O‘ZBEKISTON RESPUBLIKASI
OLIY VA O‘RTA MAXSUS TA’LIM VAZIRLIGI

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RADIOTEXNIK ZANJIRLAR VA SIGNALLAR

fanidan amaliy mashg‘ulotlar uchun
o‘quv-uslubiy qo‘llanma

TOSHKENT – 2012

UDK 621.396.61

“Radiotexnik zanjirlar va signallar”. O‘quv-uslubiy qo‘llanma. / Hasanov M. M. Toshkent, ToshDTU, 2012.

Ushbu qo‘llanma 5311100 – „Radioelektron qurilmalar va tizimlar” va 5111000 – „Kasb ta’limi (Radioelektron qurilmalar va tizimlar)” yo‘nalishlar bo‘yicha ta’lim oluvchi talabalarga mo‘ljallangan bo‘lib, „Radiotexnik zanjirlar va signallar” fanining o‘quv dasturiga asosan amaliy mashg‘ulotlar uchun masalalar to‘plamini va ularni yechish uchun uslubiy ko‘rsatmalarni o‘z ichiga olgan.

Masalalar to‘plami talabalar tomondan ma’ruza mashg‘ulotlarida olgan nazariy bilimlarini mustahkamlash uchun mo‘ljallangan.

Abu Rayhon Beruniy nomidagi Toshkent davlat texnika universitetining ilmiy-uslubiy kengashi qarori bilan chop etildi.

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Muqaddima

Radiotexnika va radioelektronika sohasi bo‘yicha zamonaviy muhandislarni tayyorlashda „Radiotexnik zanjirlar va signallar” fani asosiy fanlardan biri hisoblanadi. Bu fanning asosiy maqsadi signallarni qanday qilib hosil qilish, ularni aloqa kanallari bo‘yicha uzatish, radiotexnik zanjirlarda signallarni qayta ishlash va o‘zgartirishlar bilan bog‘liq bo‘lgan fundamental qonuniyatlarni o‘rganishdan iborat. “Matematika”, “Fizika” va “Elektrotexnika nazariyalari asoslari” fanlariga tayanuvchi “Radiotexnik zanjirlar va signallar” fani talabalarni yangi tushunchalar va terminlar doirasiga olib kiradi va bularni chuqur bilish va o‘zlashtirish navbatdagi yo‘nalish fanlarini o‘rganishda katta omil hisoblanadi.

“Radiotexnik zanjirlar va signallar” fanida keltiriladigan signallarni va radiotexnik zanjirlarni tahlil qilish usullari talabalar uchun asosan avvalgi fanlardan ma’lum bo‘lgan matematik apparatlar hisoblanadi. “Radiotexnik zanjirlar va signallar” fanining asosiy vazifasi talabalarning yechilayotgan masalani aniq tasvirlovchi matematik apparatlarni tanlash, radiotexnika sohasi bo‘yicha konkret ilmiy va texnik masalalarni yechishda bu tanlangan matematik apparatlar qanday ishlashini ko‘rsatishdan iborat. Shu bilan bir qatorda talabalarni matematik ifodalash bilan ko‘rilayotgan hodisalarning fizik tomonlarini bog‘liqligini ko‘rish, o‘rganilayotgan jarayonlarga matematik modellar tuzishni o‘rganishdan iborat.

“Radiotexnik zanjirlar va signallar” fani ko‘rib chiqadigan masalalar – bular signallar nazariyasiga kiradigan masalalar: informatsion va boshqaruvchi signallarni spektral va korrelyatsion tahlil qilish; diskret va raqamli signallar nazariyasi asoslari; determik signallar bilan bir qatorda o‘rganiladigan tasodifiy signallar va xalaqitlarni statistik tahlil qilish; chiziqli zanjirlarda signallarni o‘zgartirish nazariyasi; nochiziq va parametrik qurilmalar nazariyasi kabilar.

1. Signal va uning matematik modeli

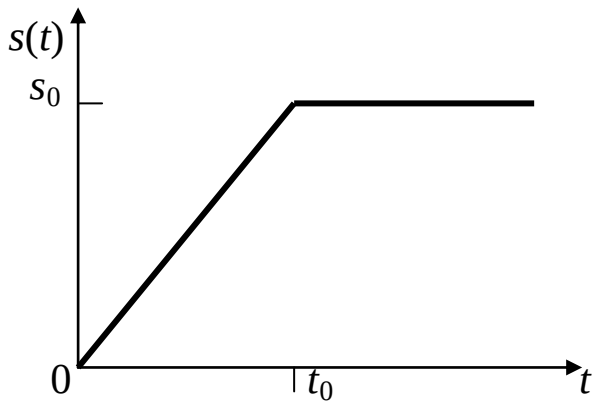
1.1. Kuchlanish o‘lchamiga ega (V) impulsli $u(t)$ signal quyidagi ifoda orqali berilgan:

$$u\,(t)=25[\exp(-10^5 t)-\exp(-2\cdot 10^5 t)]\sigma(t)$$

Topshiriq: berilgan impulsning grafigini quring. u_{max} signalning maksimal qiymatini va vaqtning maksimumga erishish t_{max} momentini aniqlang. Impuls davomiyligi τ_i ni vaqtning noldan signal oniy qiymati maksimal qiymatga nisbatan 10 barobar kamayadigan nuqtagacha bo‘lgan kesim uzunligi sifatida aniqlab hisoblang.

1.2. Signal $s(t)$ quyidagi matematik model ko‘rinishida berilgan (1.1-rasm):

$$s(t)=\begin{cases} 0, & t<0, \\ s_0(t/t_0), & 0\le t\le t_0, \\ s_0, & t>t_0. \end{cases}$$



1.1-rasm. $s(t)$ signalning grafik tasviri

Topshiriq: berilgan bog‘liqlikni qisman-chiziqli funksiyalar yig‘indisi ko‘rinishida tasvirlang.

1.3. Sig‘imi $C(t)=C_0(1+m\sin\Omega t)$ qonuniyat bo‘yicha o‘zgarayotgan kondensatorga $u(t)=U_1\sin\omega_1 t_1$, $-\infty<t<\infty$ kuchlanish ta’sir etmoqda.

Topshiriq: kuchlanish manbasidan olinayotgan tokni aniqlang va tokning spektral tarkibini tahlil qilib chiqing.

Uslubiy ko‘rsatmalar va javoblar

1.1. Signal oniy qiymatlarining vaqt bo‘yicha o‘zgarish grafigi 1.2-rasmda ko‘rsatilgan. $u'(t_{max})=0$ shartidan t_{max} ni aniqlash uchun tenglamani olamiz:

$$-\exp(-10^5 t_{max})+2\exp(-2\cdot 10^5 t_{max})=0,$$

undan esa

$$10^5 t_{max}= -\ln(1/2),$$

ya’ni, $t_{max}=6{,}931\cdot 10^{-6}$ s=6,931 mks. Bunda $u_{max}=6{,}25$ V.

Impuls davomiyligi masala sharti bo‘yicha quyidagi tenglamaning ildizi hisoblanadi:

$$\exp(-10^5\tau_i) -\exp(-2\cdot 10^5\, \tau_i)=0{,}025.$$

$x=10^5\, \tau_i$ o‘lchamsiz kattalikni kiritib, quyidagiga ega bo‘lamiz:

$$\exp(-x) - \exp(-2x)=0{,}025,$$

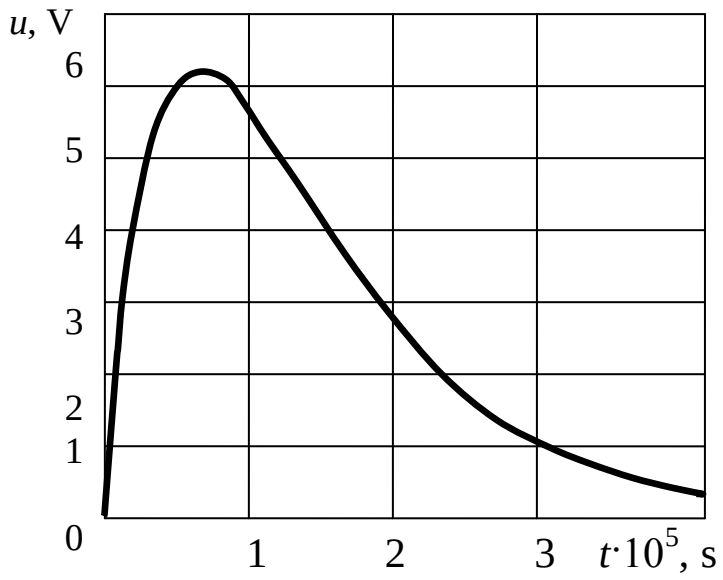
undan x ga nisbatan ruxsat berilgan tenglamaga o‘tib,

$$x = -\ln(0{,}025+e^{-2x}) \qquad (*)$$

natijani olamiz.

Bunday transsendent tenglamalarning ildizlarini mikrokalkulyatordan foydalanib, ketma-ket yaqinlashishlar usuli orqali aniqlash qulaydir. Signal grafigidan foydalanib, faraz qilinayotgan ildizga yaqin x_0 yaqinlashishni tanlaymiz. $x_0=3$ ni olaylik. Bu qiymatni (*) ga qo‘yib, birinchi yaqinlashishni aniqlaymiz, $x_1= -\ln(0{,}025+e^6)=3{,}5943$. Ko‘rsatilgan jarayonni iteratsion prinsip bo‘yicha davom ettiramiz:

$$x_n= -\ln(0{,}025+e^{-2x}n-1),\ n=2,3,\ldots$$

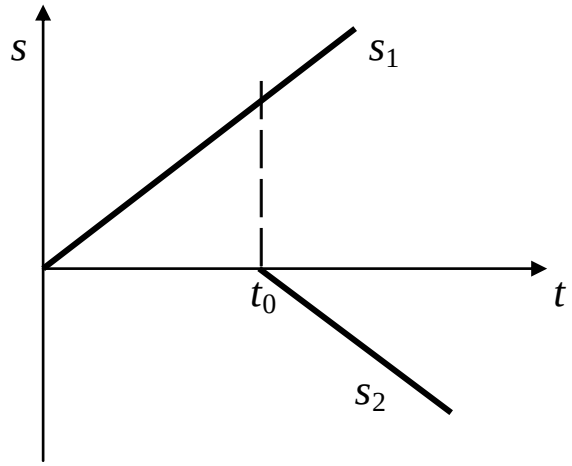


1.2-rasm. Signal oniy qiymatlarining vaqt bo‘yicha o‘zgarish grafigi

va u ikki ketma-ket taxminiy qiymatlar hisobning aniqligini belgilovchi oldindan berilgan kichik songacha farq qilmaguncha olib boriladi. Shu amallarni bajargandan so‘ng, x =3,6628862 (aniq son) ildizni olamiz.

Ildizni x =3,66 qabul qilib, τ_i =3,66·10^{-5} s=36,6 mks ni olamiz.

1.2. Ko‘rilayotgan $s(t)$ signalni chiziqli o‘sib borayotgan, kattaligi bir xil va burchakli og‘ish koeffitsienlari ishorasi har xil ikkita funksiyalar $s_1(t)$ va $s_2(t)$ yig‘indisi sifatida tasavvur qilish mumkin (1.3-rasm). Shunga asosan $s(t)=(s_0/t_0)t\sigma(t)-(s_0/t_0)(t-t_0)\ \sigma(t-t_0)$.



1.3-rasm. Ikkita funksiyalar $s_1(t)$ va $s_2(t)$ yig‘indisi

1.3. Kondensator zaryadi $q(t)=u(t)C(t)$, tok esa quyidagiga teng:

$$i(t)=\frac{dq}{dt}=\frac{du(t)}{dt}C(t)+u(t)\frac{dC(t)}{dt}=(U_1\omega_1\cos\omega_1 t)\cdot[C_0(1+m\sin\Omega t)]+$$

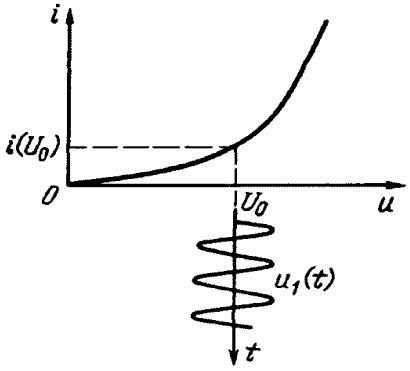
$$+U_1\sin\omega_1 t(mC_0\Omega\cos\Omega t)=U_1[\omega_1 C_0\cos\omega_1 t+\frac{m}{2}(\omega_1+\Omega)\sin(\omega_1+\Omega)t-$$

$$-\frac{m}{2}(\omega_1-\Omega)C_0\sin(\omega_1-\Omega)t].$$

ω_1 chastotali birinchi qo‘shiluvchi o‘zgarmas C_0 sig‘imli kondensatorga kuchlanish $U_1\sin\omega_1 t$ manbasidan yuboriladigan tokni aniqlaydi. Qolgan $\omega_1\pm\Omega$ chastotali qo‘shiluvchilar esa sig‘im variatsiyasining natijasi hisoblanadi va ta’sir spektrida bo‘lmaydi.

2. Radiosignal turlari va ularning garmonik tahlili

2.1. Volt-amper xarakteristikasi 2.1-rasmda ko‘rsatilgan diodga $u_1(t)=U_1\cos\omega_1 t$ garmonik tebranish ta’sir qilmoqda. $|u_1(t)|<U_0$ oraliqda xarakteristikani $i=i(U_0)+a_1u_1+a_2u_1^2$ ifoda bilan approksimatsiyalash mumkin.



2.1-rasm. Diod volt-amper xarakteristikasi

Topshiriq: tok $i(t)$ aniqlansin va uning spektri tahlil qilinsin.

2.2. Oldingi masaladagi diodga

$$u(t)=u_1(t)+u_2(t)=U_1\cos\omega_1 t+U_2\cos\omega_2 t,\ \ \omega_1\neq\omega_2$$

kuchlanishlar yig‘indisi ta’sir qilmoqda.

Topshiriq: tok $i(t)$ aniqlansin va uning spektri tahlil qilinsin.

2.3. f_0=500 kGs chastotaga sozlangan qabul qilgichga T=50 mks davrli va A=10 mV amplitudali davriy to‘g‘riburchaksimon impulslar ketma-ketligi ko‘rinishidagi xalaqit ta’sir qilmoqda. Qabulqilgichning o‘tkazish kengligiga davriy ketma-ketlikning garmonikalaridan biri tushadi.

Topshiriq: shu garmonikaning raqami aniqlansin va qabul qilgich chiqishida xalaqit amplitudasining impulslar davomiyligi τ_i ga T/τ_i nisbatning 20, 15, 10 va 5 qiymatlarida bog‘liqligi topilsin.

Uslubiy ko‘rsatmalar va javoblar

2.1. Tok $i(t)$ quyidagicha aniqlanadi:

$$i(t) = i(U_0) + a_1 U_1 \cos\omega_1 t + a_2 U_1^2 \cos^2 \omega_1 t =$$
$$= i(U_0) + \frac{a_2 U_1^2}{2} + a_1 U_1 \cos\omega_1 t + \frac{a_2 U_1}{2} \cos 2\omega_1 t.$$

Spektr tahlili quyida keltirilgan:

$i(U_0) + \frac{a_2 U_1^2}{2}$ – doimiy (o‘zgarmas) tashkil etuvchi;

$a_1 U_1 \cos\omega_1 t$ – birinchi garmonika; $\frac{a_2 U_1}{2} \cos 2\omega_1 t$ – ikkinchi garmonika.

