Обобщённая расстройка:

$$\xi(f_0) = Q \cdot \left(\frac{f_0}{f_0} - \frac{f_0}{f_0} \right) = 0$$

$$\xi(f_0 + F) = Q \cdot \left(\frac{f_0 + F}{f_0} - \frac{f_0}{f_0 + F} \right) = 50 \cdot \left(\frac{403}{400} - \frac{400}{403} \right) = 0{,}747$$

$$\xi(f_0 + 2F) = Q \cdot \left(\frac{f_0 + 2F}{f_0} - \frac{f_0}{f_0 + 2F} \right) = 50 \cdot \left(\frac{406}{400} - \frac{400}{406} \right) = 1{,}489$$

$$\xi(f_0 - F) = Q \cdot \left(\frac{f_0 - F}{f_0} - \frac{f_0}{f_0 - F} \right) = 50 \cdot \left(\frac{397}{400} - \frac{400}{397} \right) = -0{,}753$$

$$\xi(f_0 - 2F) = Q \cdot \left(\frac{f_0 - 2F}{f_0} - \frac{f_0}{f_0 - 2F} \right) = 50 \cdot \left(\frac{394}{400} - \frac{400}{394} \right) = -1{,}511$$

Расчет параметров для одноконтурного усилителя:

Коэффициент усиления:

$$|K(f)| = \frac{k_p}{\sqrt{1 + (\xi(f))^2}} \qquad |K(f_0)| = \frac{k_p}{\sqrt{1 + (\xi(f_0))^2}} = k_p = 100$$

$$|K(f_0 + F)| = \frac{k_p}{\sqrt{1 + (\xi(f_0 + F))^2}} = \frac{100}{\sqrt{1 + (0{,}747)^2}} = \frac{100}{1{,}248} = 80{,}107$$

$$|K(f_0 + 2F)| = \frac{k_p}{\sqrt{1 + (\xi(f_0 + 2F))^2}} = \frac{100}{\sqrt{1 + (1{,}489)^2}} = \frac{100}{1{,}794} = 55{,}755$$

$$|K(f_0 - F)| = \frac{k_p}{\sqrt{1 + (\xi(f_0 - F))^2}} = \frac{100}{\sqrt{1 + (-0{,}753)^2}} = \frac{100}{1{,}252} = 79{,}891$$

$$|K(f_0 - 2F)| = \frac{k_p}{\sqrt{1 + (\xi(f_0 - 2F))^2}} = \frac{100}{\sqrt{1 + (-1{,}511)^2}} = \frac{100}{1{,}812} = 55{,}179$$

Фаза усилителя:

$$arg(K(f)) = \operatorname{arctg}\left(\frac{Im\,K(f)}{Re\,K(f)} \right) = \Delta\varphi_p - \operatorname{arctg}(\xi(f))$$

$$arg(K(f_0)) = \Delta\varphi_{p1} - \operatorname{arctg}(\xi(f_0)) = 180^\circ - 0 = 180^\circ$$

$$arg(K(f_0+F)) = \Delta\varphi_{p1} - \operatorname{arctg}(\xi(f_0+F)) = \Delta\varphi_{p1} - \operatorname{arctg}(0{,}747) = 180^\circ - 36{,}767^\circ = 143{,}233^\circ$$

$$arg(K(f_0+2F)) = \Delta\varphi_{p1} - \operatorname{arctg}(\xi(f_0+2F)) = \Delta\varphi_{p1} - \operatorname{arctg}(1{,}489) = 180^\circ - 56{,}114^\circ = 123{,}886^\circ$$

$$arg(K(f_0-F)) = \Delta\varphi_{p1} - \operatorname{arctg}(\xi(f_0-F)) = \Delta\varphi_{p1} - \operatorname{arctg}(-0{,}753) = 180^\circ + 36{,}974^\circ = 216{,}974^\circ$$

$$arg(K(f_0-2F)) = \Delta\varphi_{p1} - \operatorname{arctg}(\xi(f_0-2F)) = \Delta\varphi_{p1} - \operatorname{arctg}(-1{,}511) = 180^\circ + 56{,}51^\circ = 236{,}51^\circ$$

