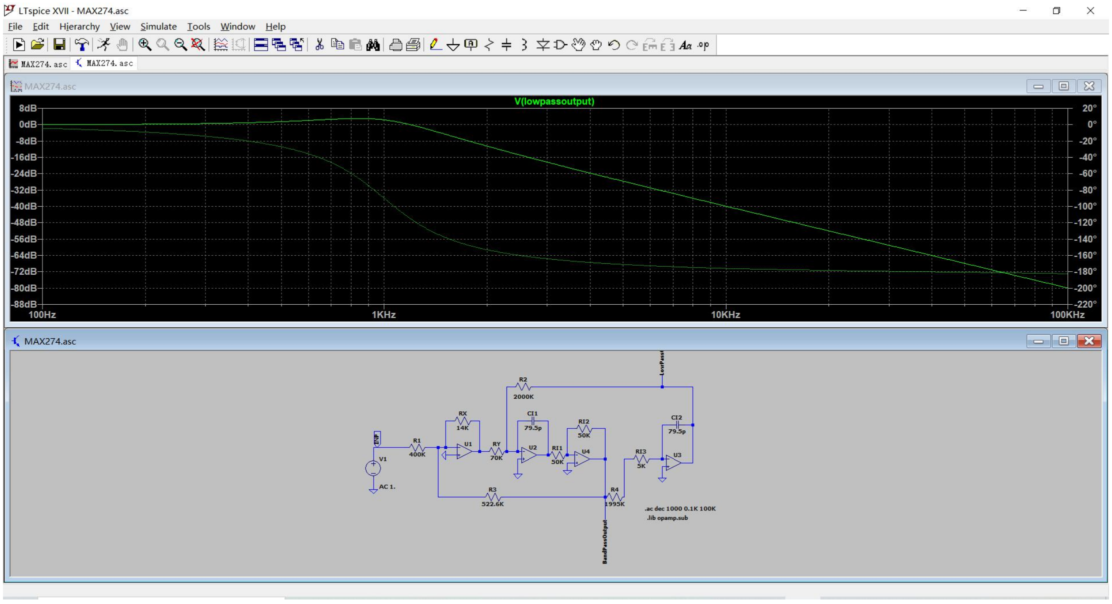
$$R_3 = Q_{LP,1}R_2\left(\frac{R_X}{R_Y}\right) \approx 216.48\ \text{k}\Omega$$

$$R_1 = \frac{R_2}{H_{OLP}}\left(\frac{R_X}{R_Y}\right) \approx 400\ \text{k}\Omega$$