2.2. Oldingi masaladagi kabi $i(t)$ tokni aniqlaymiz va garmonik tahlil qilamiz:

$$i(t) = i(U_0) + a_1 (U_1 \cos\omega_1 t + U_2 \cos\omega_2 t) + a_2 (U_1 \cos\omega_1 t + U_2 \cos\omega_2 t)^2 =$$

$$= \underbrace{i(U_0) + \frac{a_2 U_1^2}{2} + \frac{a_2 U_2^2}{2}}_{\text{doimiy tashkil etuvchi;}} + \underbrace{a_1 U_1 \cos\omega_1 t + a_2 U_2 \cos\omega_2 t}_{\omega_1 \text{ va } \omega_2 \text{ birinchi garmonikalari;}} +$$

$$+\frac{a_2U_1^2}{2}\cos 2\omega_1 t+\frac{a_2U_2^2}{2}\cos 2\omega_2 t+a_2U_1U_2\cos(\omega_2+\omega_1)t+a_2U_1U_2\cos(\omega_2-\omega_1)t.$$

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$2\omega_1$ va $2\omega_2$ ikkinchi garmonikalari; $\omega_2+\omega_1$ va $\omega_2-\omega_1$ kombinatsion chastotalari.

$2\omega_1$ va $2\omega_2$ garmonikalar bilan bir qatorda tok spektrida $|\omega_2\pm\omega_1|$ kombinatsion chastotalar vujudga keladi. Ular nochiziqli elementda (diodda) $u_1(t)$ va $u_2(t)$ garmonik tebranishlarning o‘zaro ta’siri natijasidir.

2.3. Ko‘rilayotgan davriy ketma-ketlikning diskret spektri $n/T=n\cdot 20$ kGs chastotalardan tashkil topgan garmonikalarga ega. 500 kGs chastotaga sozlangan qabulqilgichning shaffoflik kengligiga raqami n=500/20=25 bo‘lgan garmonika to‘g‘ri keladi. Bu garmonikaning amplitudasi quyidagiga teng:

$$|a_n|=\frac{2A}{n\pi}\left|\sin\frac{n\pi\tau_i}{T}\right|.$$

n=25, A=10 mV va T/τ_i=20, 15, 10, 5 larni qo‘yib, mos ravishda $|a_n|$ uchun 180, 220, 254, 0 mkV natijalarni olamiz.

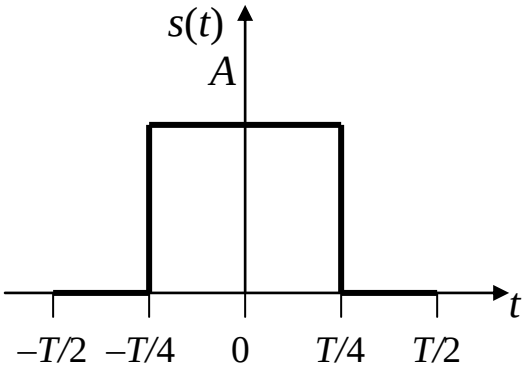
3. Mutlaq aniq signalning xarakteristikalari. Nodavriy signallarning garmonik tahlili

3.1. To‘g‘riburchaksimon A amplitudali (3.1-rasm) $[-T/2,\ T/2]$ vaqt oralig‘ida aniqlangan impuls uchun

$$1,\cos\frac{2\pi}{T}t,\cos 2\frac{2\pi}{T}t,\ldots,\cos n\frac{2\pi}{T}t,\ldots$$

funksiyalar tizimi bo‘yicha Furye umumlashtirilgan qatori yozilsin. Impuls davomiyligi $\tau_i=T/2$. $s(t)$ funksiyani Furye umumlashtirilgan qatorining ikkita, uchta va to’rtta qo‘shiluvchilari orqali approksimatsiyalaganda nisbiy o‘rtacha kvadratik xatoligi aniqlansin.

3.2. $\alpha=10^3$ s^{-1} da $s(t)=A\exp(-\alpha|t|)$ signalning spektral zichligi, samarali davomiyligi, spektr samarali kengligi hamda spektr samarali davomiyligi bilan kengligi ko‘paytmasini aniqlansin. Spektral zichlik o‘zining maksimal qiymatidan 1/10 ga teng bo‘lishiga olib keluvchi chastotani topilsin.



3.1-rasm. To‘g‘riburchaksimon videoimpuls

3.3. Signal $s(t)=A[\delta(t+\tau_i/2)-\delta(t-\tau_i/2)]$ ko‘rinishda berilgan.

Topshiriq: signalning spektral zichligi $S(\omega)$ aniqlansin. Integrallaganda signal shakli va spektri qanday o‘zgaradi? Takroran integrallaganda spektr aniqlansin.

Uslubiy ko‘rsatmalar va javoblar

3.1. Funksiyalar normalarining kvadratlarini aniqlaymiz:

$$\|\varphi_n\|^2=\int_{-T/2}^{T/2}1^2dt=T,\|\varphi_n\|^2=\int_{-T/2}^{T/2}\cos^2 2\pi n\frac{t}{T}dt=\frac{T}{2}.$$

Furye umumlashtirilgan qatorining koeffitsientlarini aniqlaymiz:

$$c_0=\frac{1}{T}\int_{-T/4}^{T/4}Adt=A/2,\quad c_n=\frac{2}{T}\int_{-T/4}^{T/4}A\cos 2\pi n\frac{t}{T}dt=A\frac{\sin n\pi/2}{n\pi/2}.$$

Furye umumlashtirilgan qatori berilgan funksiyalar tizimi bo‘yicha:

$$s(t)=\frac{A}{2}+\frac{2}{\pi}\cos\frac{2\pi}{T}t-\frac{2}{3\pi}\cos 3\frac{2\pi}{T}t+\frac{2}{5\pi}\cos 5\frac{2\pi}{T}t-\ldots-\frac{2A(-1)^n}{\pi(2n-1)}\cos\frac{(2n-1)2\pi}{T}t\ldots.$$

Nisbiy o‘rtacha kvadratik xatolik quyidagi ifoda orqali aniqlanadi:

$$M_N=\left(\int_{-T/4}^{T/4}s^2(t)dt-\sum_{n=0}^{N}c_n^2\|\varphi_n\|^2\right)\Bigg/\int_{-T/4}^{T/4}s^2(t)dt.$$

Aniqlangan c_n va $\|\varphi_n\|^2$ qiymatlarini qo‘yib, quyidagilarni olamiz:

$$M_2=1-\frac{1}{2}-\frac{2^2}{\pi^2}\approx 0{,}095,\quad M_3=1-\frac{1}{2}-\frac{2^2}{\pi^2}-\frac{2^2}{9\pi^2}\approx 0{,}049,$$

$$M_4=1-\frac{1}{2}-\frac{2^2}{\pi^2}-\frac{2^2}{9\pi^2}-\frac{2^2}{25\pi^2}\approx 0{,}033.$$

3.2. Simmetrik eksponensial impulsning spektral zichligi quyidagiga teng:

$$S(\omega)=\frac{2A\alpha}{\alpha^2+\omega^2}=\frac{2A}{\alpha}\frac{1}{1+\omega^2/\alpha^2}.$$

Impulsning samarali davomiyligi

$$T_{sam}=\left[\int_0^\infty A^2t^2e^{-2\alpha t}dt\Bigg/\int_0^\infty A^2e^{-2\alpha t}dt\right]^{1/2}=\frac{1}{\sqrt{2}\alpha}=0{,}707\ \text{ms}.$$

Impuls spektrining samarali kengligi

$$\Omega_{sam}=\left[\frac{1}{\pi}\int_0^\infty\left(\frac{2\alpha A\omega}{\alpha^2+\omega^2}\right)^2d\omega\Bigg/\left(\frac{1}{\pi}\int_0^\infty\left(\frac{2\alpha A}{\alpha^2+\omega^2}\right)^2d\omega\right)\right]^{1/2}=\alpha=10^3\ \text{rad/s};$$

$$f_{sam}=\Omega_{sam}/2\pi\approx 159\ \text{Gs}.$$

Kenglikning davomiylikka ko‘paytmasi

$$\Omega_{sam}T_{sam}=1/\sqrt{2}\approx 0{,}707.$$

Spektral zichlikning maksimal qiymati $S(0)=2A/\alpha$.

Spektral zichlik $1/(1+\omega^2_{\text{cheg}}/\alpha^2)=0{,}1$ tenglamadan aniqlanadigan ω_{cheg} chastotalarda 10 barobar kamayadi. Bu chastotalar $\omega_{\text{cheg}}=\pm 3\alpha=\pm 3\cdot 10^3$ rad/s ga teng, shunga mos ravishda $f_{cheg}\approx 477$ Gs.

3.3. Signalning spektral zichligi vaqt bo‘yicha siljigan ikkita δ-funksiyalar yig‘indisi ko‘rinishida quyidagicha aniqlanadi:

$$S(\omega)=A[\exp(i\omega\tau_i/2)-\exp(-i\omega\tau_i/2)]=2Ai\sin\frac{\omega\tau_i}{2}.$$

Integrallaganda A amplitudaga va τ_i davomiylikka ega simmetrik, bir qutbli to‘g‘riburchak shaklidagi impuls hosil qilinadi. Uning spektral zichligi

$$S_1(\omega)=S(\omega)/(i\omega)=\frac{2A}{\omega}\sin\frac{\omega\tau_i}{2}.$$

Spektrni aniqlashda takroran integrallagandan keyin shuni inobatga olish kerakki, to‘g‘riburchakli impuls $S_1(0)=A\tau_i$ yuzaga ega bo‘ladi, shuning uchun

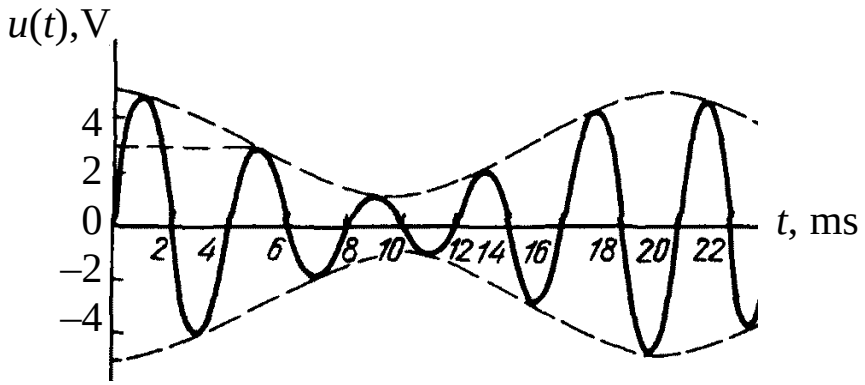
$$S_2(\omega)=\frac{S_1(\omega)}{i\omega}+\pi S_1(0)\delta(\omega)=\frac{2A}{i\omega^2}\sin\frac{\omega\tau_i}{2}+\pi A\tau_i\delta(\omega).$$

4. Radiosignallar modulyatsiyasi. Amplituda bo‘yicha modulyatsiyalangan radiosignallar

4.1. To‘lqin uzunliklari λ=2–5 m oralig‘ida bo‘lgan diapazonda o‘zaro xalaqitlarsiz ishlashi mumkin bo‘lgan radioeshittirish, radiotelefoniya, televizion va telegraf kanallari sonini quyida berilganlarga asosan aniqlang: uzatiladigan ma’lumotlar spektrlarida

maksimal chastotalar telegraf kanallari uchun 300 Gs, raditelefoniya uchun 3 kGs, radioeshittirish uchun 5 kGs, televizion kanallar uchun 6 MGs; televizion signal uzatilishi amplitudasi modulyatsiyalangan tebranishlar (AMT) chastotalarining bir yon polosasida olib boriladi; aloqa kanallari orasidagi kesishish xalaqitlarini bartaraf etish uchun ma'lumot spektrining maksimal chastotasidan 10% kenglikda himoya intervallarini hisobga olinsin. λ=2 va 5 m da AMT chastotalarining nisbiy polosasi baholansin.

4.2. AMT diagrammasi ko'rsatilgan 4.1-rasmdagi signalning analitik ifodalanishi yozilsin va uning spektrogrammasi qurilsin. Modulyatsiya davridagi 1 Om qarshilikda ajraladigan o'rtacha quvvatni hisoblang.



4.1-rasm. Amplitudasi modulyatsiyalangan tebranish diagrammasi

4.3. Amplituda bo'yicha modulyatsiyalangan signal (V) quyidagi ifoda orqali keltirilgan:

$$u(t)=12(1+0{,}6\cos\Omega t+0{,}2\cos 2\Omega t)\cos\omega_0 t.$$

Topshiriq: berilgan signal og'uvchisi $U(t)$ ning eng katta va eng kichik qiymatlarini toping.

Uslubiy ko'rsatmalar va javoblar

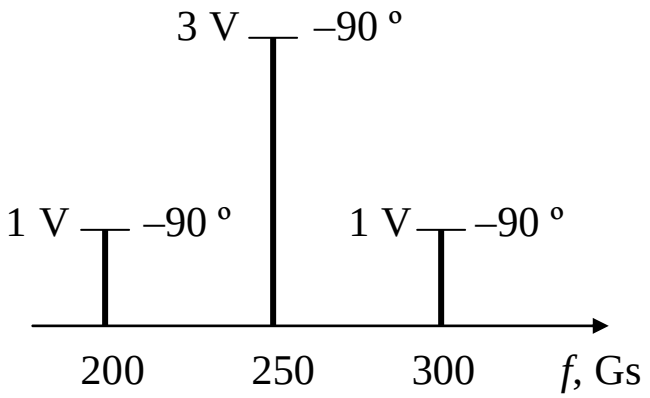
4.1. Amplituda bo'yicha modulyatsiyalangan tebranish spektr kengligining modulyatsiyalovchi tebranish spektrida maksimal chastota F_{max} ga bog'liqligi quyidagicha: $\Delta f = 2F_{max}$. Shunga asosan, signal spektrining kengligi himoya intervalini hisobga olganda

radioeshittirish kanali uchun 11 kGs, radiotelefoniya uchun 6,6 kGs; televizion kanal uchun AMT bir yon polosasida uzatilganda 6,6 MGs; telegraf uchun 0,66 kGs. Sanab o‘tilgan kanallarning ishlashi uchun mo‘ljallangan chastota diapazoni 90 MGs ni tashkil etadi, shuning uchun televizion kanallar soni 13 ta, radioeshittirish kanallari soni 8182 ta, radiotelefoniyaniki 13636 ta, telegrafniki 136363. λ=2 m da AMT chastotalarining nisbiy polosasi televizion kanal uchun $4\cdot10^{-2}$, radioeshittirish uchun $6{,}7\cdot10^{-5}$, radiotelefoniya uchun $4\cdot10^{-5}$, telegraf uchun $4\cdot10^{-6}$ ni tashkil etadi. λ=5 m da mos ravishda 0,1; $1{,}7\cdot10^{-4}$; 10^{-4}; 10^{-5}.

