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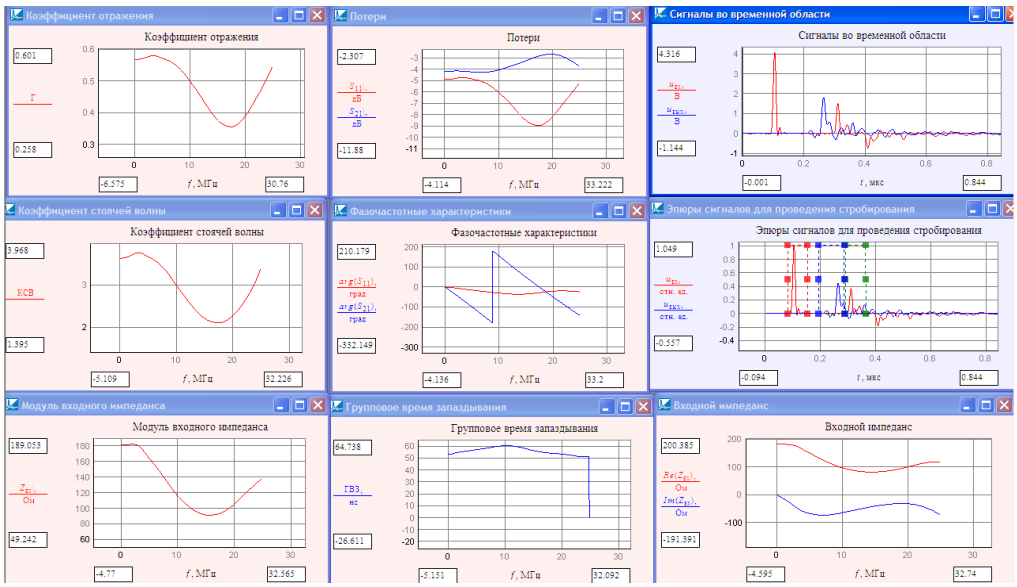

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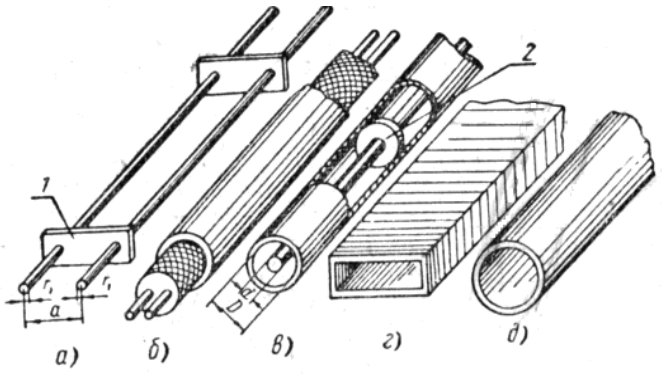

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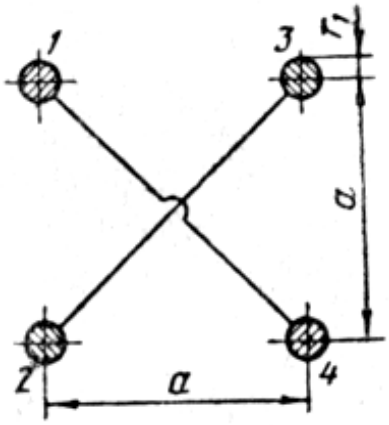

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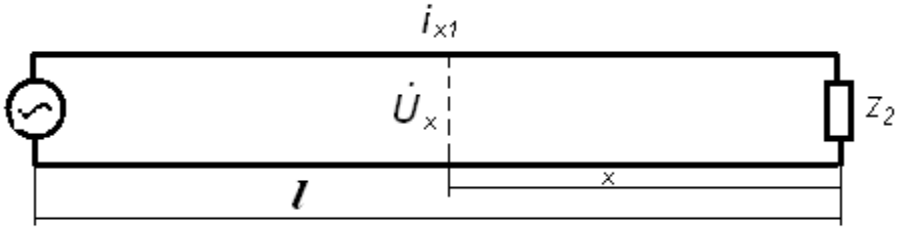