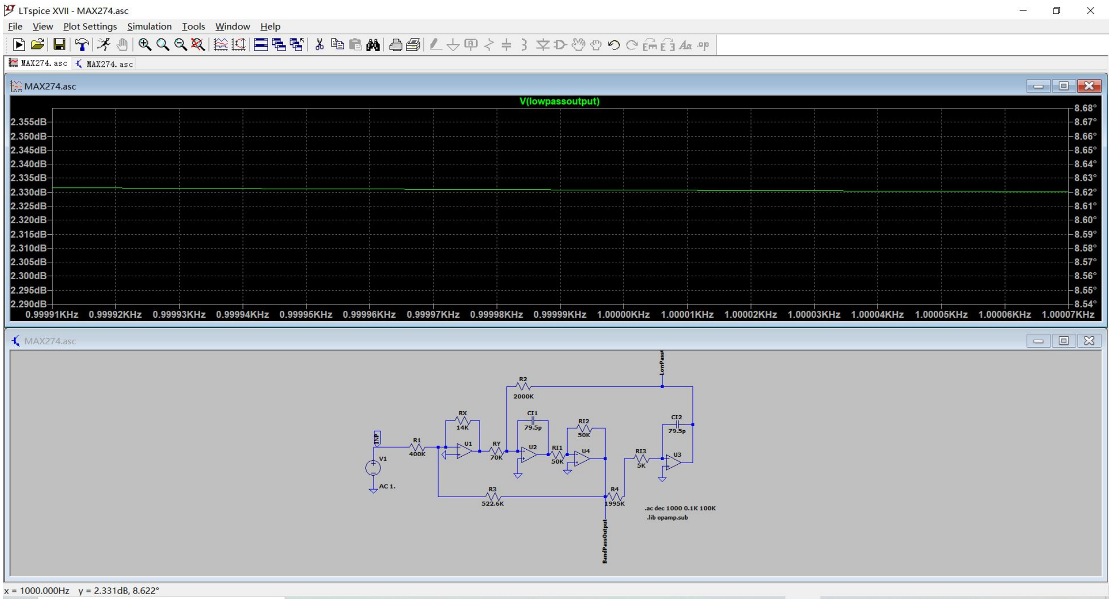



centralelille

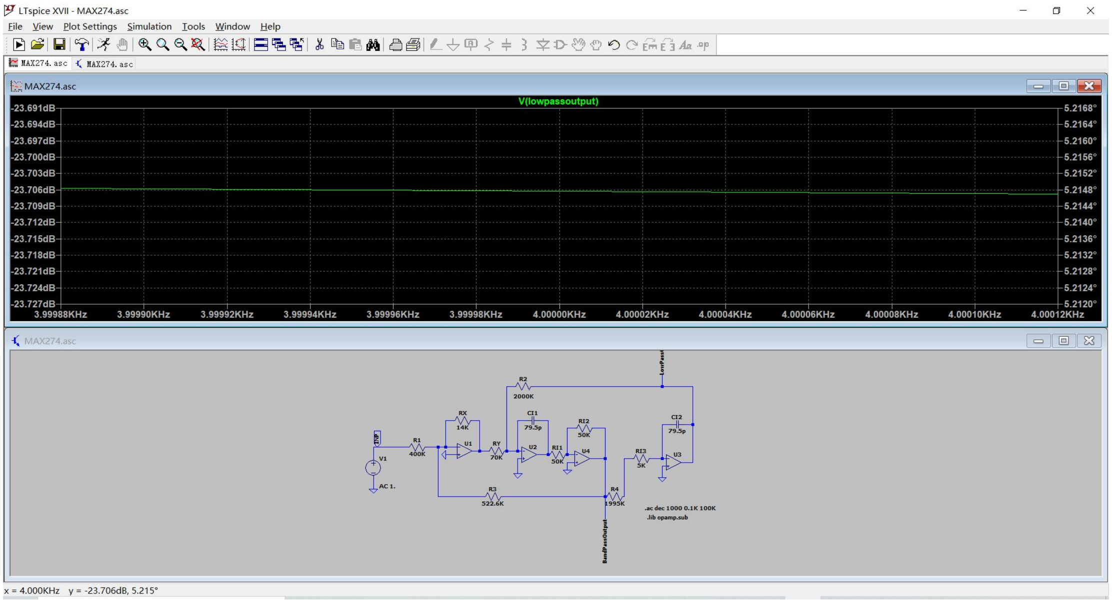
Donc, pour le section 1



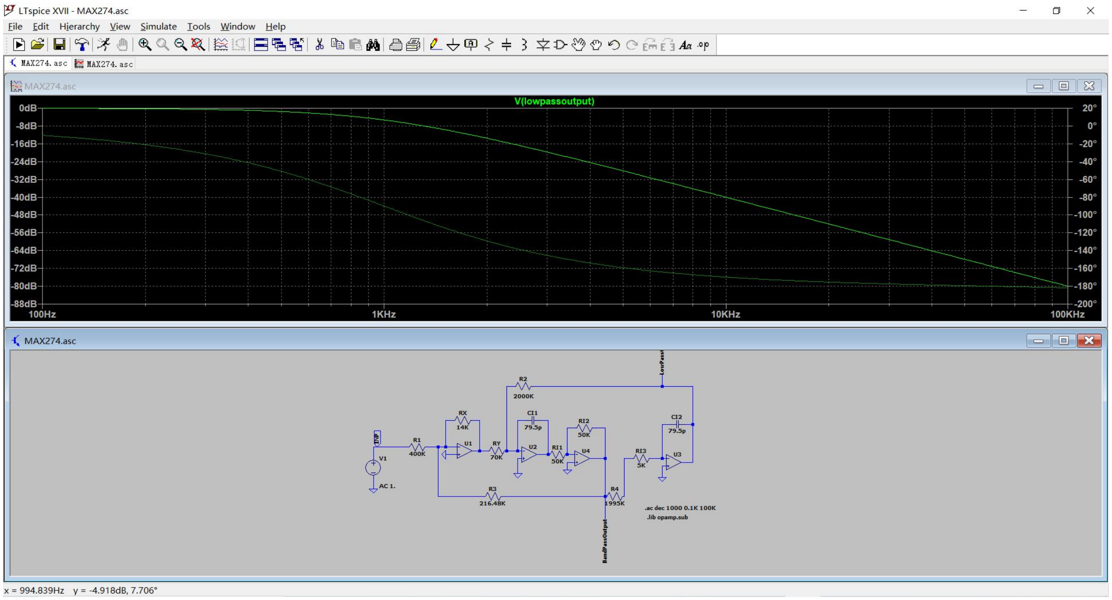
Pour le courbe au-déssus de -3dB à 1kHz



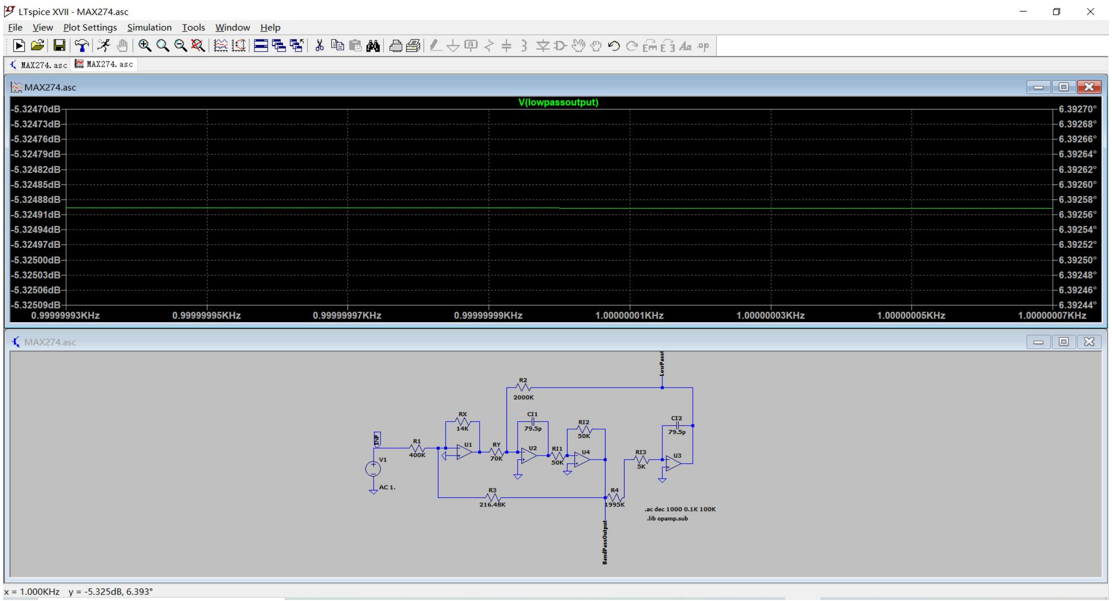
il est au-déssus de -45dB à 4kHz



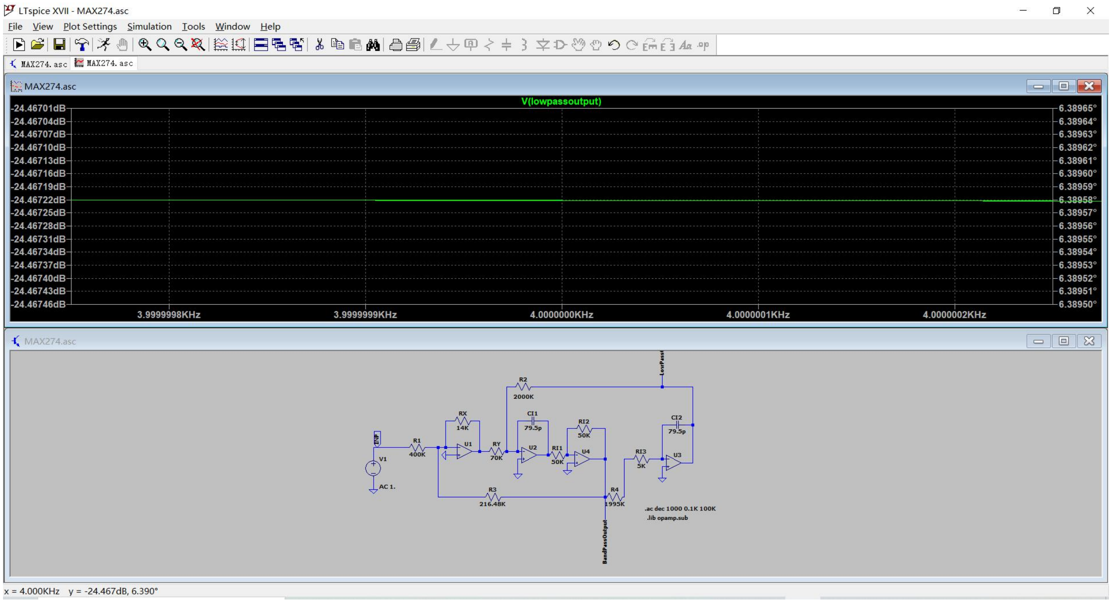
Pour la section 2




Le courbe est au-dessous de -3dB à 1kHz

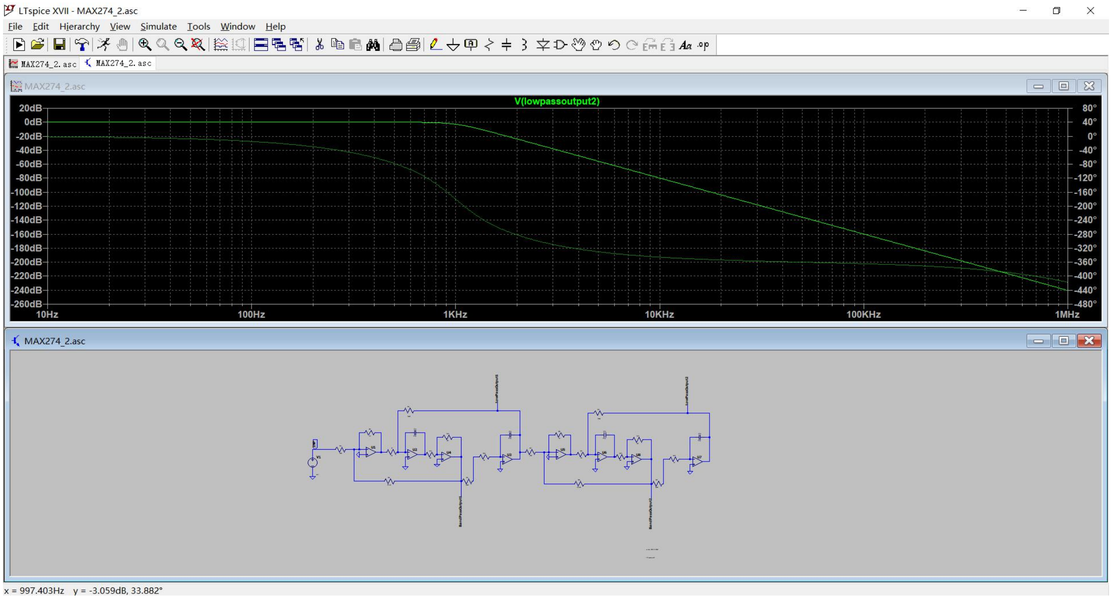


il est aussi au-déssus de -45dB à 4kHz

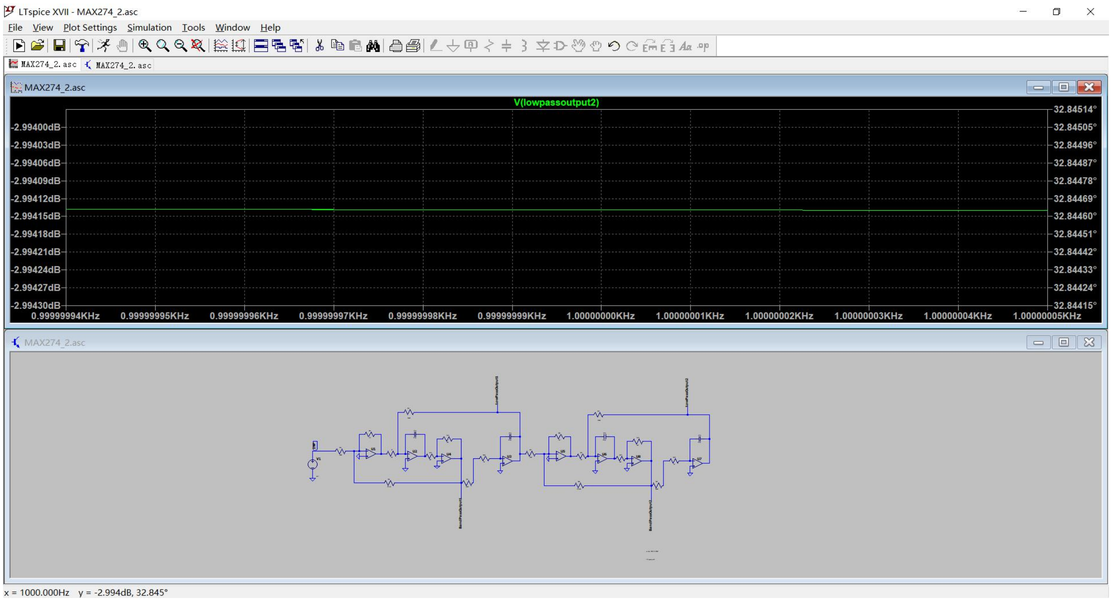


MAX274_2.asc

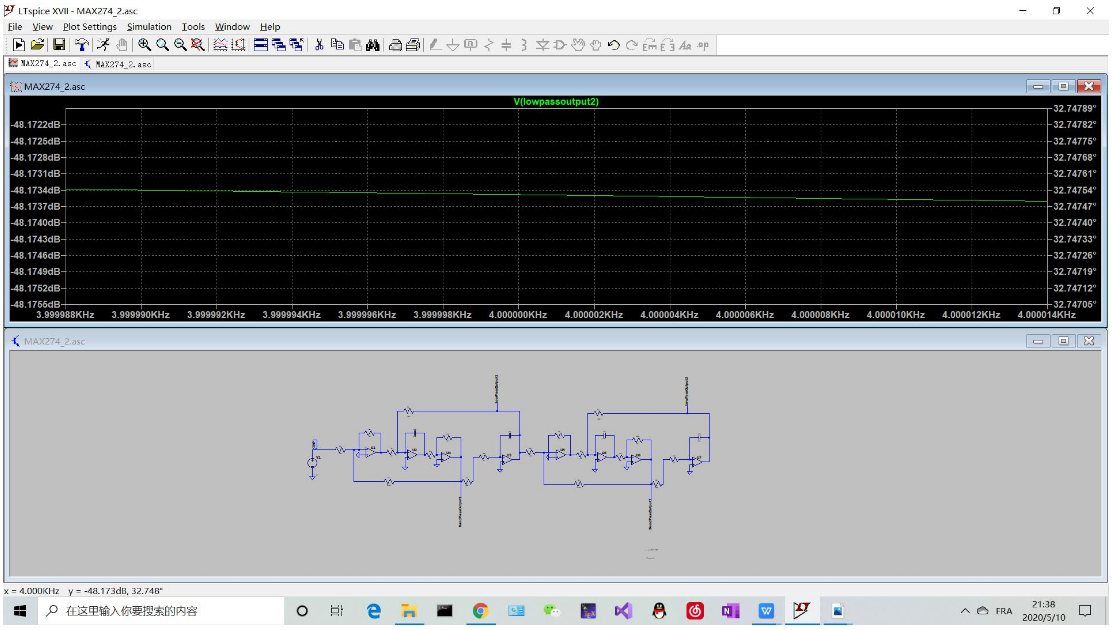
Deux section en semble