4.2. Keltirilgan grafik bo‘yicha AMT parametrlarini aniqlaymiz: T_0=4 ms, T_{mod}=20 ms, U_0=3 V, ΔU=2 V, θ_0= –90º, γ=0º, modulyatsiya koeffitsienti M=2/3. U holda berilgan AMT ning analitik ifodalanishi quyidagi ko‘rinishda bo‘ladi:

$$u(t) = 3\left(1+\frac{2}{3}\cos 2\pi 50t\right)\cos\left(2\pi 250t - 90°\right),\ \text{V}.$$

Spektral diagramma 4.2-rasmda ko‘rsatilgan. 1 Om qarshilikda ajraladigan o‘rtacha quvvat 5,5 Vt ni tashkil qiladi.



4.2-rasm. Spektral diagrammaning ko‘rinishi

4.3. Signal og‘uvchisi U(t)=12(1+0,6cosΩt+0,2cos2Ωt), V ifoda orqali berilmoqda. $x=\Omega t$ o‘lchamsiz argumentni kiritib, x ning og‘uvchi ekstremal qiymatlarga erishadigan qiymatlari quyidagi tengalamaning ildizlari bo‘lishi kerak ekanligini ko‘ramiz:

$$0{,}6\sin x+0{,}4\sin 2x=0. \qquad (*)$$

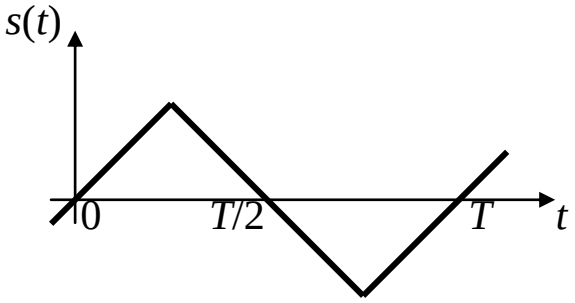
Yaqqol ildiz x=0 og‘uvchining U_{max}=21,6 V maksimumiga mos keladi. (*) tenglamaning boshqa ildizini ikkala qismni $\sin x\neq 0$ ga bo‘lib topamiz. Shunda $\cos x = -0{,}75$, ya’ni, x =2,419 va U_{min}=6,9 V.

5. Faza modulyatsiyasi. Impuls modulyatsiyasi

5.1. Faza modulyatsiyasi qo‘llanilgan radioaloqa kanali uchun f_0=10 MGs tashuvchi chastotada 100 kGs chastotalar polosasi ajratilgan.

Topshiriq: burchak modulyatsiyasi m indeksi 5 dan kam bo‘lmasligi sharti bilan eng yuqori bo‘lishi mumkin modulyatsiya chastotasi F ni aniqlang.

5.2. Faza modulyatori kirishiga 5.1-rasmda ko‘rsatilgan $s(t)$ signal berilgan.



5.1-rasm. Faza modulyatori kirishiga berilgan signal

Topshiriq: modulyatsiyalangan tebranish fazasi $\theta(t)$ va oniy chastotasining o‘zgarish qonunlarini aniqlang.

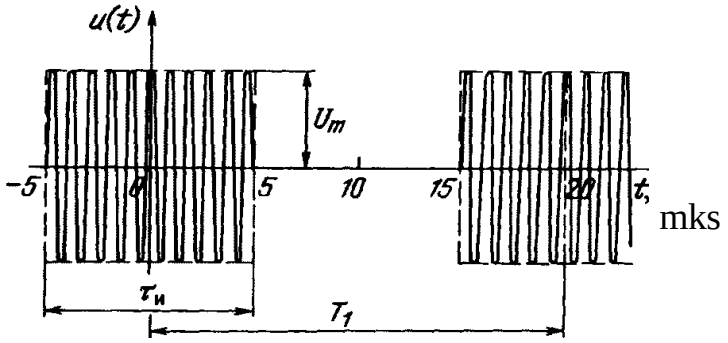
5.3. FMT chastotasi $\omega(t)=2\pi\cdot 10^6(1+0{,}1\cos 2\pi\cdot 10^4 t)$, rad/s qonuni bo‘yicha o‘zgaradi.

Topshiriq: bu tebranishning amplitudasi 20 V ga teng deb olib, u uchun analitik ifodani aniqlang.

5.4. To‘g‘riburchak og‘uvchili radioimpulslar davriy ketma-ketligi berilgan (5.2-rasm). U quyidagi ko‘rsatkichlarga ega: impuls

davomiyligi τ_i = 10 mks, takrorlanish davri T_1 = 20 mks, to‘ldirish chastotasi $\omega_0=2\pi/T_0$, $\tau_i/T_0>>1$, impulslar amplitudasi U_m=10 V.

Topshiriq: shu tebranish uchun analitik ifoda tuzilsin va spektrogramma qurilsin.



5.2-rasm. To‘g‘riburchakli radioimpulslar ketma-ketligi

Uslubiy ko‘rsatmalar va javoblar

5.1. Fazasi modulyatsiyalangan tebranish quyidagicha ifodalanadi:

$$u(t)=U_m\cos[2\pi f_0 t+m\cos(2\pi Ft)],$$

bu yerda $m=f_d/F$, f_d – chastota deviatsiyasi.

Kanalning 100 kGs chastota kengligida deviatsiya 50 kGs dan ko‘p bo‘lishi mumkin emas, shuning uchun quyidagi shart bajarilishi zarur:

$$F_{max}\leq f_d/m=10 \text{ kGs}.$$

5.2. $\theta(t)$ faza $s(t)$ signalning o‘zgarishiga mos qonun bo‘yicha o‘zgaradi, $\omega(t)=\omega_0+d\theta/dt$ oniy chastota esa o‘zining o‘rtacha qiymati ω_0 ga nisbatan meandr shaklida o‘zgaradi.

5.3. Analitik ifoda quyidagicha aniqlanadi:

$$u(t)=20\cos(2\pi\cdot 10^6 t+10\sin 2\pi\cdot 10^4 t), \text{ V}.$$

5.4. 5.2-rasmda ko‘rsatilgan AMT og‘uvchisi bir qutbli to‘g‘riburchaksimon impulslarning davriy ketma-ketligi bo‘lib, Furye qatori orqali quyidagicha aniqlanadi:

$$U(t) = \frac{U_m}{2} + a_1 \cos\frac{2\pi}{T_1}t + a_3 \cos 3\frac{2\pi}{T_1}t + a_5 \cos 5\frac{2\pi}{T_1}t + ...,$$

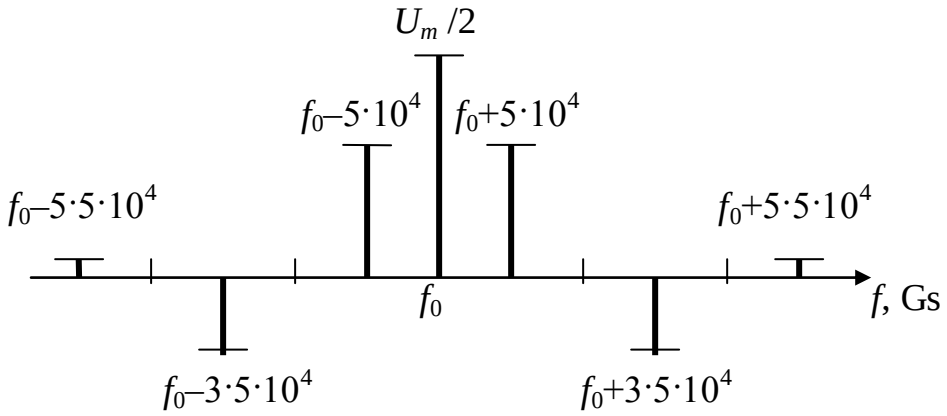
bu yerda $a_n = \frac{2U_m}{\pi n}\sin n\pi\frac{\tau_i}{T_1}$ – qator koeffitsientlari.

τ_i /T_1=1/2, a_1=2U_m /π, a_3= –2U_m /3π, a_5=2U_m /5π,… bo‘lganda izlanayotgan analitik ifoda quyida keltirilgan:

$$u(t) = U(t)\cos(\omega_0 t + \theta_0) = \frac{U_m}{2}\left\{\cos(\omega_0 t + \theta_0) + \frac{2\pi}{\pi}\left[\cos\left(\omega_0 t + \frac{2\pi}{T_1}t + \theta_0\right) + \right.\right.$$

$$\left.\left. + \cos\left(\omega_0 t - \frac{2\pi}{T_1}t + \theta_0\right)\right] - \frac{2}{\pi}\left[\cos\left(\omega_0 t + 3\frac{2\pi}{T_1}t + \theta_0\right) + \cos\left(\omega_0 t - 3\frac{2\pi}{T_1}t + \theta_0\right)\right] + ...\right\}.$$

AMT spektri 5.3-rasmda ko‘rsatilgan. Modulyatsiyaning alohida koeffitsientlari 2/$n\pi$=M_n/2 tenglikdan aniqlanadi; shunday qilib, M_1=4/π=1,27, M_3=4/3π=0,42 va hokazo.



5.3-rasm. AMT spektri

M_1>1 bo‘lishiga qaramasdan bu holda qayta modulyatsiya bo‘lmaydi, sababi $U(t)$ modulyatsiyalovchi funksiyaning uchinchi, yettinchi va h.k. garmonikalari birinchi gamonika bilan teskari fazada qo‘shilib ketadi.

6. Chastota modulyatsiyasi. Chastotasi modulyatsiyalangan signallarning energetik spektri

6.1. To‘g‘riburchak og‘uvchili chastotasi modulyatsiyalangan radioimpuls 1 ms davomiylikka ega. Uning amplitudasi oniy chastota quyidagi qonuniyat bo‘yicha o‘zgarganda 5 V ga teng:

$$\omega(t) = \omega_{\min} + \beta t, 0 \le t \le 1 \text{ ms},$$

bu yerda $\omega_{min}=2\pi 5\cdot 10^4$ rad/s – chastotaning boshlang‘ich qiymati; $\beta=2\,\pi 2\cdot 10^7$ rad/s^2 – chastota o‘zgarish tezligi.

Topshiriq: agar tebranishning boshlang‘ich fazasi $\pi/6$ bo‘lsa, radiosignalning bazasi aniqlansin va analitik ifodasi yozilsin.

6.2. Burchak modulyatsiyali tebranish quyidagi ifoda orqali berilgan:

$$u(t)=15\cos(10^8 t+3\sin 10^6 t+1{,}4\sin 10^5 t+\pi/4).$$

Topshiriq: berilgan signalning oniy chastotasi $\omega(t)$ qiymatini t =1 mks vaqt momentida aniqlang.

6.3. Qo‘ng‘iroqsimon og‘uvchili chiziq-chastotaviy modulyatsiyalangan radiosignalning analitik ifodasi quyidagicha berilgan:

$$a(t)=A\exp(-\alpha^2 t^2)\cos(\omega_0 t+\beta t^2), \quad -\infty<t<\infty.$$

Topshiriq: berilgan signalning A=10 V, f_0=1 MGs, $\alpha=10^4$ s^{-1}, $\beta=10^9$ rad·s^{-2} bo‘lganda energiyasi va bazasi aniqlansin. Berilgan α qiymatida va β ning 0…10^8 1/s^2 oralig‘ida o‘zgarganida spektr samarali kengligining β ga bog‘liqligi qurilsin.

6.4. Amplitudasi U_0, davomiyligi τ_i va chastotasi o‘sib borish tezligi μ ma’lum bo‘lgan to‘g‘riburchakli chiziq-chastotaviy modulyatsiyalangan $u(t)$ impuls berilgan bo‘lsin. Bu impulsning energiyasi E_i taxminiy qiymatini hisoblang. Masalani ikki usul orqali yeching: a) vaqt mintaqasida bevosita integrallab, b) signal energetik spektri W_i tushunchasini qo‘llab. Signal bazasini B>>1 deb oling.

Uslubiy ko‘rsatmalar va javoblar

6.1. Tebranishning to‘liq oniy fazasi quyidagiga teng:

$$\psi(t)=2\pi\cdot 50\cdot 10^3 t+2\pi\cdot 10^7 t^2+\pi/6$$

Chastota deviatsiyasi f_d=10 kGs; tebranishning bazasi $N=\Delta f_{sam}\tau_i=$ $=m=2\,f_d\tau_i=20$. Bu tebranishni quyidagi ifoda orqali hisoblanadi:

$$u(t)=\begin{cases}5\cos(2\pi\cdot 5\cdot 10^4 t+2\pi\cdot 10^7 t^2+\pi/6, & 0<t<\tau_i,\\ 0, \quad t<0, \quad t>0.\end{cases}$$

6.2. Berilgan signalning to‘liq fazasi:

$$\psi(t)=10^8 t+3\sin 10^6 t+1{,}4\sin 10^5 t+\pi/4.$$

Oniy chastota esa to‘liq fazadan olingan hosila hisoblanadi:

$$\omega(t)=10^6+3\cdot 10^6\cos 10^6 t+1{,}4\cdot 10^5\cos 10^5 t.$$

$t=10^{-6}$ s qiymatni qo‘yib, $\omega=1{,}0176\cdot 10^8$ s^{-1} olinadi.

6.3. Signal bazasi quyidagicha aniqlanadi:

$$N=\Delta t_{sam}\Delta f_{sam},$$

bu yerda $\Delta t_{sam}=\dfrac{1}{A}\cdot\int\limits_{-\infty}^{\infty}|s(t)|^2\,dt$ – signalning samarali davomiyligi; $\Delta f_{sam}=\dfrac{1}{2\pi S_{\max}^2(\omega)}\int\limits_{-\infty}^{\infty}S^2(\omega)d\omega$ – spektrning samarali kengligi.

Tor polosali signalning energiyasini aniqlaymiz:

$$э_s=\int\limits_{-\infty}^{\infty}s^2(t)dt=A^2\int\limits_{-\infty}^{\infty}e^{-2\alpha^2 t^2}\cos^2(\omega_0 t+\beta t^2)dt\approx$$

$$\approx \frac{A^2}{2\alpha}\sqrt{\frac{\pi}{2}} = 6{,}25\cdot 10^{-3}\ \text{V}^2\cdot\text{s}.$$

Bundan signalning samarali davomiyligi kelib chiqadi:

$$\Delta t_{sam} = \frac{1}{2}\sqrt{\frac{\pi}{2}}10^{-4} = 62{,}65\ \text{mks}.$$

Δf_{sam} ni aniqlash uchun berilgan signalning spektral zichligini topish kerak:

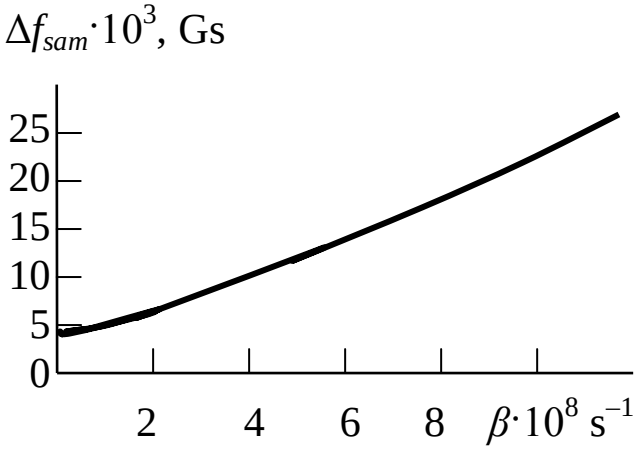
$$S(\omega) = \int_{-\infty}^{\infty} A\frac{1}{2}\exp(-\alpha^2 t^2)\exp[i(\omega_0 t + \beta t)^2]dt =$$

$$= \frac{\sqrt{5}}{2}\frac{1}{\sqrt{\alpha^2 - i\beta}}\exp[-\frac{(\omega-\omega_0)^2}{4(\alpha^2 - i\beta)}],\ \ -\infty < \omega < \infty.$$

U holda $\Delta f_{sam} = \frac{1}{2\sqrt{2\pi}}\frac{\sqrt{\alpha^4+\beta^2}}{\alpha}$, demak, signal bazasi

$$m = \Delta t_{sam}\Delta f_{sam} = \frac{1}{8\alpha^2}\sqrt{\alpha^4+\beta^2} = 1{,}26.$$

Δf_{sam} ning β ga bog‘liqlik grafigi 6.1-rasmda ko‘rsatilgan.