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ebgbb \ dhlhjuo gZ ex[hf we_f_glZjghf mqZkld_ ih]hg
?keb ebgby ^ebfghc bg^mdlb\ghklvLijZvdh^hgh_ khijhlb\
ijh\h^hR\ Z lZd`_ _fdhklZdlm\g ijh\h^bfhklv Gmf_q^mm
ijh\h^Zfb lhggju_h iZjZf_lju ebgbb [m^ml hij_^_ey
\ujZ`_gbyfb

$$L_1=\frac{L}{l};\quad R_1=\frac{R}{l};\quad C_1=\frac{C}{l};\quad G_1=\frac{G}{l}.$$

lhegh_ ih]hggh_ khijhlb\e_gb_ ijh\h^h\ ebgbb khkl Z\eyxs R_1 mx j_Zdlb\g ωL_1 mx Z ihegZy ihijjhgbZlv kh^_j Zdlb\gmx khklZ\eyxs G_1 yx sj_Zdlb\g ωC_1 mx Ke_^h\Zl_evgh \ dhfie_ khijhlb\e_gb_ ijh\h^h\ ebgbb hgZbgh

$$Z_1 = R_1 + j\omega L_1$$

Zihegzy ih]hggZy ijh\h^bfhklv

$$Y_1 = G_1 + j\omega C_1.$$

< ebgbyo i_j_^Zqb bkihevam_fuo \ \ukhdl

$R_1 << \omega L_1$ u $G_1 << \omega C_1$ GZ wlhf hkgh\Zgbb \ jy^_ kemqZ_\ f

ZgZebahf jZ[hlu b^_Zevghc ebgbb \ dhlhjhc $R_1 = 0, G_1 = 0$ l\m

.

lh]hggu_ bg^mdLbhgh_ kdvhC $_1$ dhZdkbZevghc ebgbb hij ih ke_^mxsbf nhjfmeZf

$$L_1 = \frac{\mu}{2\pi} \ln \frac{D}{d},$$

$$C_1 = \frac{2\pi\varepsilon}{\ln \frac{D}{d}}.$$

]^D- \gmlj_ggbc ^bZf_lj \g_rg_]h ijh\h^Z

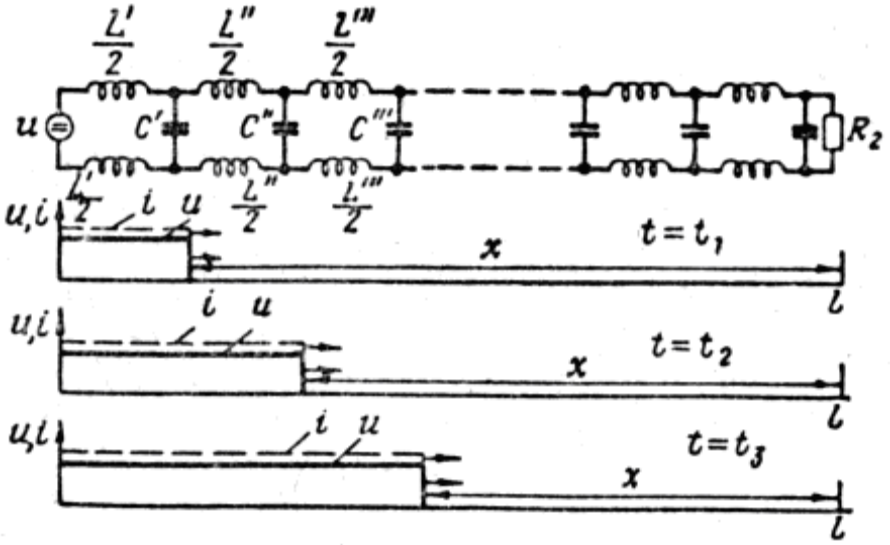
d- \g_ggbc ^bZf_lj \gmlj_gg_]h ijh\h^Z

μ- fZ]gblgZy ijhgbpZ_fhklv

ε - hlghkbl_evgZy ^bwe_dljbq_kdZy ijhgbpZ_fhklv

:. JZkijhkljZgwebdljhfZ]gblguo \heg \ ^ebgguo eb

lj_^iheh`bf qlh b^_Zevgkzyjzkbjgh^y e_ggufb iZjZ
iblZ_lky hl bkhqgbdZ ihklhyggh]hjgZkinyg`4dby