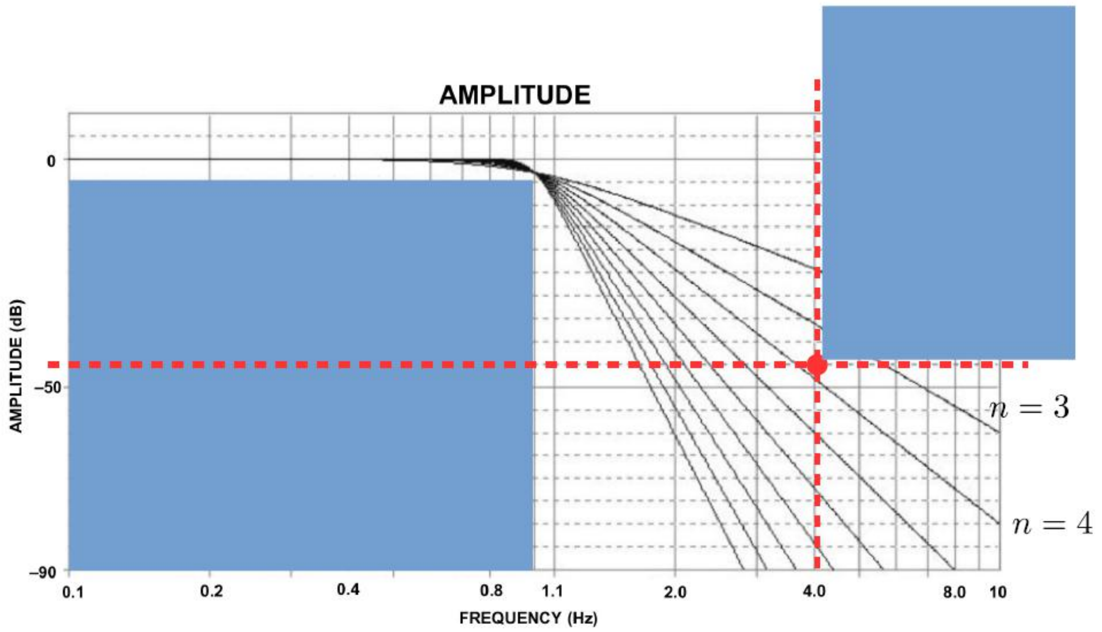

On peut voir que le courbe est presque à 3dB à 1kHz



il est au-dessous de -45dB à 4kHz




En comparant la figure et celle de ButterWorth


il est un filtre Butterworth avec la fréquence coupure de 1kHz, un bande d'arrêt de 4kHz et son atténuation minimale de 45dB. Donc, cela répond bien au cahier des charges.

Q2

| Type de filtre | Passe-bande |
|---|---|
| Fréquence centrale | 10 kHz |
| Bande passante (BP) | $B = 1$ kHz |
| Bande d'atténuation (BA) | $B' = 3$ kHz |
| Atténuation minimale dans la BA | 10 dB |
| Contrainte | Amplitude la plus plate possible dans la BP |