6.1-rasm. Δf_{sam} ning β ga bog‘liqlik grafigi

6.4. a). Vaqt hisobining boshlanishi impuls o‘rtasi bilan mos kelishini nazarda tutib, quyidagiga egamiz:

$$E_i = \int_{-\tau_i/2}^{\tau_i/2} \cos^2\left(\omega_0 t + \frac{\mu t^2}{2}\right) dt = U_0^2 \int_{-\tau_i/2}^{\tau_i/2} \frac{1 + \cos 2\left(\omega_0 t + \frac{\mu t^2}{2}\right)}{2} dt.$$

Integral ostidagi ifodaning suratidagi ikkinchi qo‘shiluvchi ishorasi o‘zgaruvchi funksiya hisoblanadi; uning kiritmasi signal bazasi o‘sishi bilan nolga intilib boradi. Shunday qilib,

$$E_i \approx U_0^2 \tau_i / 2.$$

b). Signalning energetik spektri amalda $\Delta\omega = \mu\tau_i$ chastotalar oralig‘ida o‘zgarmasdir va $W_i = \pi U_0^2/(2\mu)$ ga teng. U holda signal energiyasi yuqorida boshqa usul orqali olingani singari

$$E_i = W_i \cdot \Delta\omega / \pi = U_0^2 \tau_i / 2.$$

7. Nochiziqli zanjirlar va ularni tahlil qilish usullari

7.1. Biqutbli tranzistor o‘tish xarakteristikasining ish qismi 7.1-jadvalda keltirilgan tok qiymatlari orqali berilgan.

7.1-jadval

u_b, V	0,2	0,24	0,28	0,32
i_k, mA	0,1	0,6	1,9	8,0

Topshiriq: ish qismining o‘rtasida bazadagi U_0 siljishni o‘zgartirib borib, tranzistor xarakteristikasini uchinchi darajali polinom bilan approksimatsiyalansin.

7.2. Biqutbli tranzistor o‘tish xarakteristikasi ish nuqta U_0 atrofida quyidagi uchinchi darajali polinom orqali berilgan:

$$i_k=0{,}9+28{,}3(u_b-U_0)+875(u_b-U_0)^2+10400(u_b-U_0)^3,\ \text{mA}.$$

Tranzistor bazasidagi kuchlanishning o‘zgaruvchan tashkil etuvchisi 60 va 10 mV amplitudali hamda chastotalari 1 va 0,8 MGs bo‘lgan ikki garmonik tebranishlar yig‘indisiga teng.

Topshiriq: kollektor tokini spektral tahlil qilinsin va spektri qurilsin.

7.3. Oldingi masalada berilgan o‘tish xarakteristikani ikkinchi darajali polinom orqali, tokni 0,2; 0,26; 0,32 V kuchlanishlarda mos kelishini talab etib approksimatsiyalansin. Kollektor tokining spektral tahlilini 7.2-masaladagi ta’sir ostida bajarilsin. Natijalar taqqoslansin.

Uslubiy ko‘rsatmalar va javoblar

7.1. Ish nuqtasining berilgan holatiga mos keluvchi bazadagi kuchlanish 7.1-jadvalga asosan quyidagicha aniqlanadi:

$$U_0=0{,}2+(0{,}32-0{,}2)/2=0{,}26\ \text{V}.$$

Xarakteristikani approksimatsiyalovchi polinom

$$i_k=a_0+a_1(u_b-U_0)+a_2(u_b-U_0)^2+a_3(u_b-U_0)^3.$$

Bu ifodaga 7.1-jadvaldan tok va kuchlanish qiymatlarini qo‘yib, noma’lum a_0, a_1, a_2, a_3 koeffitsientlarni aniqlash uchun to‘rtta tenglamani olamiz:

$$0{,}1=a_0-a_1 0{,}06+a_2(0{,}06)^2-a_3(0{,}06)^3;$$
$$0{,}6=a_0-a_1 0{,}02+a_2(0{,}02)^2-a_3(0{,}02)^3;$$
$$1{,}9=a_0+a_1 0{,}02+a_2(0{,}02)^2-a_3(0{,}02)^3;$$
$$8=a_0+a_1 0{,}06+a_2(0{,}06)^2-a_3(0{,}06)^3.$$

Tenglamalar tizimini noma’lum parametrlarga nisbatan yechib, quyidagilarni topamiz: a_0=0,9 mA, a_1=28,3 mA/V, a_2=875 mA/V^2, a_3=10400 mA/V^3.

Shunday qilib, tranzistor o‘tish xarakteristikasini approksimatsiyalovchi ifoda quyidagi ko‘rinishda bo‘ladi:

$$i_k=0{,}9+28{,}3(u_b-0{,}26)+875(u_b-0{,}26)^2+10400(u_b-0{,}26)^3$$

(tok o‘lchami mA, kuchlanish o‘lchami V da olingan).

7.2. Tok spektri tashkil etuvchilarining amplitudalari va chastotalarini aniqlash uchun quyidagini bajaramiz:

$$u=U_0+U_a\cos\omega_a t+U_b\cos\omega_b t,$$

bu yerda U_a=60 mV, U_b=10 mV, $\omega_a=2\pi f_a$, $\omega_b=2\pi f_b$, $f_a=10^6$ Gs, $f_b=0{,}8\cdot10^6$ Gs.

Kollektor toki

$$i_k=a_0+a_1(U_a\cos\omega_a t+U_b\cos\omega_b t)+a_2(U_a\cos\omega_a t+U_b\cos\omega_b t)^2+$$
$$+a_3(U_a\cos\omega_a t+U_b\cos\omega_b t)^3.$$

Ikki garmonik tebranish yig‘indisining kvadrati va kubi uchun ma’lum trigonometrik ifodalarni qo‘llab, kollektor tokining spektridagi quyidagi tashkil etuvchilarga kelamiz:

doimiy tashkil etuvchi

$$I_0=a_0+(a_2U_a^2)/2+(a_2U_b^2)/2=2{,}51 \text{ mA};$$

$f_a=10^6$ Gs chastotali va $I_{a1}=a_1U_a+\left(\frac{3}{2}U_b^2U_a+\frac{3}{4}U_a^3\right)=3{,}47$ mA,

$I_{a2}=a_2U_a^2/2=1{,}57$ mA, $I_{a3}=a_3U_a^3/4=0{,}56$ mA

amplitudali tebranish garmonikalari;

$f_b=0{,}8\cdot10^6$ Gs chastotali va

$$I_{b1}=a_1U_b+a_3\left(\frac{3}{2}U_bU_a^3+\frac{3}{4}U_b^3\right)=0{,}85 \text{ mA},$$

$I_{b2}=a_2U_b^2/2=0{,}044$ mA, $I_{b3}=a_3U_b^3/4=0{,}0026$ mA

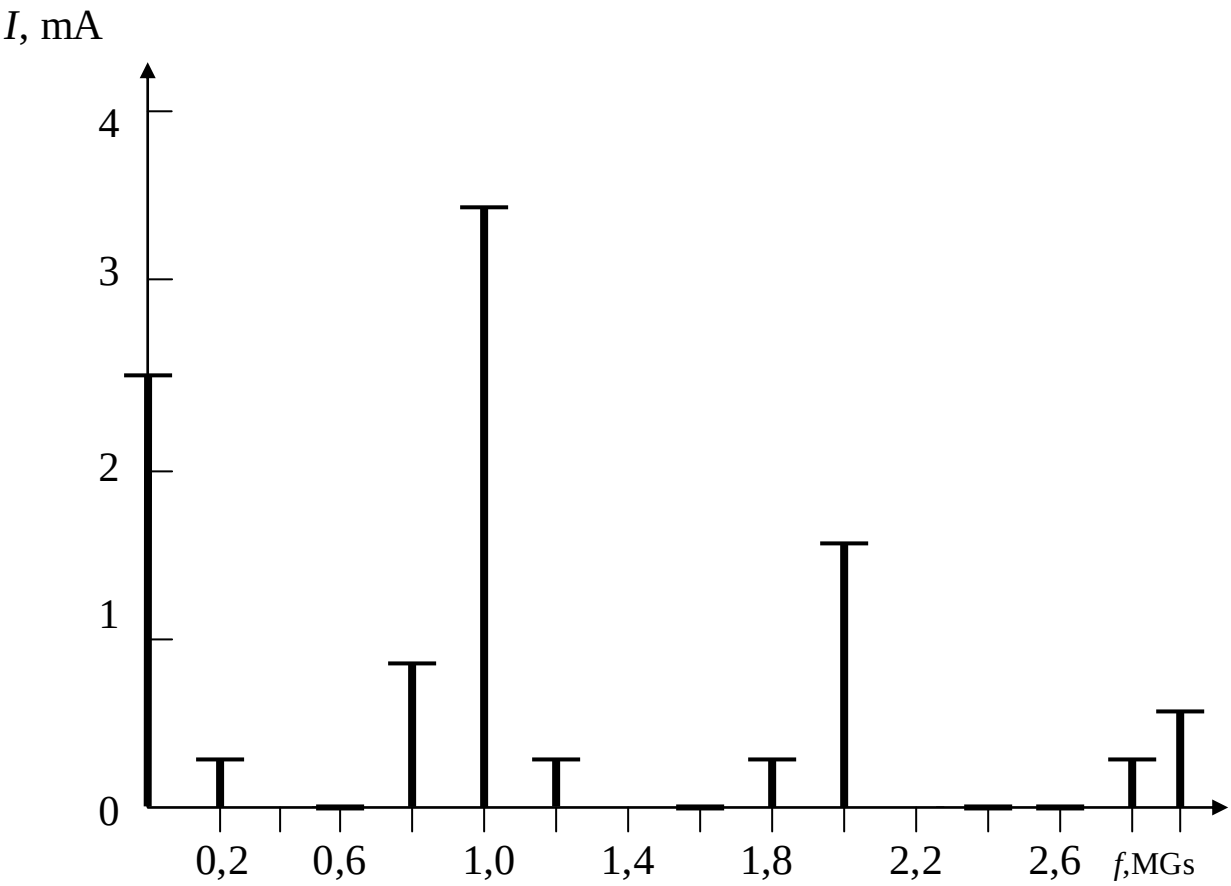
amplitudali tebranish garmonikalari hamda $f_a+f_b=1{,}8\cdot10^6$ Gs va $f_a-f_b=$

$=0{,}2\cdot10^6$ Gs chastotali va $I_{11}=\frac{a_2}{2}U_aU_b=0{,}26$ mA amplitudali kombinatsion tebranishlar;

$2f_a+f_b=2{,}8\cdot10^6$ Gs va $2f_a-f_b=1{,}2\cdot10^6$ Gs chastotali va $I_{21}=a_3\frac{3}{4}U_a^2U_b=0{,}28$ mA amplitudali kombinatsion tebranishlar;

$2f_b+f_a=2{,}6\cdot10^6$ Gs va $2f_b-f_a=0{,}6\cdot10^6$ Gs chastotali va $I_{12}=a_3\frac{3}{4}U_aU_b^2=0{,}047$ mA amplitudali kombinatsion tebranishlar.

Kollektor tokining amplitudaviy spektral diagrammasi 7.1-rasmda ko‘rsatilgan.



7.1-rasm. Kollektor tokining amplitudaviy spektral diagrammasi

7.3. O‘tish xarakteristikasini approksimatsiyalovchi polinomni quyidagicha yozamiz:

$$i_k=a_0+a_1(u_b-0{,}26)+a_2(u_b-0{,}26)^2.$$

Bazadagi berilgan kuchlanishlarga mos keluvchi tok qiymatlarini aniqlab va ularni yozilgan ifodaga qo‘yib, uch tenglamali tizimni olamiz

$0{,}1=a_0-a_1 0{,}06+a_2(0{,}06)^2$;
$0{,}9= a_0$;
$8= a_0+a_1 0{,}06+a_2(0{,}06)^2$.

Bu tizimni yechib, quyidagilarni olamiz a_0=0,9 mA, a_1=65,8 mA/V, a_2=875 mA/V^2.

Bu holda tokni spektral tahlili tokning o‘zgarmas tashkil etuvchisi I_0 ni, ikkala tebranishning birinchi va ikkinchi garmonikalari amplitudalari hamda birinchi tartibli kombinatsion tebranishlarning amplitudalarini aniqlashga imkon beradi. Bunda oldingi masaladagi uslubiy ko‘rsatmalardan a_3=0 uchun keltirilgan ifodalardan foydalansa bo‘ladi. Tokning o‘zgarmas tashkil etuvchisi, tebranishlar ikkinchi garmonikalarining amplitudalari va birinchi tartibli kombinatsion tebranishlar amplitudalari xarakteristikani ikkinchi va uchinchi darajali polinom orqali ko‘rsatganda bir xil bo‘ladi. Birinchi garmonikalarning amplitudalari ikkinchi darajali polinom bilan approksimatsiyalaganda quyidagicha bo‘ladi:

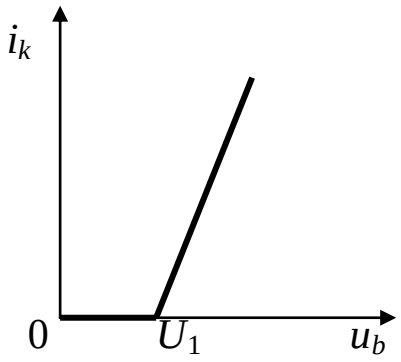
$I_{a1}=a_1U_a$=3,95 mA; $I_{b1}=a_1U_b$=0,66 mA.

Xatoliklar mos ravishda quyidagiga teng:

$$\delta_a = \frac{3{,}95-3{,}47}{3{,}95}100 = 12\%,\ \ \delta_b = \frac{|0{,}66-0{,}85|}{0{,}85}100 = 22\%.$$

8. Nochiziqli rezonans kuchaytirgichlar. Chastota ko‘paytirgichlari

8.1. Tranzistor o‘tish xarakteristikasining (8.1-rasm) qisman-chiziqli approksimatsiyasi quyidagi ko‘rsatkichlar orqali aniqlanadi: chiziqli qismning qiyaligi S=400 mA/V, buzilish nuqtasiga mos keluvchi kuchlanish U_1=0,5 V.



8.1-rasm. Tranzistor o‘tish xarakteristikasi

Topshiriq: tebranish xarakteristikasi $I_{k1}(E)$ tenglamasini oling, bu yerda I_{k1} – kollektor toki birinchi garmonikasining amplitudasi; E – bazadagi garmonik kuchlanishning amplitudasi. Ish (U_0) nuqtasining ikki: 0,4 va 0,6 V holati uchun $0 \le E \le 0{,}4$ V amplitudalar oralig‘ida tebranish xarakteristikalarini quring.