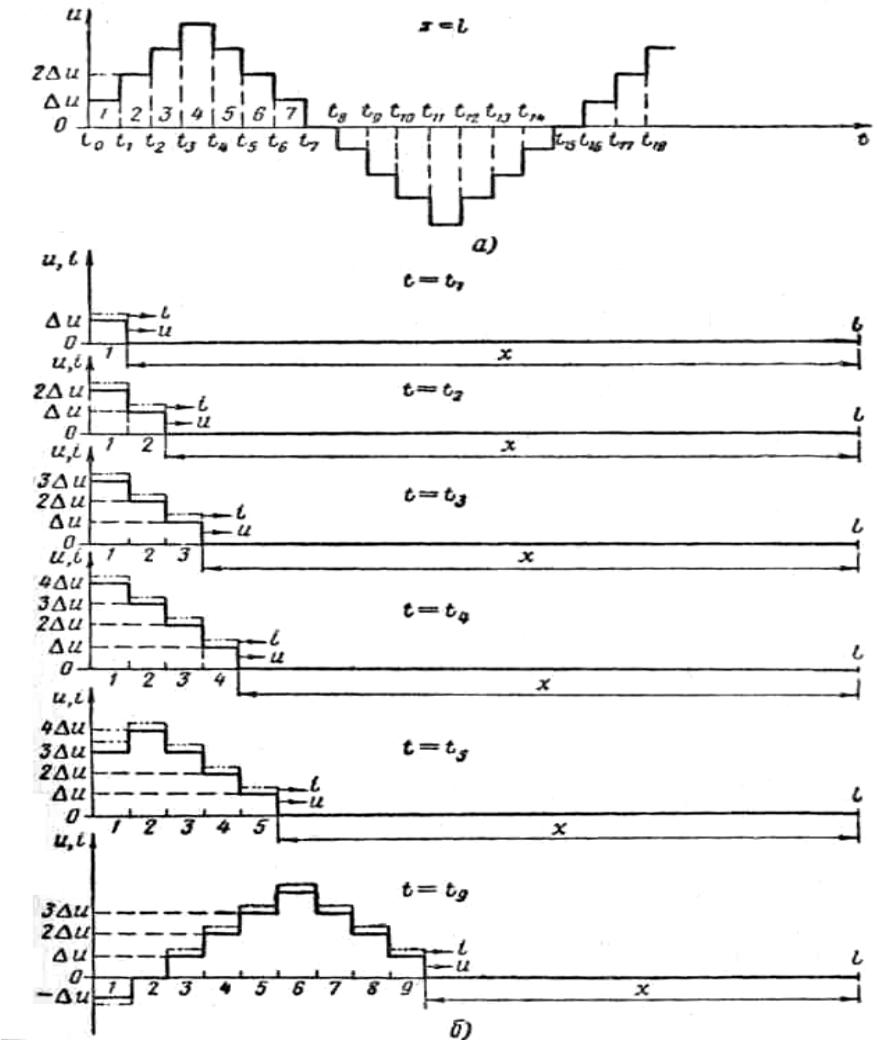


Jbkmgh4d<hegu lhdZ b gZijy`_gby kha^Z\Z_fu_ \
bklhqgbdhf ihklhygghc W>K

D fhf_glm \j_1f_gdhklv i_j\h]h we_f_glZjgh]h kmqZ
aZjy^blky q_j_a bg^mdlb\ghklb lhgbZlby `u_gabZy_f d fhf_glm t2j_f
_fdhklv \lhjh]h wgeh_fh_ghZjZkldZ K aZjy^blky K hlj_af
bg^mdlb\ghklb lh/2lbh wlh]h `_ gZijy`_gby Z bklhqgbd gZij
\hkklZgh\bl aZjy^ gZ _fdhkl_b^mKxsbc hlj_ahd \j_f_gb
_fdhkl'vlZKd `_ aZjy^blky ^h ihklhyggh]h gZijy`_gby b l
ihke_^h\Zl_evgh]h aZjy^Z we_f_glZjguo _fdhkl_c
bg^mdlb\ghklb kha^Z_l \hegm lhdZ b gZijy`_gby ^\b
dhgpm ebgbb WlZ \hegZ gZau\Zj_lfyy _iZ^jZkxsjhckljZhg_gb
ebgbb mklZgZ\eb\Zxlky ihklhyggu_ lhd b gZijy`_gb_

?keb gZ]jmadZ \dexq_ggZy gZ dhgp_ ebgbb g_
wg_j]bx kdhgp_gljbjh\Zggmx \ iZ^Zxs_c \heg_ lh
hljZ`_ggZy \hegZ lhdZyb dhZihjZygbZd `_ dZd iZ^Z
ij_^klZ\ey_l kh[hc ijhp_kk ihke_^h\Zl_evgh]h aZjy^Z
_fdhkl_c q_j_a we_f_glZjgu_ bg^mdlb\ghklb LZdbf h[j