$$Q = \frac{\omega_0}{2\pi B} = \frac{1}{2}\sqrt{\frac{C_2}{C_1}} \qquad \omega_0 = 2\pi f_0 = \frac{1}{R\sqrt{C_1 C_2}}$$

Donc, $Q = \dfrac{2\times 10\times \pi}{2\times \pi\times 1} = 10$

*Avec les expression données dans le cours ou dans la fiche technique du composant MAX274, on détermine les valeurs des résistances. Avec la fréquence centrale:*

$$R_2 = \frac{1}{2\pi f_0 C} \approx 200\ k\Omega$$

*D'où:*

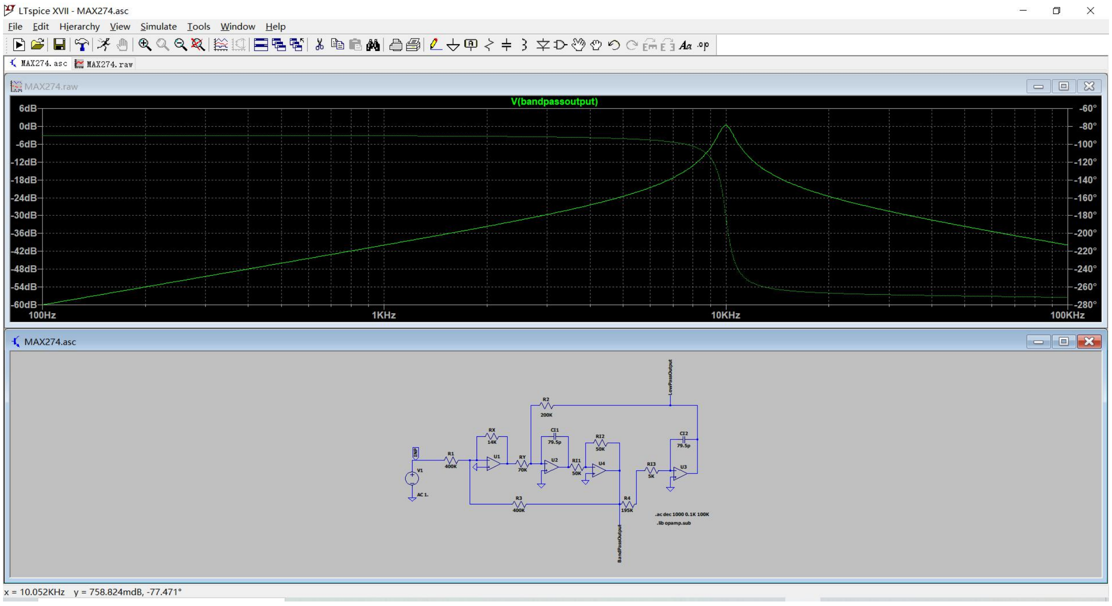
$$R_4 = R_2 - 5\ k\Omega \approx 195\ k\Omega$$

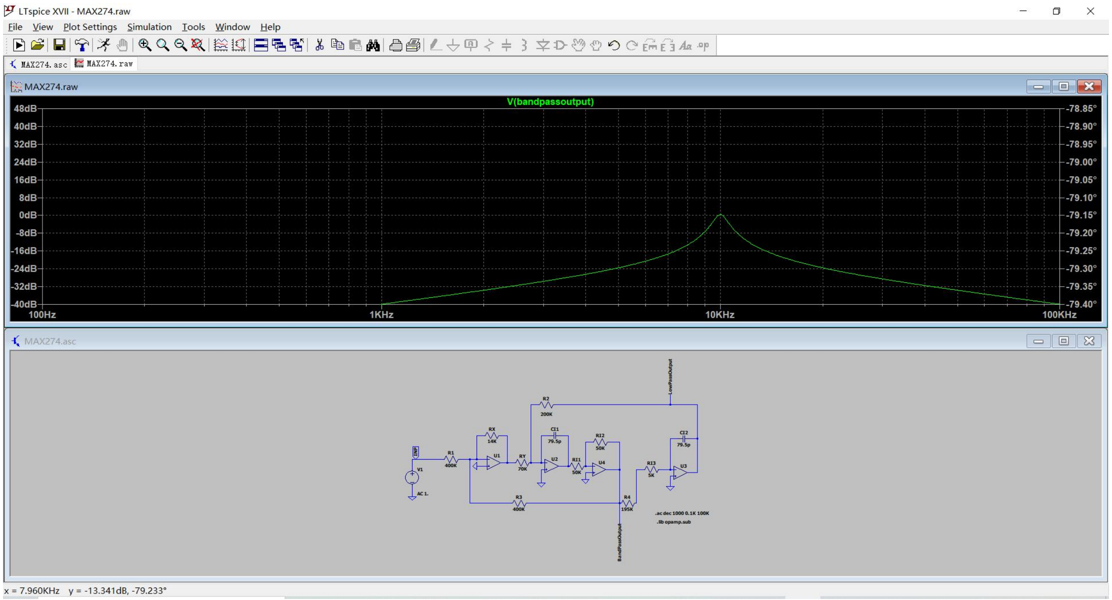
*Si on fixe $R_Y/R_X = 5$ (FC=GND), le facteur de qualité Q fixe la valeur de $R_3$:*