8.2. Chastotani ko‘paytirishda qo‘llanilayotgan tranzistorning o‘tish xarakteristikasi quyidagi ifoda orqali approksimatsiyalanadi:

$$i_k = \begin{cases} 0, & u_b \le U_1, \\ S(u_b - U_1), & u_b > U_1. \end{cases}$$

Tranzistorning parametrlari: S=50 mA/V, U_1=0,5 V. Impulsdagi I_m tokning maksimal qiymatini 12,5 mA ga teng qilib olib, chastotani ikkiga ko‘paytirish uchun eng qulay sharoitlarga ega vaziyat topilishiga ish nuqtasi U_0 holatini va bazadagi kuchlanish E amplitudasi aniqlansin.

8.3. Rezonansli chastotani ikkiga ko‘paytirgich kritik rejimda ishlamoqda, ya’ni, chiqish kuchlanishi $U_{m\text{chiq}}$ ta’minot manbasi E_{tam} kuchlanishiga teng.

Topshiriq: ko‘paytirgich foydali ish koeffitsienti η ning kirish signali $U_{m\text{kir}}$ o‘zgarmas amplitudasida tokni kesish burchagi qiymatiga bog‘liqligini toping.

Uslubiy ko‘rsatmalar va javoblar

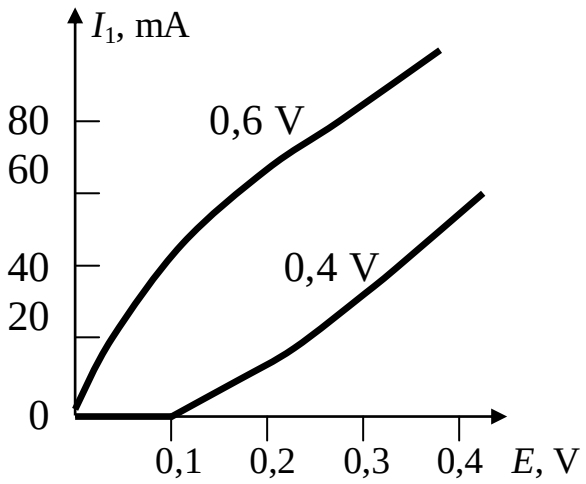
8.1. Tok birinchi garmonikasining amplitudasi $I_1=\alpha_1 I_m$, bu yerda $\alpha_1=[\theta-\sin\theta\cos\theta]\ /\ [\pi(1-\cos\theta)]$ – Berg koeffitsienti. I_1 tokni bevosita U_1-U_0 orqali $\theta=\arccos(U_1-U_0)/E$ nisbat yordamida ifodalash maqsadga muvofiq. Shunda quyidagi natijaga kelish mumkin:

$$I_1=\frac{SE}{\pi}\left[\arccos\frac{U_1-U_0}{E}-\frac{U_1-U_0}{E}\sqrt{1-\left(\frac{U_1-U_0}{E}\right)^2}\right].$$

Agar $E<U_1-U_0$ bo‘lsa, u holda kollektor toki nolga teng. Agar $E<U_0-U_1$ bo‘lsa, boshqaruvchi kuchlanishning o‘zgarishlari o‘tish xarakteristikasi chiziqli qismining chegarasidan chiqib ketmaydi va tok birinchi garmonikasining amplitudasi $I_1=SE$ bo‘ladi. 8.1-jadvalda E va U_0 qiymatlariga mos keluvchi I_1 ning hisoblangan natijalari keltirilgan. 8.2-rasmda siljish kuchlanishining 0,4 va 0,6 V qiymatlari uchun mos keluvchi tebranish xarakteristikalari ko‘rsatilgan.

8.1-jadval

U_0, V	E ning (V) quyidagi qiymatlarida I_1, mA							
	0,05	0,1	0,15	0,2	0,25	0,3	0,35	0,4
0,4	0	0	6,6	15,6	25,2	35,0	44,8	55,0
0,6	20	40	53,4	64,3	74,7	84,9	95,1	105,2



8.2-rasm. Tebranish xarakteristikalari

8.2. Kollektor toki ikkinchi garmonikasi (n=2) amplitudasining impulsdagi tokning eng yuqori qiymatiga maksimal nisbatini ta'minlash nuqtai nazaridan chastotani ikkiga ko'paytirish uchun eng qulay sharoitlar $\theta=120^\circ/n=60^\circ$ kesish burchagida sodir bo'ladi. Tokning impulsdagi maksimal qiymati $I_m=SE(1-\cos\theta)$, undan esa $E=I_m/[S(1-\cos\theta)]=0{,}5$ V. Kesish burchagi tranzistor bazasidagi kuchlanish bilan $\cos\theta=(U_1-U_0)/E$ nisbat orqali bog'langan, undan esa ish nuqtasining holati aniqlanadi:

$$U_0= U_1-E\cos\theta=0{,}25 \text{ V}.$$

8.3. Ta'minot manbasidan olinadigan quvvat,

$$P_0=E_{tam}I_0=E_{tam}SU_{max}\gamma_0(\upsilon).$$

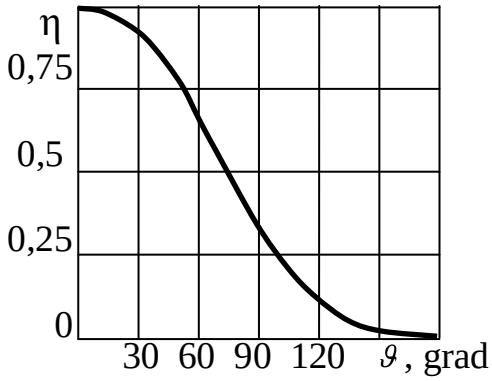
Foydali quvvat

$$P_2=U_{mchiq}I_2/2\approx E_{tam}SU_{max}\gamma_2(\upsilon).$$

Undan kelib chiqqan holda FIK

$$\eta=\frac{\gamma_2(\vartheta)}{2\gamma_0(\vartheta)}=\frac{1}{6}\cdot\frac{\sin 2\vartheta\cdot\cos\vartheta-2\cos 2\vartheta\cdot\sin\vartheta}{\sin\vartheta-\vartheta\cos\vartheta}.$$

Bu ifodaga asosan qurilgan grafik 8.3-rasmda ko'rsatilgan. Grafikdan ko'rinib turibdiki, yetarli FIK bilan ta'minlash uchun, ko'paytirgichda tokni kesish burchagini 90° dan kamroq olish zarur.



8.3-rasm. Tokni kesish burchagini aniqlash

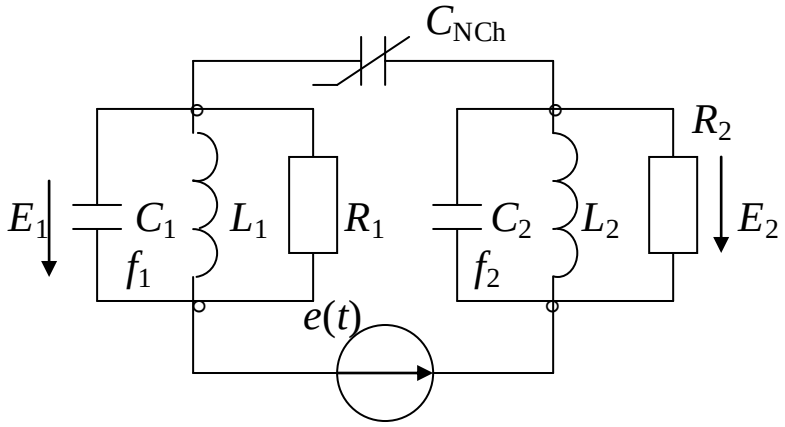
9. Chastota o‘zgartirgichlari. Nosimmetrik spektrli signallar

9.1. Nochiziqli sig‘imga ega ketma-ket tebranma konturga siljish kuchlanishi E_0=5 V va E amplitudali garmonik EYuK manbalari ulangan. Berilgan siljishda differensial sig‘im C_0=100 pF, sig‘im $C=q/u$=80 pF, kichik amplitudalar rejimida rezonans chastota f_0=10 MGs, kontur asilligi Q=40 ga teng. Volt-amper xarakteristikani nochiziqliligini hisobga oluvchi parametr quyidagiga teng:

$$B_3=[1/LC-(2\pi f_0)^2]/(CE_0)^2=6{,}16\cdot 10^{33}\ \mathrm{Kl}^{-2}\cdot \mathrm{s}^{-2}.$$

Topshiriq: agar E=0,1 V bo‘lsa, sig‘imda zaryad amplitudasi maksimal bo‘ladigan chastotani aniqlang. Konturdagi tok va induktivlikdagi kuchlanish amplitudalari shu chastotada nechaga teng? Maksimal amplitudaning 0,7 sathiga mos keluvchi chastotalarni aniqlang.

9.2. Chastota o‘zgartirgichi ikki yuqori asillikka ega konturlar tizimidan tashkil topgan (9.1-rasm). Konturlar nochiziqli sig‘im orqali bog‘langan bo‘lib, rezonans chastotalari f_1=10 MGs va f_2=50 MGs. Rezonansda konturlar qarshiligi $R=R_1=R_2$=10 kOm. Garmonik EYuK manbasi chastotasi f = 60 MGs.



9.1-rasm. Ikki konturli chastota o‘zgartirgichi

Topshiriq: chastotasi 10 MGs va amplitudasi E_1=1 V tebranishni qo‘zg‘atish uchun zarur bo‘lgan manba quvvatini aniqlang. Shunda E_2 amplitudasi nechaga teng bo‘ladi?

Uslubiy ko‘rsatmalar va javoblar

9.1. Kontur induktivligi quyidagiga teng:

$$L=1/[C_0(2\pi f_0)^2]=2{,}53\cdot 10^{-6}\ \text{Gn},$$

qarshiligi

$$r=2\pi f_0 L/Q=3{,}98\ \text{Om},$$

so‘nish koeffitsienti

$$\alpha= r/(2L)=0{,}785\cdot 10^6\ \text{s}^{-1}.$$

Zaryad amplitudasi A berilib, chastotaning mos qiymatlarini quyidagi ifoda orqali aniqlash mumkin:

$$\omega^2=\omega_0^2-2\alpha^2+\frac{3}{4}b_3A^2\pm\left[\frac{E^2}{A^2L^2}-4\alpha^2\omega_0^2+2\alpha^2\left(2\alpha^2-\frac{3}{2}A^2b_3\right)\right]^{1/2}.$$

Ildiz ostidagi ifoda nolga teng bo‘lganda amplituda maksimal qiymatga erishadi $A=A_m$, ya’ni,

$$A_m^4+\frac{4}{3}A_m^2\frac{\omega_0^2-\alpha^2}{b_3}-\frac{E^2}{3\alpha^2b_3L^2}=0.$$

Bu tenglamani A_m ga nisbatan yechib, quyidagini olamiz:

$$A_m=\left\{-\frac{3}{2}\frac{\omega_0^2-\alpha^2}{b_3}+\left[\left(\frac{2}{3}\frac{\omega_0^2-\alpha^2}{b_3}\right)^2+\frac{E^2}{3\alpha^2b_3L^2}\right]^{1/2}\right\}^{1/2}=3{,}71\cdot 10^{10}\ \text{Kl}.$$

Mos keluvchi chastota

$$f_m=\frac{1}{2\pi}\left(\omega_0^2-2\alpha^2+\frac{3}{4}b_3A_m^2\right)^{1/2}=10{,}77\ \text{MGs}.$$

Shu chastotadagi tok amplitudasi

$$I=A_m 2\pi f_m=2{,}51\cdot 10^{-2}\ \text{A}.$$

Induktivlikdagi kuchlanish amplitudasi

$$E_L=2\pi f_m\, IL=4{,}31\ \text{V}.$$

$0{,}7A_m$ zaryad amplitudalariga mos keluvchi chastotalar 10,24 va 10,52 MGs ga teng. Bu chastotalarning ko‘pi f_m dan kichik bo‘lgani sababli, kirish kuchlanishining berilgan amplitudasida turg‘unsiz holatlar vujudga kelishi mumkin degan xulosa chiqarsa bo‘ladi.

9.2. Konturdagi tebranishning E_1 amplituda qiymatida ajraladigan quvvat $P_1=E_1^2/(2R)=5\cdot 10^{-5}$ Vt. Manbadan olinadigan P quvvatni aniqlash uchun quyidagi proporsiyadan foydalanamiz:

$P_1/f_1= -P/f$, undan $P= -(f/f_1)P_1= -3\cdot 10^{-4}$ Vt.

Bu yerda manfiy ishora quvvat manbadan olinayotganligini ko‘rsatadi. $P_2/f_2= -P/f$ proporsiyadan boshqa konturdagi quvvatni va amplitudani topamiz

$$P_2=-Pf_2/f=2\cdot 10^{-4}\ \text{Vt},\ E_2=\sqrt{2RP_2}=2{,}33\ \text{V}.$$

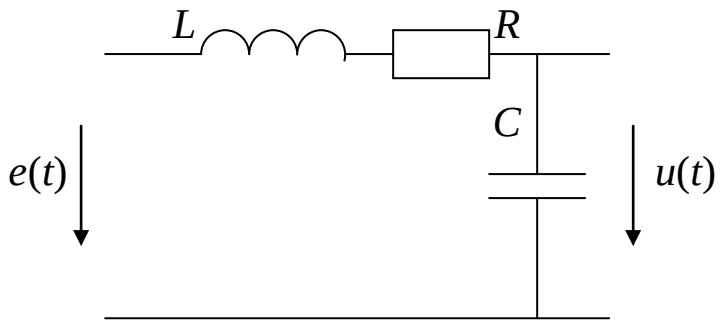
10. Amplitudasi modulatsiyalangan signallarning chastota tanlovchi zanjirlardan o‘tishi

10.1. Rezonans kuchaytirgich N ta bir xil bir konturli, vaqt doimiysi τ_k qiymatlari ma’lum pog‘onalarning kaskadli ulanishidan tashkil topgan.

Topshiriq: berilgan kuchaytirgichning o‘tkazish kengligi $\Pi_{0,707}$ ni hisoblash uchun ifodani keltirib chiqaring.

10.2. 10.1-rasmda ko‘rsatilgan zanjir kirishiga t=0 vaqt momentida quyidagi EYuK berilmoqda:

$$e(t)=E(1+M\cos\Omega_M t)\cos(\omega_0 t+\theta_0)$$



10.1-rasm. Past chastotalar uchun *RLC*-zanjiri

Topshiriq: o‘ram integral (taxminiy) usuli orqali $\omega_0=\omega_r$, $\Omega_M=2/\tau_k$ (bu yerda $\tau_k=2Q/\omega_r$) bo‘lganda zanjir chiqishidagi kuchlanishni hisoblang.

10.3. 10.1-rasmda ko‘rsatilgan zanjir kirishiga $t=0$ vaqt momentida quyidagi EYuK ta’sir etmoqda:

$$e(t)=E\exp(-\alpha t)\cos(\omega_0 t+\theta),\ t\geq 0,$$

bu yerda $E=2$ V, $\alpha=10^4$ s^{-1}, $\omega_0=2\pi\cdot 10^6$ rad/s, $\theta=\pi/4$.

Topshiriq: taxminiy spektral usuldan foydalanib, $\omega_r=\omega_0$ da zanjir chiqishidagi kuchlanishni aniqlang. O‘tkazish kengligi $2\Delta\omega_0=2\pi\cdot 10^4$ rad/s. Chiqish kuchlanishning grafigi qurilsin.