ex[h_ k_q_gb_ ebgbb ijhoh^yl ^_ \hegu ZhdZxsZy g
hljZ`_ggZy

L_i_jvhi^mklbf qlh ebgby iblZ_lky]_g_jZlhjhf gZ
q_j_a hlj_adb \ $t_0=t_2-t_1=t_3-t_2$ W baf_gy_lky kdZqdhf guZjb_kemgqhc
:.5, Z ljb wlhf mkeh\bb aZ ^Zggu_ hlj_avdeb_f\jgfZigdu
mqZkld aZ«jy^ylky dZd ihdZaZgh5 [gZLhjcb\megxh[df k_q
ebgbb baf_gy_lky h^gh\j_f_ggh k gZijy`_gb_f

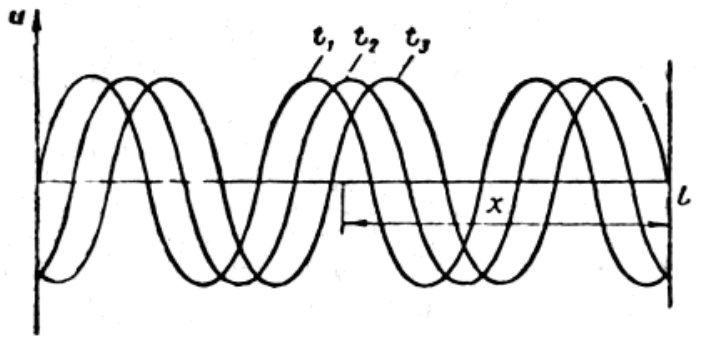


Z±baf_g_gb_ gZijy`_gby jZgaZZbhfZ k l_q_gb_f \j_f_gb
[±jZkij_^_e_gb_ gZijy`_gby b lhdZ \^hefvhfe_ggb\j_fZabqgu

Jbkmg:h5d- <hegu gZijy`_gby b lhdZ kha^Z\Z_fu_ \
]_g_jZlhjhf kh klmi_gqZlh baf_gyxsbfky gZijy`_gb_f

?keb b^_ZevgZy ebgby iblZ_lky]_g_jZlhjhf kbgml
:. lh dZd \ ij_^u^ms_f kemqbZ_lhdgZkijyh\khby_gghc kc
jZkijhkljZgyxlky hl h^gh]h k_q_gby d ^jm]hfm gh w
klmi_gqZlh_ Z ieZ\gh_ ijbjZs_gb_ < gZqZe_ ebgbb k
\j_f_gb gZijy`_gb_ b lhd Hgb ih\lhjyxlky \ khk_^gbc
hlklZ\Zgb_f ih nZa_ dhlhjh_ l_f [hevr_ q_f [hevr_
ebgbb hl __ gZqZeZ