$$R_3 = Q\sqrt{R_2(R_4 + 5\ k\Omega)}\frac{R_X}{R_Y} \approx 400\ k\Omega$$

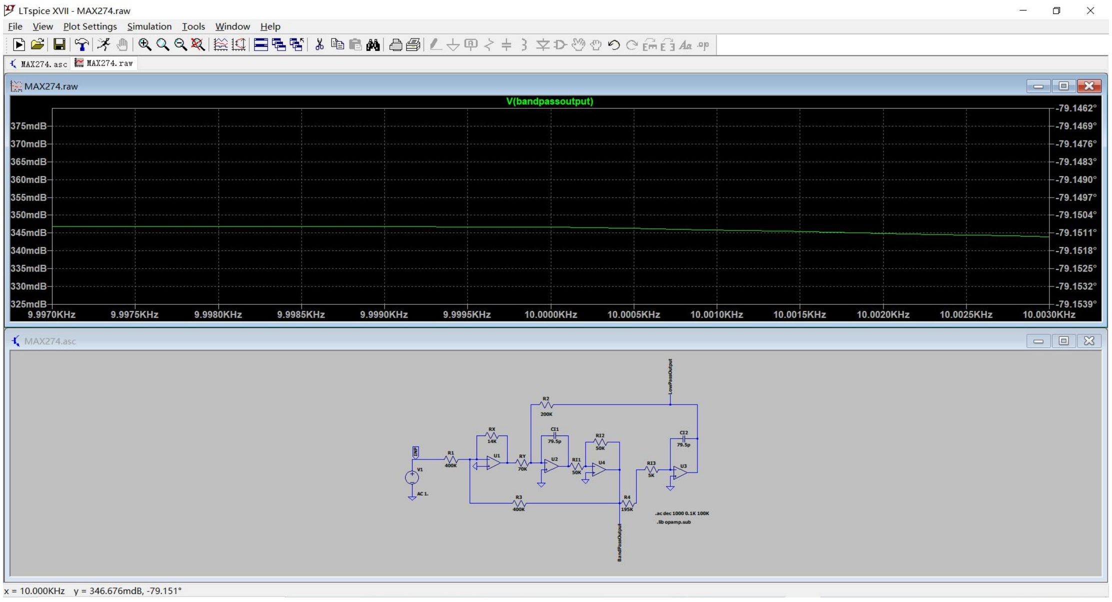
*Pour finir, si on souhaite un gain statique $K = 1$, on détermine $R_1$:*