Uslubiy ko‘rsatmalar va javoblar

10.1. *N*-tartibli kuchaytirgichning uzatish koeffitsienti quyidagicha aniqlanadi:

$$K(j\omega)=\frac{(-K_{rez})^N}{\left[1+j\tau_k(\omega-\omega_{rez})\right]^N}.$$

Berilgan tizimning amplituda-chastotaviy xarakteristikasi quyidagi ko‘rinishga ega:

$$|K(j\omega)|=\frac{K_{rez}^N}{\left[1+\tau_k^2(\omega-\omega_{rez})^2\right]^{N/2}}.$$

O‘tkazish polosasining chegaraviy ω_{cheg} chastotasida

$$\left[1+\tau_k^2(\omega_{cheg}-\omega_{rez})^2\right]^{N/2}=\sqrt{2}$$

tenglik o‘rinlidir, unga asosan o‘tkazish kengligi

$$\Pi_{0,707}=\frac{1}{\pi\tau_k}\sqrt{\sqrt[N]{2}-1}.$$

10.2. Zanjir chiqishidagi kuchlanishni quyidagi ifoda orqali aniqlaymiz:

$$u_{chiq}(t)=\mathrm{Re}\left[\frac{1}{2}\exp(i\omega_0 t)\int_{-\infty}^{\infty}A(x)G(t-x)dx\right],$$

bu yerda $A(t)=E(1+M\cos\Omega t)\exp(i\theta_0)$ – kirishdagi kuchlanishning kompleks og‘uvchisi, $G(t)=\frac{Q}{\tau_k}\exp(-i\pi/2)\exp(-t/\tau_k),\ \ t\geq 0,$ – tor polosali zanjirning $\omega=\omega_0$ da impuls xarakteristika kompleks og‘uvchisi.

Integralni yechib quyidagi natijaga kelamiz:

$$u_{chiq}(t)=-\frac{1}{2}QE\left\{1+\frac{M}{\sqrt{1+\Omega^2\tau_k^2}}\cos(\Omega t-\varphi)-\right.$$

$$\left.-\exp(-t/\tau_k)\left[1+\frac{M}{\sqrt{1+\Omega^2\tau_k^2}}\cos\varphi\cdot\cos(\omega_0 t+\theta_0)\right]\right\},$$

bu yerda $\varphi=\mathrm{arctg}\Omega\tau_k=\mathrm{arctg}2=63{,}4^\circ$.

Statsionar rejimda ($t\to\infty$)

$$u_{chiq}(t)=-\frac{1}{2}QE\left[1+\frac{M}{\sqrt{5}}\cos(\Omega t-\varphi)\cos(\omega_0 t+\theta_0)\right].$$

Kontur inersionligi $\Omega\tau_k$=2 da modulatsiya chuqurligini $\sqrt{5}$ marta kamayishiga va og‘uvchini faza bo‘yicha kirish tebranishi og‘uvchisiga nisbatan 63,4° ortda qolishiga olib keladi.

10.3. Berilgan EYuK kompleks og‘uvchisi $A(t)=E\exp(-\alpha t+i\theta)$, $t \geq 0$, ko‘rinishga ega, bu funksiyaning Laplas bo‘yicha tasviri esa $S(p)=E\exp(i\theta)/(\alpha+p)$.

Zanjirning (past chastotali ekvivalentning) soddalashtirilgan uzatish funksiyasi $K_1(p)=Q/(1+p\tau_k)$.

Demak,

$$A_{chiq}(t)=\frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty} S(p)K_1(p)e^{pt}dp = EQe^{i\theta}\frac{1}{2\pi i}\int_{c-i\infty}^{c+i\infty}\frac{e^{pt}dp}{(\alpha+p)(1+p\tau_k)} =$$

$$=\frac{EQe^{i\theta}}{1-\alpha\tau_k}(e^{-\alpha t}-e^{-t/\tau_k})$$

va

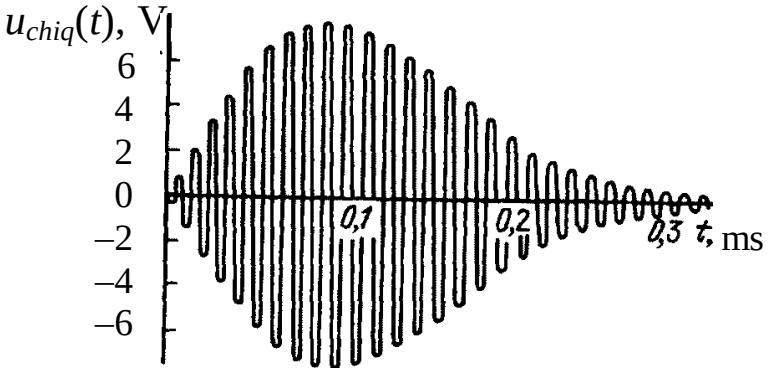
$$u_{chiq}(t)=\frac{EQ(e^{-\alpha t}-e^{-t/\tau_k})}{1-\alpha\tau_k}\cos(\omega_0 t+\theta).$$

Berilgan parametrlarga asosan

$$u_{chiq}(t)=14{,}7(e^{-10^4 t}-e^{-\pi\cdot 10^4 t})\cos(2\pi\cdot 10^6 t+\pi/4),\ \text{V}.$$

$u_{chiq}(t)$ grafigi 10.2-rasmda ko‘rsatilgan.

Diagramma qurishni yengillashtrish uchun yuqori chastotali to‘ldirish davri 10 barobar kattalashtirilgan.



10.2-rasm. 10.1-rasmdagi zanjir chiqishidagi kuchlanish

11. CHM va FM signallarning chastota tanlovchi zanjirlardan o‘tishi

11.1. Radiostansiya 4,25 m to‘lqinida chastota modulatsiyasini qo‘llagan holda ishlamoqda. Modulatsiyaning eng yuqori chastotasi F_m=100 kGs, burchak modulatsiyasi indeksi m=0,1.

Topshiriq: shu stansiyaga sozlangan tunerda konturning asilligi, modulatsiya indeksining kamayishi 3 dB dan oshmasligi uchun qanday bo‘lishi kerak?

11.2. $K(i\omega) = 2Q/[1 + i(\omega - \omega_r)/\Delta\omega_0]$ uzatish funksiyali rezonans kuchaytirgich kirishiga chiziqli chastotaviy modulatsiyalangan $s(t) = E\cos(\omega_0 t + \beta t^2/2),\ 0 \le t \le \tau_i$ impuls signal berilgan. Kontur parametrlari: Q=50, ω_r=10^6 rad/s, $\Delta\omega_0$=10^4 rad/s; signal parametrlari: E=0,1 V, ω_0=ω_r, β=10^7 rad/s^2, τ_i=4 ms.

Topshiriq: berilgan masala shartlarida oniy chastota usuli qo‘llanilishi tekshirilsin.

11.3. Oldingi masalada chiqish impulsi og‘uvchisining o‘zgarish qonuni aniqlansin.

Uslubiy ko‘rsatmalar va javoblar

11.1. Berilgan modulatsiya m=0,1 indeksida ChMT spektrida uchta spektral tashkil etuvchilarni hisobga olsa bo‘ladi: f_0, $f_0 \pm F$, shuningdek burchak modulatsiyasi indeksi birinchi yon chastota amplitudasiga proporsional. Konturda modulatsiya indeksining kamayishi 3 dB dan oshmasligi uchun quyidagi shart bajarilishi kerak:

$$[1+(2FQ/f_r)^2]^{1/2}=1,$$

ya’ni, $Q=f_r/(2F)$.

Bu holda $f_r=f_0=c/\lambda$=70,6 MGs, F_m=100 kGs va $Q=70{,}6\cdot10^6/100\cdot10^3=353$.

11.2. Oniy chastota usulining qo’llanilish shartlari $\Omega/\Delta\omega \ll 1$ va

ω_d /$\Delta\omega \leq 1$. Chiziqli-chastotaviy modulatsiya uchun Ω kattalik ostida $2\pi/\tau_i$ qiymatni tushunish mumkin, ω_d ostida esa $\beta\tau_i/2$ qiymatni. Shunday qilib, yuqorida keltirilgan shartlarga asosan,

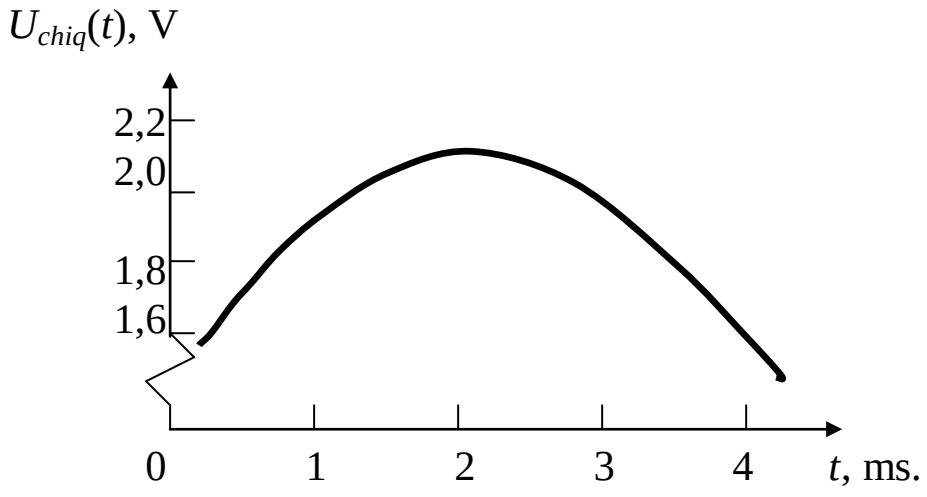
$$\Omega/\Delta\omega=2\pi/(\tau_i\ \Delta\omega)\approx 0{,}075;\ \omega_d/\Delta\omega=\beta\tau_i/(2\Delta\omega)=1.$$

Demak, tahlil qilish uchun oniy chastota usuli qo‘llanilishi mumkin.

11.3. Konturni signalning o‘rtacha chastotasiga ($\omega_r=\omega_0$) aniq sozlaganda va EYuK chastotasining f_0-f_d dan f_0+f_d gacha oraliqlarda chiziqli o‘zgarganida chiqishdagi amplitudalarning og‘uvchisi

$$U_{chiq}(t) = 2Q\Big/\sqrt{1+\{2[\omega(t)-\omega_r]/\Delta\omega_{0,7}\}^2},\ \ \omega_0-\omega_d<\omega(t)<\omega_0+\omega_d.$$

$U_{chiq}(t)$ og‘uvchi kuchaytirgich ACHX sining shaklini ko‘rsatadi (11.1-rasm).



11.1-rasm. Kuchaytirigich ACHXsi

12. *LC*-avtogeneratorning stabillik shartlari

12.1. Transformatorli bog‘langan avtogeneratorda o‘rtacha qiyaligi S_1 (mA/V) boshqaruvchi kuchlanish U (V) ga bog‘liqligi 2-darajali ko‘p had bilan approksimatsiyalangan elektron qurilma qo‘llanilgan:

$$S_1(U)=a_1+3/4a_3U^2,$$

bu yerda a_1=1 mA/V, a_3=−2,5 mA/V^3. Generator tebranish konturi quyidagi parametrlarga ega: $\omega_0=6\cdot10^8$ s^{-1}, Q=25.

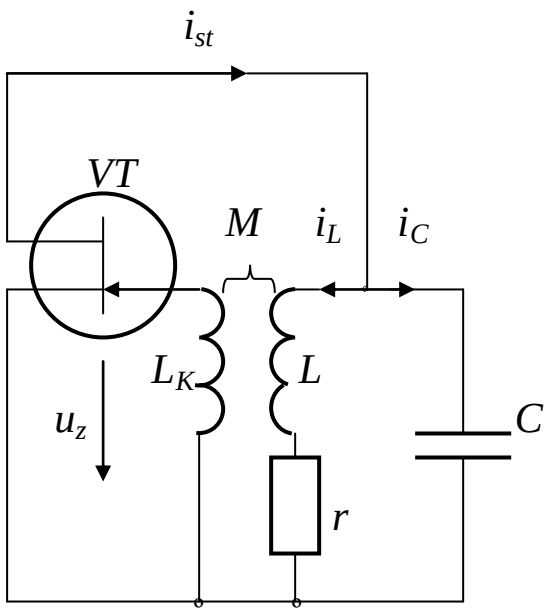
Topshiriq: o‘zaro induksiya koeffitsienti M_{min} ning qanday minimal qiymatida tizimda avtotebranishlar vujudga keladi? Agar $M=3M_{min}$ bo‘lsa, statsionar rejimda U_{st} amplitudani hisoblang.

12.2. Tranzistor xarakteristikasi $i_k=10+2(u_b-U_0)-0{,}5(u_b-U_0)^3$, mA ifoda orqali approksimatsiyalanadi, sinxronlovchi kuchlanish esa baza zanjiriga kiritilib, E=0,16 V amplitudaga ega.

Topshiriq: agar kontur parametrlari Q=50, ρ=200 Om, f_r=1 MGs, teskari aloqa koeffitsienti K_{TA}=0,1 bo‘lsa, kollektor zanjirida konturli generator chastotasini egallash sodir bo‘ladigan chastotalar polosasi aniqlansin.

12.3. Kontur parametrlari: L=500 mkGn, C=2000 pF, r=5 Om. Tranzistor parametrlari: S=5 mA/V, μ=20.

Topshiriq: 12.1-rasmda tasvirlangan avtogenerator o‘z-o‘zidan qo‘zg‘alishi uchun zarur bo‘lgan minimal o‘zaro induktivlik M aniqlansin.



12.1-rasm. Maydon tranzistorli avtogenerator

Uslubiy ko‘rsatmalar va javoblar

12.1. U=0 va o‘z-o‘zidan qo‘zg‘alish chegarasida

$$a_1=RC/M_{min}=1/(\omega_0 QM_{min})$$

bajarilishi lozim. Undan kelib chiqqan holda

$$M_{min}=1/(a_1\omega_0 Q)=6{,}66\cdot 10^{-8}\ \text{Gn}.$$

Agar $M=M_{min}$ bo‘lsa, u holda

$$1/(\omega_0 QM)=3{,}34\cdot 10^{-4}\ \text{Sm}.$$

Statsionar rejimda tebranishlar amplitudasi quyidagi tenglamani qoniqtirishi zarur:

$$10^{-3}-1{,}875\cdot 10^{-3}U_{st}^{2}=3{,}34\cdot 10^{-4}.$$

Uni yechgandan so‘ng U_{st}=0,596 V ni olamiz.