Выходное напряжение:

$$U_{вых}(f) = U_{вх}(f) \cdot |K(f)|$$

$$U_{вых}(f_0) = U_{вх}(f_0) \cdot |K(f_0)| = U_0 \cdot k_p = 100 \times 10^{-6} \cdot 100 = 10\,мВ$$

$$U_{вых}(f_0+F) = U_{вх}(f_0+F) \cdot |K(f_0+F)| = \frac{U_0 M_1}{2} \cdot |K(f_0+F)| = \frac{100 \times 10^{-6} \cdot 0{,}5}{2} \cdot 80{,}107 = 2{,}003\,мВ$$

$$U_{вых}(f_0+2F) = U_{вх}(f_0+2F) \cdot |K(f_0+2F)| = \frac{U_0 M_2}{2} \cdot |K(f_0+2F)| = \frac{100 \times 10^{-6} \cdot 0{,}3}{2} \cdot 55{,}755 = 0{,}836\ мВ$$

$$U_{вых}(f_0-F) = U_{вх}(f_0-F) \cdot |K(f_0-F)| = \frac{U_0 M_1}{2} \cdot |K(f_0-F)| = \frac{100 \times 10^{-6} \cdot 0{,}5}{2} \cdot 79{,}891 = 1{,}997\ мВ$$

$$U_{вых}(f_0-2F) = U_{вх}(f_0-2F) \cdot |K(f_0-2F)| = \frac{U_0 M_2}{2} \cdot |K(f_0-2F)| = \frac{100 \times 10^{-6} \cdot 0{,}3}{2} \cdot 55{,}179 = 0{,}828\ мВ$$

Разность фаз:

$$\Psi_1(f) = arg(K(f)) + \varphi_1(f)$$

$$\Psi_1(f_0) = 180^\circ + 0^\circ = 180^\circ$$

$$\Psi_1(f_0+F) = 143{,}233^\circ + 90^\circ = 233{,}233^\circ$$

$$\Psi_1(f_0+2F) = 123{,}886^\circ - 40^\circ = 83{,}886^\circ$$

$$\Psi_1(f_0-F) = 216{,}974^\circ - 90^\circ = 126{,}974^\circ$$

$$\Psi_1(f_0-2F) = 236{,}51^\circ + 40^\circ = 276{,}51^\circ$$

Расчет параметров для двухконтурного усилителя:

Коэффициент усиления:

$$\left|K(f)\right| = \frac{k_p\left(1+A^2\right)}{\sqrt{\left(1+A^2-\xi(f)^2\right)^2+\left(2\cdot\xi(f)\right)^2}}$$

$$\left|K(f_0)\right| = \frac{k_p\left(1+A^2\right)}{\sqrt{\left(1+A^2-\xi(f_0)^2\right)^2+\left(2\cdot\xi(f_0)\right)^2}} = \frac{k_p\left(1+A^2\right)}{\sqrt{\left(1+A^2\right)^2}} = k_p = 100$$

$$\left|K(f_0+F)\right| = \frac{k_p\left(1+A^2\right)}{\sqrt{\left(1+A^2-\xi(f_0+F)^2\right)^2+\left(2\cdot\xi(f_0+F)\right)^2}} = \frac{100\left(1+1{,}6^2\right)}{\sqrt{\left(1+1{,}6^2-0{,}747^2\right)^2+\left(2\cdot 0{,}747\right)^2}} = 106{,}17$$

$$\left|K(f_0+2F)\right| = \frac{k_p\left(1+A^2\right)}{\sqrt{\left(1+A^2-\xi(f_0+2F)^2\right)^2+\left(2\cdot\xi(f_0+2F)\right)^2}} = \frac{100\left(1+1{,}6^2\right)}{\sqrt{\left(1+1{,}6^2-1{,}489^2\right)^2+\left(2\cdot 1{,}489\right)^2}} = 109{,}978$$