< j_amevlZl_ _keb fu aZnbdkbjm_f \ ^Zgguc fhf_
lhd ih \k_c ^ebg_ ebgbb lh nhjfZ ihemq_gghc djb\hc i
LZdbf ha[hZ \ ex[hf k_q_gbb ebgbb ijhbkoh^yl kbgmk
gZijy`_gby b lhdZ \h \j_f_gb b \f_kl_ k l_f \ ex[hc
_ebqbgu baf_gyxlky kbgmkhb^Zevgh \^hev ebgbb



Jbkmghd6d Baf_g_gb_ gZijy`_gby \^hev b^_Zevghc e
fhf_glu \j_f_gb ijb gZebqbb bklhqgbdZ kbgmkhb^

:. J_`bfu jZ[hlu ^ebgghc ebgbb

< aZ\bkbfhklb hl khhlghr_gby f_`^m \hegh\uf khi
khijhlb\e_gb_f gZ]jmadb ebgby jZ[hlZ_l \ j_`bf_ [_]ms
h[hbo \b^h\ \heg

;_]msbfb \hegu gZ fabu\Zxlky dhe_[Zgby nZaZ dhlhju
bklhqgbdZ \ha[m`^_gby k ihklhygghc kdhjhklvx aZ\bky

Klhyqbfb \hegu gZ fabu\Zxlky dhe_[Zgby ihemq_ggu
keh`_gby ^\mo [_]msbo \heg gZijZ\e]gu jumgZ\kZ ji
iZ^Zxs_c b hljZ`_gghc \heg

:. J_`bf [_]msbo \heg

GZijy`_gby b lhdb ;_]msbb \hegu \ ebgbb ihemq
kemqZ_ _keb khijhlb\e_gb_ gZ]jmadb qbklh Zdlb\
khijhlb\e_gbx eblhke ih^klZgh\db

$$\dot{I}_2\rho = \dot{U}_2 \quad \text{b} \frac{\dot{U}_2}{\rho} = \dot{I}_2$$

bkoh^gZy kbkl_fZ mjZ\g_gbc ijbgbfZ_l \b^

$$\dot{U}_x = \dot{U}_2 \cos\alpha x + j\dot{I}_2\rho \sin\alpha x = \dot{U}_2(\cos\alpha x + j\sin\alpha x)$$

$$\dot{I}_x = \dot{I}_2 \cos\alpha x + j\dot{I}_2 \sin\alpha x = \dot{I}_2(\cos\alpha x + j\sin\alpha x) \qquad (1)$$

ljb ibl Zgbb ebgbb hl]_g_jZlhjZ kbgmkhb^Zev
gZijy`_gby gZ gZ]jmadb _kayZ\bdhfie_dkghf \b^_

$$\dot{U}_2 = U_{m2} e^{j\omega t}.$$

Wlh agZqbl qlh gZijy`_gby _l fh^m eb mZah\uc m]h
K l_q_gb_f \j_f_gb W nZah\uc m]he &W g_ij_ju\gh m
gZijy`_gby \jZsZ_lky k ihklhygghc m]eh\hc kdhjhklvx &
_dlhjZ hkv fgbfuo ^_ckl\bl_evguo qbk_e \ujZ`Z_l
kbgmkZ hdhkbgmkhb]^ gZijy`_gby

$$u_2 = U_{m2} \sin\omega t \quad i_2 = U_{m2} \sin\omega t$$

?keb kbkl_f_ mjZ\g_dbjhf_ ih^klZgh\ddb $\dot{U}_2 = U_{m2} e^{j\omega t}$ ijhba_klb
aZf_gm $\cos\alpha x + j\sin\alpha x = e^{jax}$ lh ihemqbf