12.2. Avval $S_{o‘rt}=rC/M$ shartidan o‘rnatilgan tebranishlar amplitudasi aniqlanadi. Tranzistor volt-amper xarakteristikasini kubik approksimatsiyalaganda

$$S_{o`rt}=a_1+\frac{3}{4}a_3U_{o`rn}^2=2-\frac{3}{4}0{,}5U_{o`rn}^2,\quad \text{mA/V};$$

$$\frac{rC}{M}=\frac{1}{Q\omega_r M}\frac{L}{L}=\frac{1}{Q\rho K_{TA}}=1\quad \text{mA/V};$$

$$U_{o`rn}=\sqrt{\frac{a_1-S_{o`rt.o`rn}}{0{,}75a_3}}=1{,}57\qquad V.$$

Quyidagi egallash polosasi to‘liq nisbiy kengligining ifodasidan

$$\frac{2\Delta\omega_{\max}}{\omega_r} = \frac{2|\omega - \omega_r|_{\max}}{\omega_r} \approx \left(\frac{E}{U_{TA}}\right)\left(\frac{1}{Q}\right) = \left(\frac{E}{U_{TA}}\right)d\,,$$

bu yerda d=1/Q − kontur so‘nish koeffitsienti, aniqlash zarur bo‘lgan chastotalar polosasi

$$2\Delta f = f_r \frac{1}{Q}\frac{E}{U_{o`rn}} = 2 \text{ kGs.}$$

12.3. Tizimning turg‘unlik chegarasiga mos keluvchi kritik M qiymati (ya’ni tebranishlar vujudga kelishi) quyidagicha aniqlanadi:

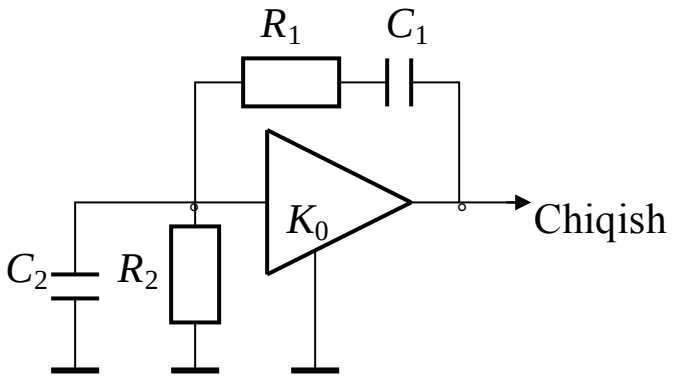
$$M_{kr} = L\left(\frac{1}{R_{ekv}S} + \frac{1}{\mu}\right) = \frac{rC}{S} + \frac{L}{\mu}.$$

Berilgan r, C, L, S va μ parametrlardan M_{kr}=4,5·10^{-6} Gn ni olamiz.

13. *RC*-avtogeneratorning energetik parametrlarini o‘rganish

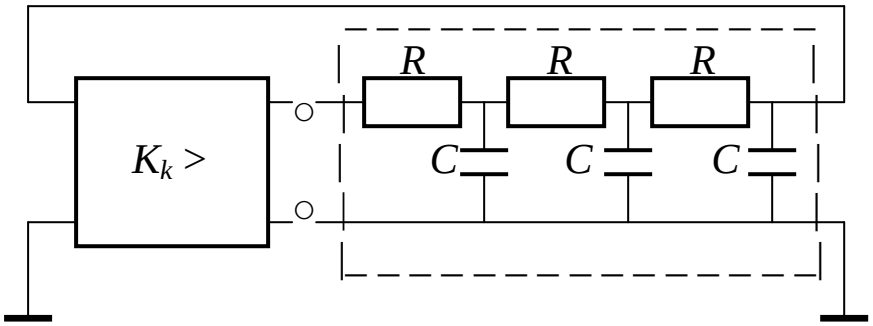
13.1. Garmonik tebranishlar *RC*-generatorining sxemasi 13.1-rasmda ko‘rsatilgan.

Topshiriq: agar R_1=R_2=3,6 kOm, C_1=0,15 mkF, C_2=0,05 mkF bo‘lganda aktiv zvenoning tizim o‘z-o‘zidan qo‘zg‘alishi sodir bo‘ladigan kuchaytirish koeffitsienti K_0 aniqlansin. Generatsiyalanuvchi chastota ω_{gen} qiymatini aniqlang.



13.1-rasm. Garmonik tebranishlar *RC*-generatori

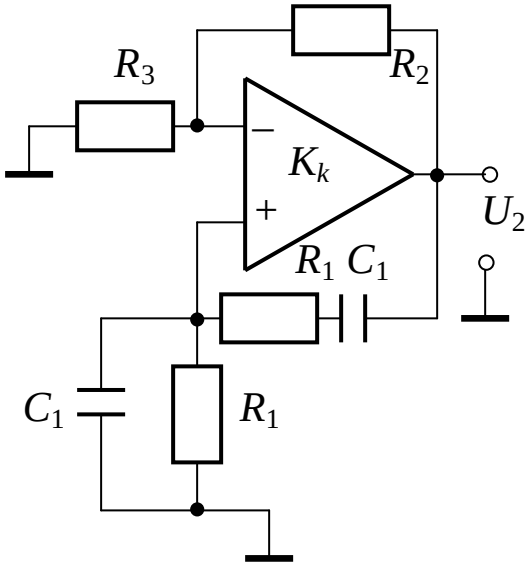
13.2. Aktiv to‘rtqutblik va teskari aloqali to‘rtqutblikdan iborat (13.2-rasm) berk tizimning qo‘zg‘alish shartlarini aniqlang. Aktiv to‘rtqutblik $R_{kir}\to\infty$ va $R_{chiq}\to 0$ qarshiliklarga ega deb hisoblansin.



13.2-rasm. Teskari aloqali *RC*-avtogenerator

13.3. Operatsion kuchaytirgichda yig‘ilgan *RC*-generatorda (13.3-rasm) rezistor R_3 qarshiligi 10 kOm.

Topshiriq: turg‘un generatsiyani ta’minlash uchun minimal mumkin bo‘lgan R_2 qarshilikni aniqlang.



13.3-rasm. Operatsion kuchaytirgichda yig‘ilgan *RC*-generator

Uslubiy ko‘rsatmalar va javoblar

13.1. O‘z-o‘zidan qo‘zg‘alish shartidan foydalanib, quyidagini olamiz:

$$K_0>1+(R_1C_1+R_2C_2)/(R_2C_1).$$

Bunga masala shartida berilgan elementlar nominallarini qo‘yib, $K_0>2{,}33$ ekanligini olamiz. Generatsiyalanuvchi chastotaning qiymati:

$$\omega_{gen} = 1\Big/\sqrt{R_1R_2C_1C_2} = 3{,}208\cdot 10^3 \ \ \mathrm{s}^{-1}.$$

13.2. Berilgan aktiv to‘rtqutblik va teskari aloqa to‘rtqutbligidan tashkil topgan berk tizim uchun qo‘zg‘alish shartlari quyidagi ko‘rinishda bo‘ladi:

$$K_kK_{TA}>1;\ \varphi_k+\varphi_{TA}=2\pi n,\ n=1,\ 2,\ 3,\ \dots\ ,$$

bu yerda K_k, φ_k − aktiv to‘rtqutblikning kuchaytirish koeffitsienti va faza siljishi; K_{TA}, φ_{TA} − teskari aloqa to‘rtqutbligining uzatish koeffitsienti va faza siljishi.

Berilgan zanjir uchun qo‘zg‘alish shartlari $\omega_{cheg}=\sqrt{6}/(RC)$ chastotada bajariladi va bunda kuchaytirish koeffitsienti $K_k>29$ bo‘lishi kerak.

13.3. Umumiy holatdan kelib chiqqan holda quyidagilarga egamiz:

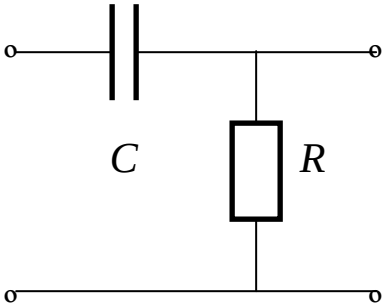
$$K_kK_{TA}>1;\ \varphi_k+\varphi_{TA}=2\pi n,\ n=1,\ 2,\ 3,\ \dots\ ,$$

va 13.3-rasmdagi teskari aloqa to‘rtqutbligi uchun generatsiya chastotasida $K_{TA}(\omega_{gen})=1/3$ ekanligini hisobga olib, $K_k(\omega_{gen})>3$ ni aniqlaymiz. Operatsion kuchaytirgich asosida yig‘ilgan masshtab kuchaytirgichi uchun $K_k=R_2/R_3$ bo‘lgani uchun, izlanayotgan R_2 minimal mumkin bo‘lgan qiymati $K_kR_3=30$ kOm bo‘ladi.

14. Differensiallovchi va integrallovchi elektr zanjirlar

14.1. Differensiallovchi zanjirga 50 mks davomiylikga ega E amplitudali to‘g‘riburchakli impuls berilmoqda (14.1-rasm). Signal manbasining ichki qarshiligi $R_i=50$ Om.

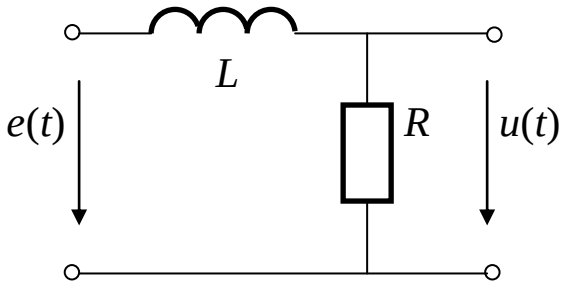
Topshiriq: $0{,}5U_{chiq\max}$ sathda aniqlanuvchi, davomiyligi 10 mks bo‘lgan qisqartirilgan birinchi musbat impulsni zanjir chiqishida olish sharti bilan R va C parametrlarini aniqlang. Bu yerda $U_{chiq\max}$ − impuls cho‘qqisi bo‘lib, u $0{,}95E$ dan kam bo‘lmasligi kerak.



14.1-rasm. Differensiallovchi *RC*-zanjir

14.2. Vaqt doimiysi τ_z=2 ms bo‘lgan zanjir kirishiga (14.2-rasm) t=0 vaqt momentida davomiyligi τ_i=2 ms, amplitudasi E=1 V ga teng to‘g‘riburchakli impuls berilmoqda.

Topshiriq: zanjir chiqishidagi signalni aniqlang. Quyidagi holatlarda: a) zanjirning vaqt doimiysini uzaytirganda; b) zanjirning vaqt doimiysini kamaytirganda, chiqishdagi signal shakli qanday o‘zgarishini tekshiring. Mos keluvchi vaqt diagrammalarini tasvirlang va ularni vaqt hamda spektral nuqtai nazarlaridan tushuntiring.



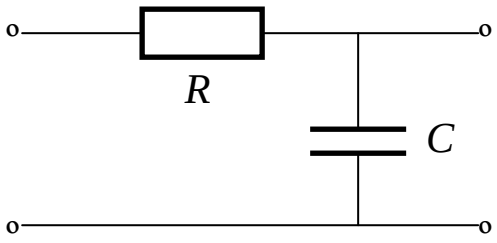
14.2-rasm. Integrallovchi *RL*-zanjir

14.3. 14.1-rasmdagi differensiallovchi zanjirga t=0 momentda τ_i=3 ms davomiylikka ega E=10 V amplitudali musbat to‘g‘riburchakli impuls berilmoqda. Zanjir vaqt doimiysi RC=1 ms.

Topshiriq: zanjir chiqishidagi signalni aniqlang.

14.4. 14.3-rasmda ko‘rsatilgan integrallovchi zanjirga t=0 momentda oldingi masaladagi singari signal berilgan bo‘lsin. Zanjir vaqt doimiysi RC=5 ms.

Topshiriq: zanjir chiqishidagi signalni aniqlang.



14.3-rasm. Integrallovchi RC-zanjir

Uslubiy ko‘rsatmalar va javoblar

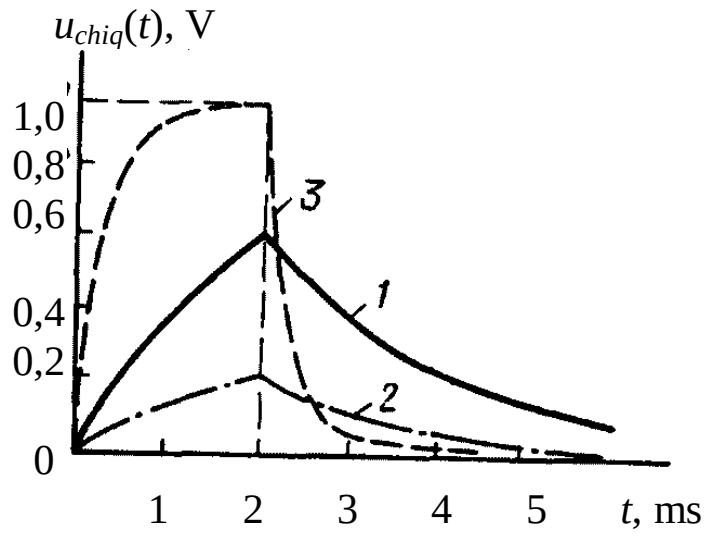
14.1. Differensiallovchi zanjir R qarshiligini $U_{chiq\max}/E=$ $=R/(R+R_i)=0{,}95$ shartdan topish mumkin, undan esa $R=0{,}95R_i/0{,}05=$ $=950$ Om. Chiqish impulsi davomiyligi 10 mks bo‘lishi kerak, shunga binoan t_1=10 mks, $u(t_1)=0{,}5U_{\max}$, R=950 Om va R_i=50 Om qiymatlarni $u(t)=U_{\max}\exp\{-t/[C(R+R_i)]\}$ ifodaga qo‘yib, C=14,4 nF olamiz.

14.2. Berilgan zanjirning uzatish funksiyasi $K(i\omega)=1/(1+i\omega\tau_z)$ orqali aniqlanadi. Laplas o‘zgartirishi yordamida chiqish signali uchun ifodani olish mumkin:

$$u_{chiq}(t)=\begin{cases}1-e^{-0{,}5\cdot10^3 t}, & 0\le t\le\tau_i,\\ 0{,}6e^{-0{,}5\cdot10^3 t}, & t>\tau_i.\end{cases}$$

$u_{chiq}(t)$ signal 14.4-rasmda 1 raqami ostida ko‘rsatilgan. 2 raqami ostida $\tau_z^{|}>\tau_z$ zanjir vaqt doimiysida chiqish signali ko‘rsatilgan, 3 raqami ostida esa $\tau_z^{||}<<\tau_z$ dagi chiqish signali.

Pasayish qiyaligining $\tau_z^{|}>\tau_z$ da kamayishi (2 egriligi) filtr AChX si $K(\omega)=[1+(\omega\ \tau_z)^2]^{-1/2}$ da signal spektri yuqori chastotali tashkil etuvchilarining kuchsizlanishi sababli tushuntiriladi. $\tau_z^{||}<<\tau_z$ da esa aksincha, pasayish qiyaligi o‘sib boradi (3 egriligi).