$$\left|K(f_0-F)\right| = \frac{k_p\left(1+A^2\right)}{\sqrt{\left(1+A^2-\xi(f_0-F)^2\right)^2+\left(2\cdot\xi(f_0-F)\right)^2}} = \frac{100\left(1+1{,}6^2\right)}{\sqrt{\left(1+1{,}6^2-(-0{,}753)^2\right)^2+\left(2\cdot(-0{,}753)\right)^2}} = 106{,}25$$

$$\left|K(f_0-2F)\right| = \frac{k_p\left(1+A^2\right)}{\sqrt{\left(1+A^2-\xi(f_0-2F)^2\right)^2+\left(2\cdot\xi(f_0-2F)\right)^2}} = \frac{100\left(1+1{,}6^2\right)}{\sqrt{\left(1+1{,}6^2-(-1{,}511)^2\right)^2+\left(2\cdot(-1{,}511)\right)^2}} = 108{,}505$$

Фаза усилителя:

$$arg(K(f)) = \operatorname{arctg}\left(\frac{Im\,K(f)}{Re\,K(f)}\right) = \Delta\varphi_p - \operatorname{arctg}\left(\frac{2\xi(f)}{1+A^2-\xi(f)^2}\right)$$

$$arg(K(f_0)) = \Delta\varphi_{p2} - \operatorname{arctg}\left(\frac{2\xi(f_0)}{1+A^2-\xi(f_0)^2}\right) = -90^\circ - 0 = -90^\circ$$

$$arg(K(f_0+F)) = \Delta\varphi_{p2} - \operatorname{arctg}\left(\frac{2\cdot\xi(f_0+F)}{1+A^2-\xi(f_0+F)^2}\right) =$$

$$= -90^\circ - \operatorname{arctg}\left(\frac{2\cdot 0{,}747}{1+1{,}6^2-0{,}747^2}\right) = -90^\circ - 26{,}467^\circ = -116{,}467^\circ$$

$$arg(\mathrm{K}(\mathrm{f}_0+2\mathrm{F}))=\Delta\varphi_{\mathrm{p}2}-\operatorname{arctg}\left(\frac{2\cdot\xi(\mathrm{f}_0+2\mathrm{F})}{1+\mathrm{A}^2-\xi(\mathrm{f}_0+2\mathrm{F})^2}\right)=$$

$$=-90^\circ-\operatorname{arctg}\left(\frac{2\cdot 1{,}489}{1+1{,}6^2-1{,}489^2}\right)=-90^\circ-65{,}723^\circ=-155{,}723^\circ$$

$$arg(\mathrm{K}(\mathrm{f}_0-\mathrm{F}))=\Delta\varphi_{\mathrm{p}2}-\operatorname{arctg}\left(\frac{2\cdot\xi(\mathrm{f}_0-\mathrm{F})}{1+\mathrm{A}^2-\xi(\mathrm{f}_0-\mathrm{F})^2}\right)=$$

$$=-90^\circ-\operatorname{arctg}\left(\frac{2\cdot(-0{,}753)}{1+1{,}6^2-(-0{,}753)^2}\right)=-90^\circ+26{,}703^\circ=-63{,}297^\circ$$

$$arg(\mathrm{K}(\mathrm{f}_0-\mathrm{F}))=\Delta\varphi_{\mathrm{p}2}-\operatorname{arctg}\left(\frac{2\cdot\xi(\mathrm{f}_0-2\mathrm{F})}{1+\mathrm{A}^2-\xi(\mathrm{f}_0-2\mathrm{F})^2}\right)=$$

$$=-90^\circ-\operatorname{arctg}\left(\frac{2\cdot(-1{,}511)}{1+1{,}6^2-(-1{,}511)^2}\right)=-90^\circ+67{,}121^\circ=-22{,}879^\circ$$