$$R_1 = \frac{R_3}{K} \approx 400\ k\Omega$$

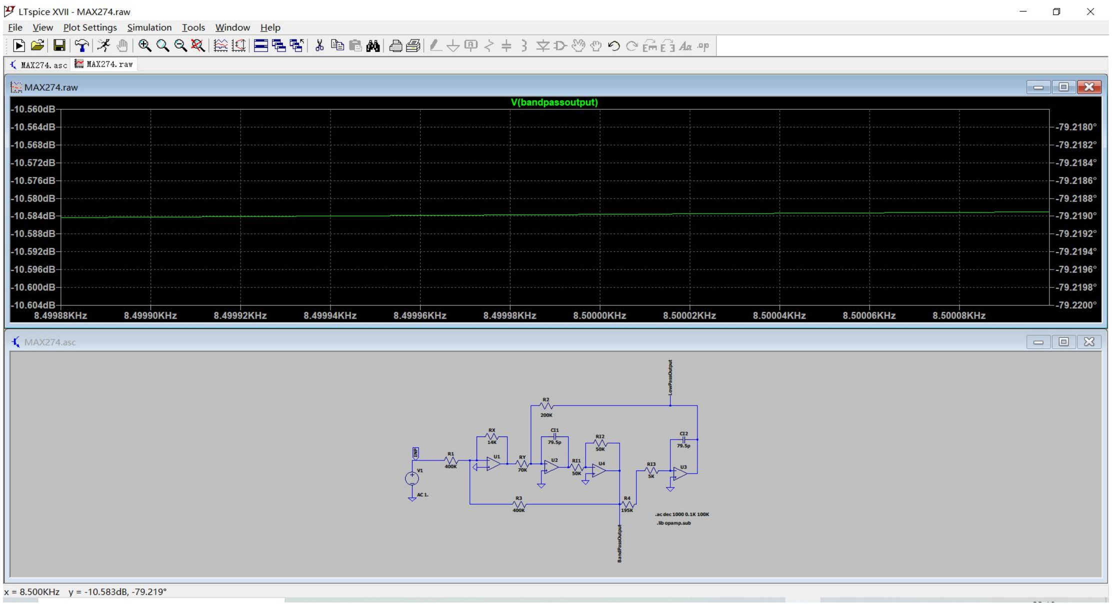




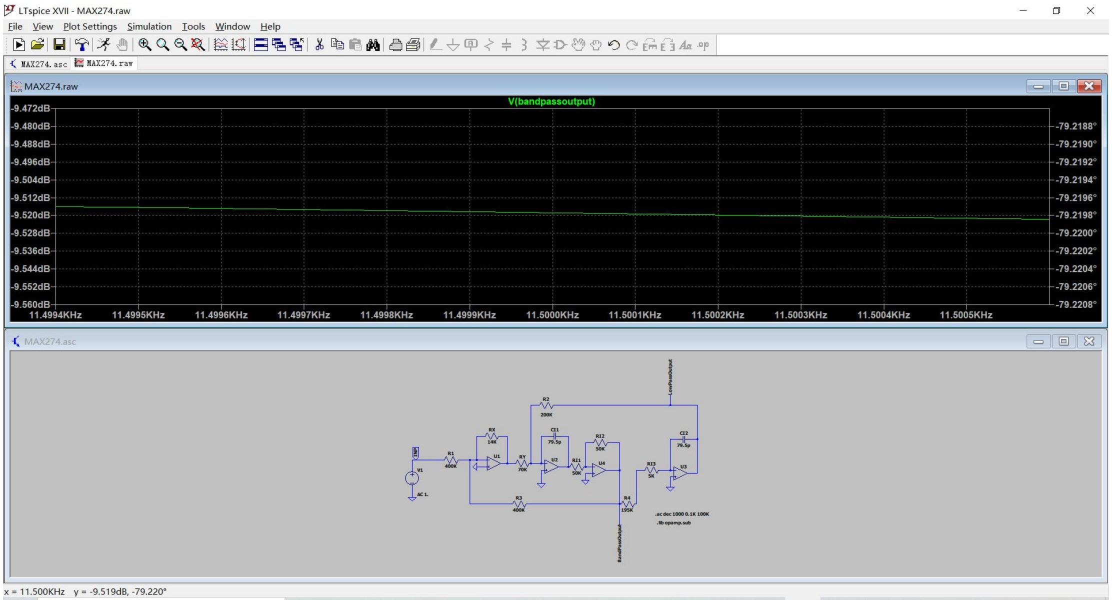
$f_0$=10kHz



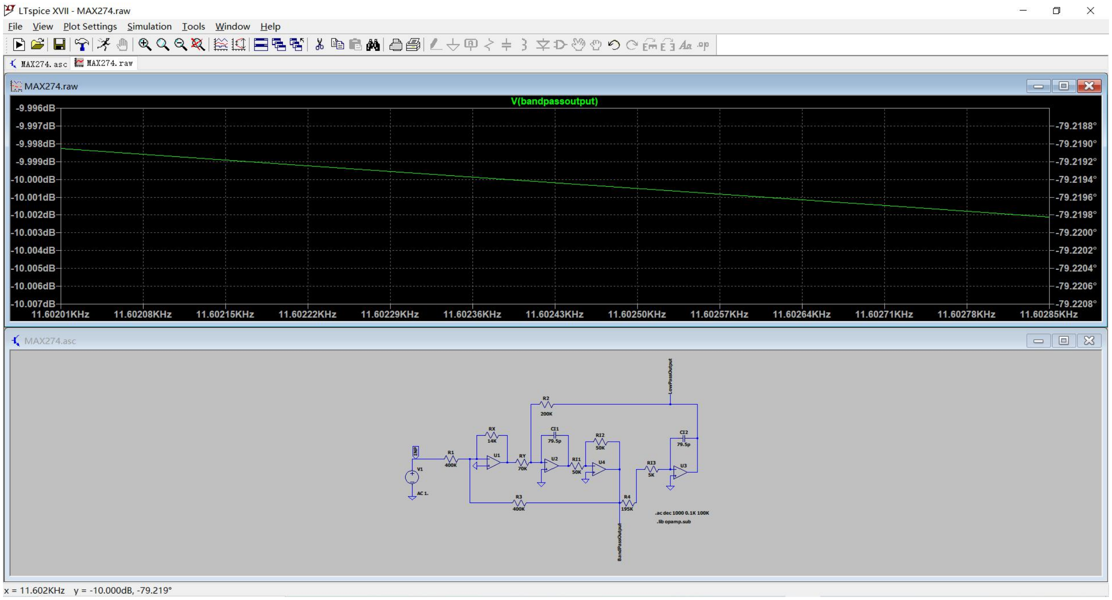
Le courbe est -10.583dB à 8.5kHz



Le courbe est -9.519dB à 11.5kHz

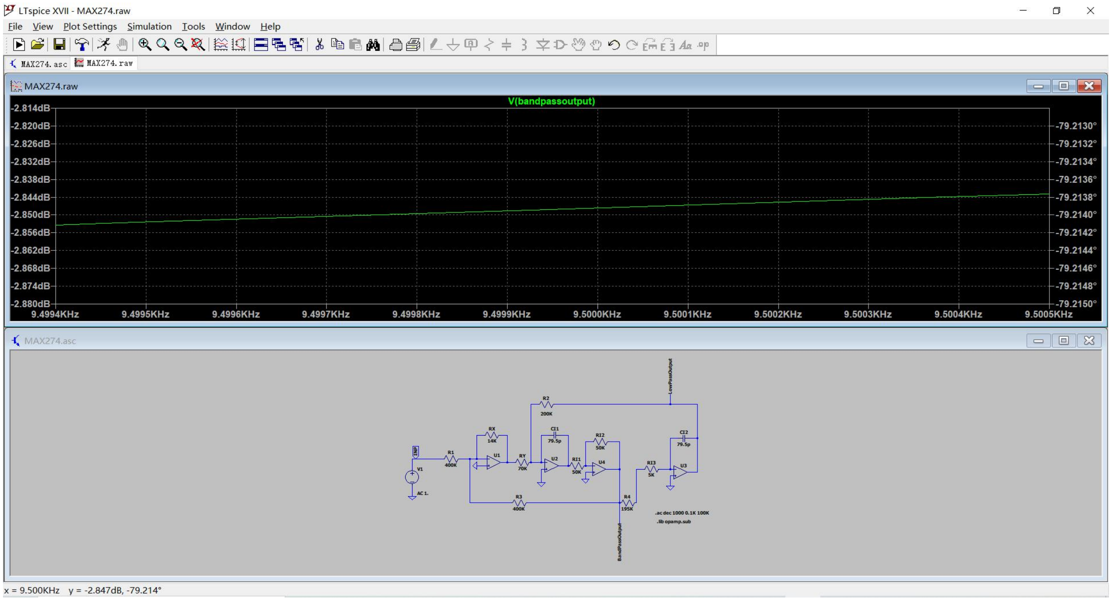


Le courbe est -10dB à 11.602kHz

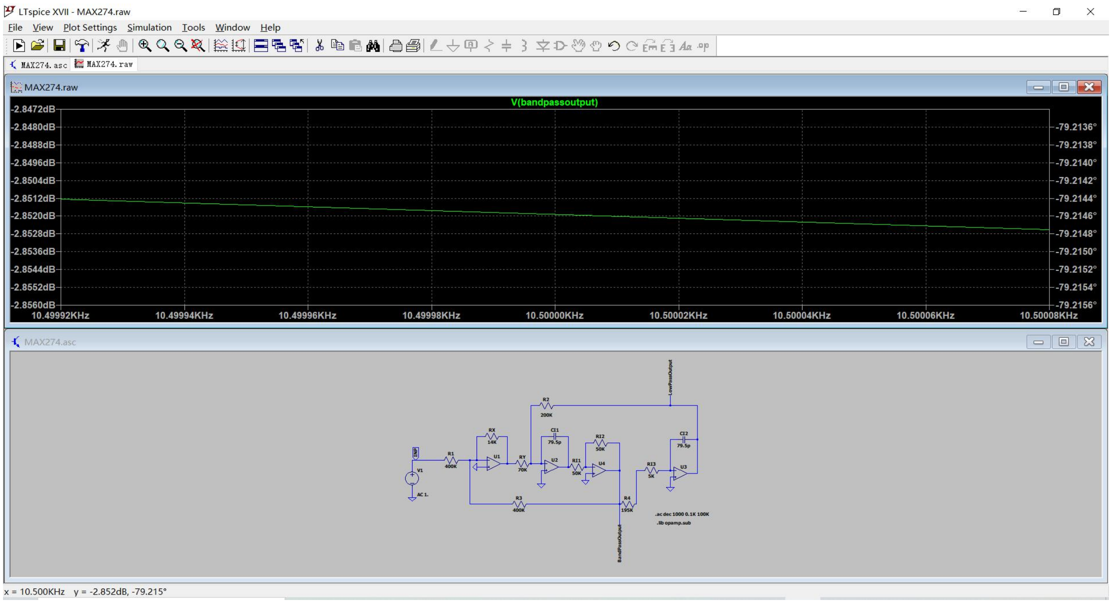


Donc, B'=3kHz

Le courbe est -2.847dB à 9.5kHz




Le courbe est -2.852dB à 10.5kHz




Donc, B=1kHz

Donc, il est un filtre Butterworth avec la fréquence de coupure de 10kHz, un bande passante de 1kHz, un dande d’attéuation de 3kHz et son atténuation minimale de 10dB. Donc il répond bien au cahier des charges.