14.4-rasm. Integrallovchi *RL*-zanjir uchun mos vaqt diagrammalari

14.3. Chiqishdagi signalni o‘ram integrali usulini qo‘llab aniqlash mumkin.

$$s_{1chiq}(t)=\begin{cases} 10e^{-10^3 t}, V, & 0\le t\le 3 \quad ms, \\ -9{,}5e^{-10^3(t-3\cdot 10^{-3})}, V, & t\ge 3 \quad ms. \end{cases}$$

14.4. Chiqish signali quyidagiga teng:

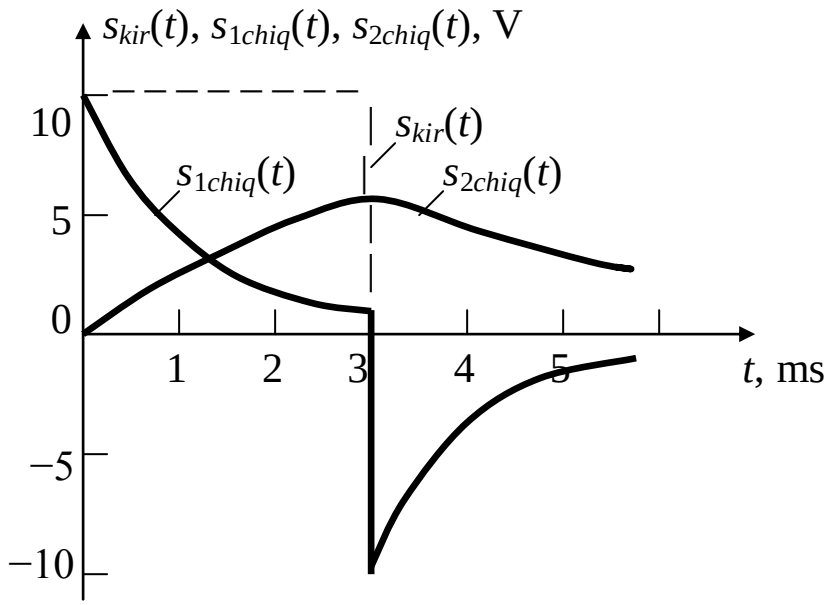
$$s_{2chiq}(t)=\begin{cases} E(1-e^{-t/(RC)}), & 0\le t\le \tau_i, \\ E(1-e^{-\tau_i/(RC)})e^{-(t-\tau_i)/(RC)}, & t>\tau_i. \end{cases}$$

14.5-rasmda 14.3 va 14.4 masalalar uchun kirish signali, $s_{1chiq}(t)$ va $s_{2chiq}(t)$ chiqish signallari ko‘rsatilgan.

15. Raqamli filtrlar va ularning uzatish funksiyasi

15.1. Signal $\xi(t)$ birlik amplitudali to‘g‘riburchak videoimpulslar cheksiz davriy ketma-ketligidan iborat. Ketma-ketlik davri Δ ga teng, bitta impuls davomiyligi τ ni tashkil etadi.

Topshiriq: berilgan ketma-ketlikning spektral zichligi $S_\xi(\omega)$ hisoblansin.



14.5-rasm. 14.3 va 14.4 masalalar uchun kirish signali, $s_{1chiq}(t)$ va $s_{2chiq}(t)$ chiqish signallari

15.2. Amplitudasi U_0, davri T va alohida impulsning davomiyligi $T/3$ parametrlarga ega to‘g‘riburchak videoimpulslar davriy ketma-ketligi shunday diskretlanganki, unda ketma-ketlikning bir davriga N ta hisoblar to‘g‘ri keladi.

Topshiriq: N=8 va N=32 qiymatlarda berilgan signalni Furye diskret o‘zgartirishida C_1 koeffitsient qiymatlarini hisoblang.

15.3. Uchta hisob (0, 10, 20) orqali berilgan $x_d(t)$ diskret davriy signalning C_n (n=0, 1, 2) Furye diskret o‘zgartirishi koeffitsientlari hisoblansin.

Uslubiy ko‘rsatmalar va javoblar

15.1. Furye kompleks qatori C_n koeffitsientlari n=0, ±1, ±2, … da quyidagiga teng:

$$C_n = \frac{1}{\Delta}\int_{-\tau/2}^{\tau/2} \exp(-j2n\pi\tau/\Delta)dt = \frac{\tau}{\Delta}\frac{\sin(n\pi\tau/\Delta)}{n\pi\tau/\Delta}.$$

Barcha garmonik tashkil etuvchilar hissalarini qo‘shib quyidagini olamiz:

$$S_{\xi}(\omega)=\frac{2\pi\tau}{\Delta}\sum_{n=-\infty}^{\infty}\sin(n\pi\,\tau/\Delta)(n\pi\,\tau/\Delta)\,\underline{\delta}(\omega-2\pi\,n/\Delta).$$

15.2. N=8 da impuls davomida uchta hisob joylashadi. U holda, n=1 qo‘yilib quyidagi natija kelib chiqadi:

$$C_1=\frac{U_0}{8}\sum_{k=0}^{2}\exp(-j\pi\,k/4).$$

Geometrik progressiyaning yig‘indisini yechib keyingi natijani olamiz:

$$C_1=\frac{U_0}{8}\frac{1-\exp(-j3\pi/4)}{1-\exp(j\,\pi/4)}=0{,}301U_0\exp(-j45°)\,. \qquad (15.1)$$

Agar N=32 bo‘lsa, u holda impuls davomida 11 hisob bo‘ladi. Shuning uchun

$$C_1=\frac{U_0}{32}\sum_{k=0}^{10}\exp(-j\pi\,k\big/16)=\frac{U_0}{32}\frac{1-\exp(-j11\pi/16)}{1-\exp(-j\,\pi/16)}=0{,}2814U_0\exp(-j56{,}28°)\,. \qquad (15.2)$$

Uzluksiz signal Furye qatorining C_1 koeffitsienti esa quyidagiga teng:

$$C_1=0{,}276U_0\exp(-j60°)\,. \qquad (15.3)$$

(15.1), (15.2) va (15.3) natijalarni solishtirib, N ortishi bilan Furye diskret o‘zgartirishining C_1 koeffitsienti diskretlangan uzluksiz signal Furye qatorining mos koeffitsientiga intilib borishiga ishonch hosil qilish mumkin.

15.3. Umumiy ifodadan quyidagilarni aniqlaymiz:

$$C_0=\frac{1}{3}(10+20)=10,\ C_1=\frac{1}{3}(10e^{-j120°}+20e^{-j240°}),$$

$$C_2=\frac{1}{3}(10e^{-j240°}+20e^{-j480°}).$$

$$e^{-j120^\circ} = e^{-j480^\circ} = -\frac{1}{2} - j\frac{\sqrt{3}}{2}, \qquad e^{-j240^\circ} = -\frac{1}{2} + \frac{\sqrt{3}}{2}$$

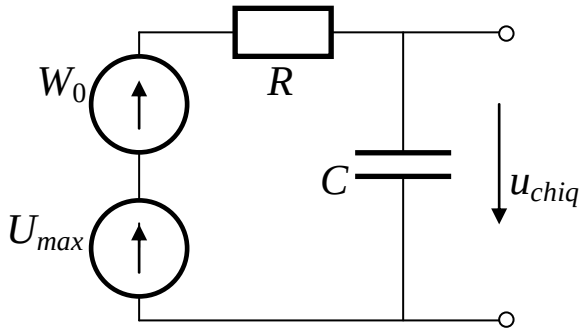
bo‘lgani sabab,

$$C_1 = \frac{5}{3}(-3 + j\sqrt{3});\ C_2 = \frac{5}{3}(-3 - j\sqrt{3}).$$

16. Radiotexnik zanjirlarda shovqinni bartaraf qilish usullari

16.1. *RC*-zanjir kirishida (16.1-rasm) ikkita ketma-ket ulangan EYuK manbasi ishlamoqda. Ulardan biri barcha chastotalarda quvvat spektri W_0 o‘zgarmas qiymatida oq shovqinni yuzaga keltiradi. Ikkinchi manba amplituda va chastotasi ma’lum bo‘lgan $U_{m\text{kir}}\cos\omega_0 t$ garmonik signalni hosil qiladi.

Topshiriq: chiqishdagi signal/shovqin nisbati $Q = U_{m\text{chiq}}/\sigma_{\text{chiq}}$ maksimal bo‘ladigan *RC* vaqt doimiysini aniqlang.



16.1-rasm. Ketma-ket ikkita manba ulangan *RC*-zanjir

16.2. Bir konturli rezonans kuchaytirgich quyidagi chastotaviy uzatish koeffitsientiga ega:

$$K(j\omega) = \frac{-K_{rez}}{1 + j(\omega - \omega_{rez})\tau_k}.$$

Kuchaytirgich kirishida quvvat spektri zichligi W_0 hamda to‘ldirish chastotasi ω_{rez}, davomiyligi τ_i va amplitudasi $U_{m\text{kir}}$ bo‘lgan to‘g‘riburchakli radioimpuls yig‘indisidan iborat oq shovqin mavjud.

Topshiriq: berilgan kuchaytirgichda mumkin bo‘lgan chegaraviy signal/shovqin nisbatining Q_{cheg} qiymati aniqlansin. Kuchaytirgich tebranish konturining optimal Q_{opt} asilligini hisoblash uchun ifoda olinsin.

16.3. Normal taqsimlangan oq shovqin fonida ishlovchi to‘g‘ri-burchakli videoimpuls bilan moslashgan filtr sintezlansin. Videoimpuls amplitudasi E=5 V, davomiyligi τ_i=2 ms, shovqin quvvatining spektral zichligi $W_0(\omega)=5\cdot10^{-2}$ V^2/Gs.

Topshiriq: filtr chiqishida signalning eng yuqori qiymatini shovqin o‘rtacha kvadratik qiymatiga nisbati aniqlansin.

Uslubiy ko‘rsatmalar va javoblar

16.1. Ko‘rilayotgan zanjir chiziqli hisoblanadi va u uchun ustma-ust qo‘yish prinsipi o‘rinli. Shuning uchun chiqishdagi shovqin va garmonik signal kuchlanishlari alohida aniqlanishi mumkin. Bu holda

$$\sigma_{chiq} = \sqrt{\frac{W_0}{2RC}}; \quad U_{mchiq} = \frac{U_{mkir}}{\sqrt{1+\omega_0^2 R^2 C^2}}.$$

Signal/shovqin nisbatini quyidagi ko‘rinishda ko‘rsatish qulay:

$$Q = U_{mkir}\sqrt{\frac{2}{\omega_0 W_0}} \cdot \sqrt{\frac{\omega_0 RC}{1+\omega_0^2 (RC)^2}}.$$

$x=\omega_0 RC$ belgilash kiritamiz. Quyidagi funksiya x=1 da yagona maksimumga ega:

$$F(x) = \sqrt{x/(1+x^2)}.$$

Undan esa $(RC)_{opt}=1/\omega_0$.

16.2. Impuls oxirida chiqish tebranishining amplitudasi

$$U_{mchiq}(\tau_i)=K_{rez}U_{mkir}(1-\exp(-\tau_i/\tau_k)).$$

Kuchaytirgich chiqishida shovqin dispersiyasi

$$\sigma_{chiq}^2 = 2W_0 K_{rez}^2 \Pi_{sh} = W_0 \, K_{rez}^2 / \tau_k .$$

Shunday qilib, $t=\tau_i$ da

$$Q = \frac{U_{mkir}(1-\exp(-\tau_i/\tau_k))}{\sqrt{W_0/\tau_k}}. \qquad (*)$$

Optimal filtr quyidagi signal/shovqin nisbatini ta'minlashni hisobga olib

$$Q_{\max} = U_{mkir}\sqrt{\tau_i/(2W_0)},$$

(*) ifodani o'zgartiramiz:

$$Q=Q_{m\mathrm{kir}}F(\tau_i/\tau_k),$$

bu yerda

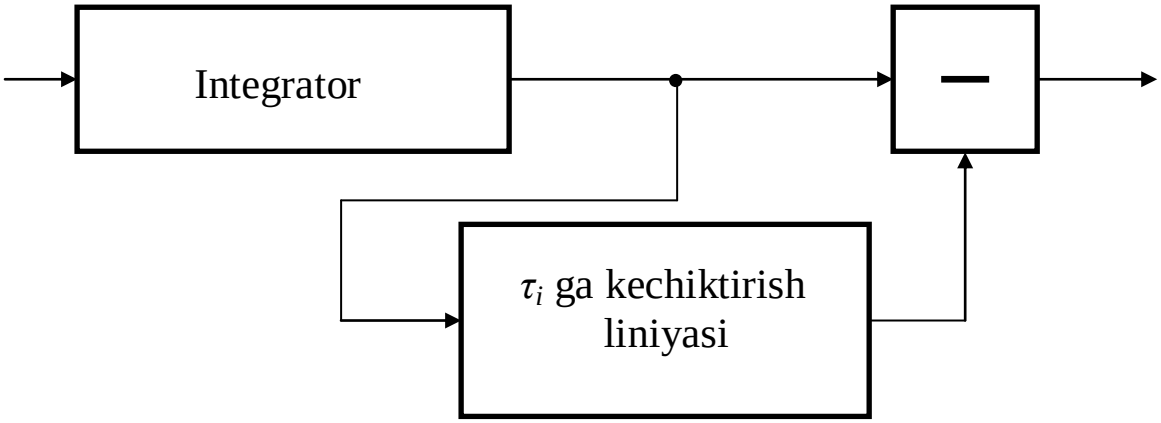
$$F(\tau_i \big/ \tau_k) = \frac{1-\exp(-\tau_i/\tau_k)}{\sqrt{(\tau_i/\tau_k)/2}}.$$

$F(\tau_i/\tau_k)$ funksiya 0,9 ga teng maksimal qiymatni τ_i/τ_k=1,25 da qabul qiladi. Demak, $Q_{cheg} = 0{,}9Q_{max}$; $\tau_k = 2Q/\omega_{rez}$ bo'lgani uchun, $Q_{opt} =$ $= 0{,}4\omega_{rez}\tau_i$.

16.3. Berilgan signal $S(\omega)=E(1-e^{-i\omega\tau_i})/(i\omega)$ spektral zichligidan va $K(i\omega)=AS^*(\omega)e^{-i\omega t_0}$ ifodadan kelib chiqqan holda $t_0=\tau_i$ da moslashgan filtr uzatish funksiyasini aniqlaymiz:

$$K(i\omega) = \frac{5A}{i\omega}(1-e^{-i\omega\tau_i}).$$

Filtr struktura sxemasi 16.1-rasmda ko‘rsatilgan. $5A/i\omega$ ko‘paytuvchi integrator orqali, $e^{-i\omega\tau_i}$ ayriluvchi esa τ_i ga kechiktirish liniyasi orqali ishlab chiqiladi.



16.1-rasm. Moslashgan filtr struktura sxemasi

Filtr chiqishida kuchlanish bo‘yicha signal/shovqin nisbati E=5 V, τ_i=2 ms va $W_0=5\cdot10^{-2}$ V^2/Gs bo‘lganda quyidagiga teng:

$$\eta = \sqrt{э/W_0} = \sqrt{E^2\,\tau_i/W_0} = 1.$$

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Mundarija

Muqaddima 3
1. Signal va uning matematik modeli 4
2. Radiosignal turlari va ularning garmonik tahlili 7
3. Mutlaq aniq signalning xarakteristikalari. Nodavriy signallarning garmonik tahlili 9
4. Radiosignallar modulatsiyasi. Amplituda bo‘yicha modulatsiyalangan radiosignallar 12
5. Faza modulatsiyasi. Impuls modulatsiyasi 15
6. Chastota modulatsiyasi. Chastotasi modulatsiyalangan signallarning energetik spektri 18
7. Nochiziqli zanjirlar va ularni tahlil qilish usullari 21
8. Nochiziqli rezonans kuchaytirgichlar. Chastota ko‘paytirgichlari 25
9. Chastota o‘zgartirgichlari. Nosimmetrik spektrli signallar . . . 29
10. Amplitudasi modulatsiyalangan signallarning chastota tanlovchi zanjirlardan o‘tishi 31
11. CHM va FM signallarning chastota tanlovchi zanjirlardan o‘tishi 35
12. *LC*-avtogeneratorning stabillik shartlari 36
13. *RC*-avtogeneratorning energetik parametrlarini o‘rganish . . 39
14. Differensiallovchi va integrallovchi elektr zanjirlar 41
15. Raqamli filtrlar va ularning uzatish funksiyasi 44
16. Radiotexnik zanjirlarda shovqinni bartaraf qilish usullari . . . 47
Adabiyotlar 51

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