Выходное напряжение:

$$\mathrm{U}_{\text{вых}}(\mathrm{f})=\mathrm{U}_{\text{вх}}(\mathrm{f})\cdot|\mathrm{K}(\mathrm{f})|$$

$$\mathrm{U}_{\text{вых}}(\mathrm{f}_0)=\mathrm{U}_{\text{вх}}(\mathrm{f}_0)\cdot|\mathrm{K}(\mathrm{f}_0)|=\mathrm{U}_0\cdot\mathrm{k}_{\mathrm{p}}=100\times10^{-6}\cdot100=10\,\text{мВ}$$

$$\mathrm{U}_{\text{вых}}(\mathrm{f}_0+\mathrm{F})=\mathrm{U}_{\text{вх}}(\mathrm{f}_0+\mathrm{F})\cdot|\mathrm{K}(\mathrm{f}_0+\mathrm{F})|=\frac{\mathrm{U}_0\mathrm{M}_1}{2}\cdot|\mathrm{K}(\mathrm{f}_0+\mathrm{F})|=$$

$$=\frac{100\times10^{-6}\cdot0{,}5}{2}\cdot106{,}17=2{,}654\,\text{мВ}$$

$$\mathrm{U}_{\text{вых}}(\mathrm{f}_0+2\mathrm{F})=\mathrm{U}_{\text{вх}}(\mathrm{f}_0+2\mathrm{F})\cdot|\mathrm{K}(\mathrm{f}_0+2\mathrm{F})|=\frac{\mathrm{U}_0\mathrm{M}_2}{2}\cdot|\mathrm{K}(\mathrm{f}_0+2\mathrm{F})|=$$

$$=\frac{100\times10^{-6}\cdot0{,}3}{2}\cdot109{,}978=1{,}635\,\text{мВ}$$

$$\mathrm{U}_{\text{вых}}(\mathrm{f}_0-\mathrm{F})=\mathrm{U}_{\text{вх}}(\mathrm{f}_0-\mathrm{F})\cdot|\mathrm{K}(\mathrm{f}_0-\mathrm{F})|=\frac{\mathrm{U}_0\mathrm{M}_1}{2}\cdot|\mathrm{K}(\mathrm{f}_0-\mathrm{F})|=$$

$$=\frac{100\times10^{-6}\cdot0{,}5}{2}\cdot106{,}25=2{,}656\ \text{мВ}$$

$$U_{вых}(f_0 - 2F) = U_{вх}(f_0 - 2F) \cdot |K(f_0 - 2F)| = \frac{U_0 M_2}{2} \cdot |K(f_0 - 2F)| =$$

$$= \frac{100 \times 10^{-6} \cdot 0{,}3}{2} \cdot 108{,}505 = 1{,}628 \text{ мВ}$$

Разность фаз:

$$\Psi_2(f) = arg(K(f)) + \varphi_2(f)$$

$$\Psi_2(f_0) = -90^\circ + 0^\circ = -90^\circ$$

$$\Psi_2(f_0 + F) = -116{,}467^\circ + 90^\circ = -26{,}467^\circ$$

$$\Psi_2(f_0 + 2F) = -155{,}723^\circ - 40^\circ = 195{,}723^\circ$$

$$\Psi_2(f_0 - F) = -63{,}297^\circ - 90^\circ = -153{,}297^\circ$$

$$\Psi_2(f_0 - 2F) = -22{,}879^\circ + 40^\circ = 17{,}121^\circ$$

f_n	f_0–2F	f_0–F	f_0	f_0+F	f_0+2F
f_n, кГц	394	397	400	403	406
U_n, мкВ	15	25	100	25	15
φ_n, гр	40°	-90°	0°	90°	-40°
Одноконтурный усилитель					
K	55,179	79,891	100	80,107	55,755
$\Delta\varphi$, гр	236,51°	216,974°	180°	143,233°	123,886°
$U_{вых.n}$, мВ	0,828	1,997	10	2,003	0,836
ψ_n, гр	276,51°	126,974°	180°	223,223°	83,886°
Двухконтурный усилитель					
K	108,505	106,25	100	106,17	108,978
$\Delta\varphi$, гр	-22,879°	-63,297°	-90°	-116,467°	-155,723°
$U_{вых.n}$, мВ	1,628	2,656	10	2,654	1,635
ψ_n, гр	17,121°	-153,297°	-90°	-26,467°	-195,723°