Q3

On prendra $R = 10\ \mathrm{k}\Omega$.

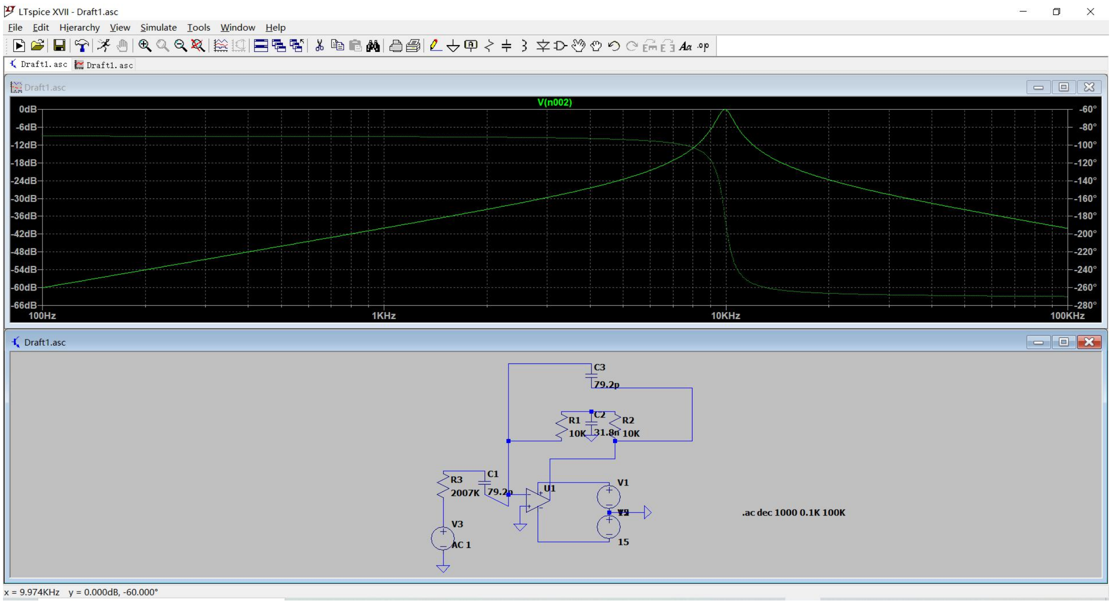
$\omega_0 = 2\pi f_0$

$$C_2 = \frac{1}{\pi B R}\ et\ C_1 = \frac{1}{R^2\omega_0^2 C_2} = \frac{\pi B}{R\omega_0^2}$$

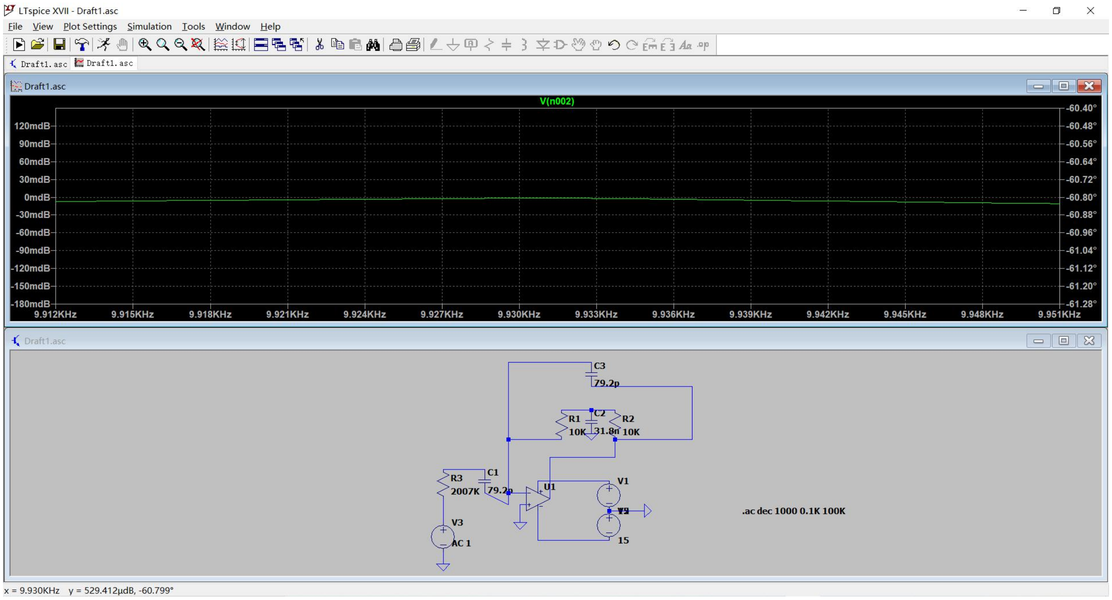
$$C_2 \approx 31,8\ nF\ et\ C_1 \approx 79,2\ pF$$

Donc, R3=(R*C2)/(2*C1)=2007KΩ

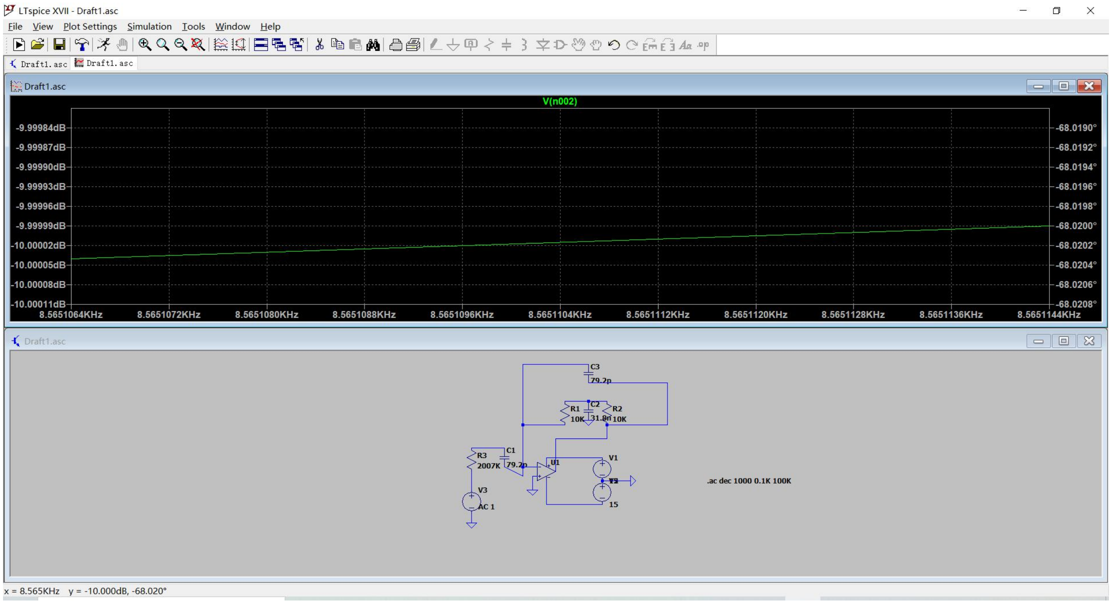
C3=C1 R2=R1=R



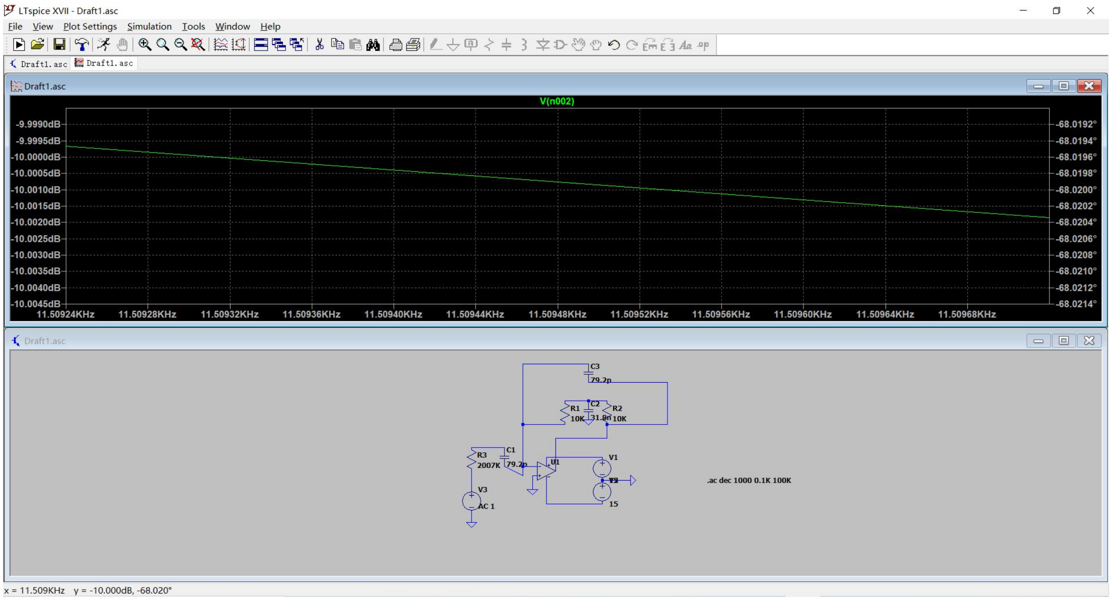
On peut obtenir $f_0$=9.930kHz




(8.565kHz,-10dB)

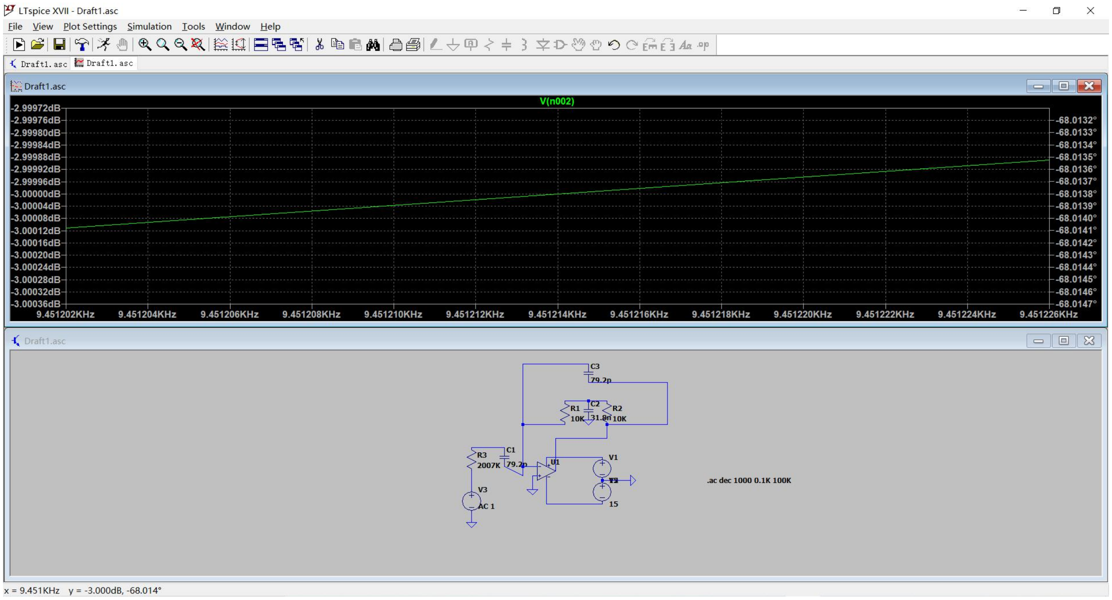


(11.509kHz,-10dB)

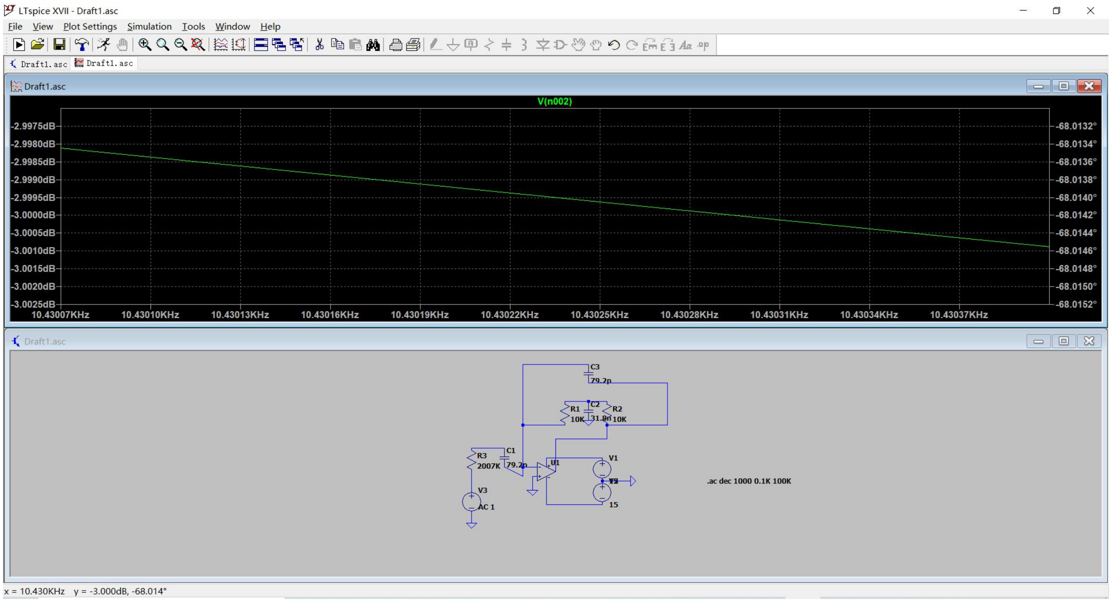


Donc, B'=3.056kHz≈3kHz

(9.451kHz,-3dB)




(10.430kHz,-3dB)




Donc, B=0.979kHz≈1kHz

Donc, c'est un filtre passe-bande Butterworth avec lafréquence de coupure de 10kHz, bande passante de 1kHz, bande d'atténuation de 3kHz, et atténuation minimale de 10dB.

Donc il répond bien au cahier des charges.