$$\dot{U}_x = U_{m2} e^{j(\omega t + ax)} \qquad (2)$$

$$\dot{I}_x = I_{m2} e^{j(\omega t + ax)}$$

hldm^Z f]gh_ggu_ agZq_gby gZijy`_gby b lhdZ hl e
gZ]jmadb khhl_lkl_ggh jZ\gu

$$\dot{U}_x = U_{m2} \sin(\omega t + ax) \qquad (3)$$

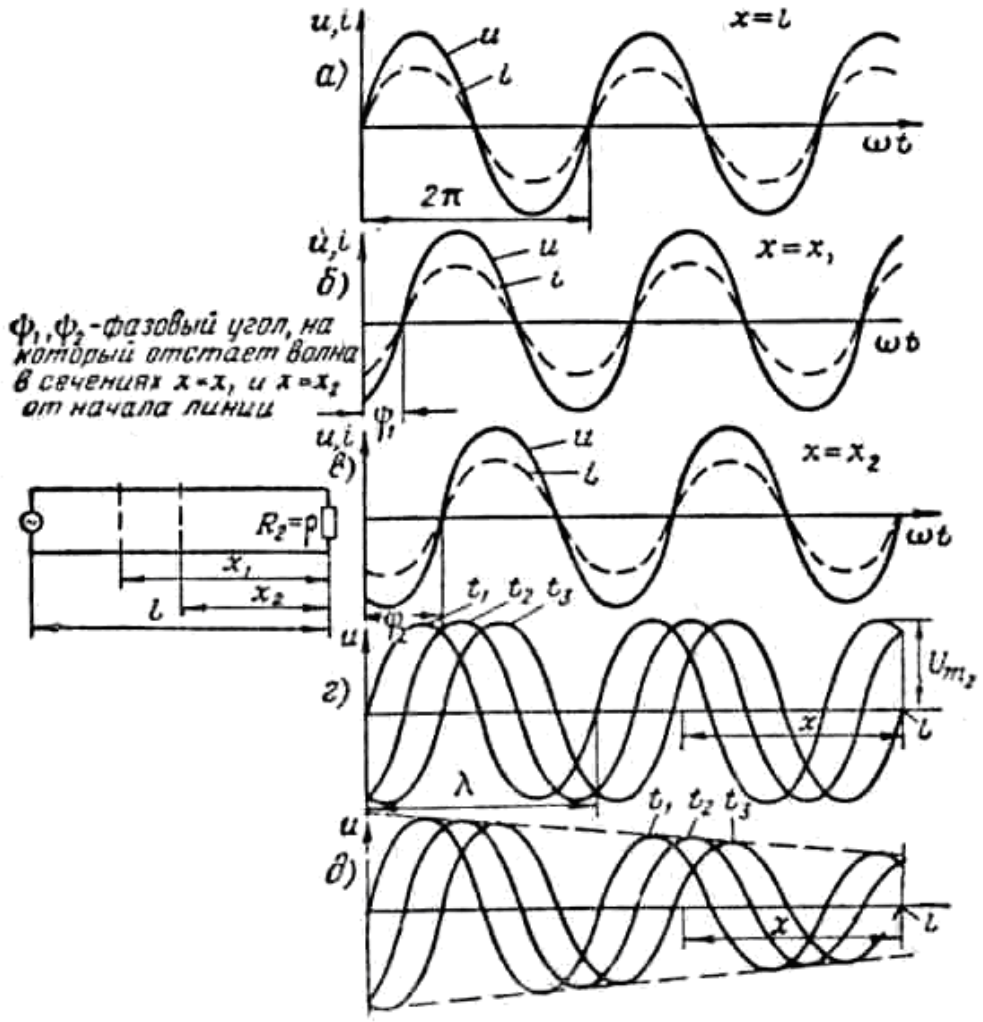
$$\dot{I}_x = I_{m2} \sin(\omega t + ax)$$

Wlh² mjZ\g_dbjymsbo \heg GZ hkgh\Zgbb ihemq
hlf_qZ_f ke_^mxsb_ k\hckl\Z [_]msbo \heg

< dZ`^hf k_q_gbb ebgbb kbgmkhb^Zevgh ba\fh_g
\j_f_gb jbk:mZgZhd[\ GZ wlh mdZausiZ $(\omega t + ax)$ f.gh`bl_ev

< k\yab k l_f qlh \hegu gZijy`_gby b lhdZ jZ
ebgbb k dhg_qghc kdhjhklvx nZaZ wlbo \heg ih
mf_gvrZ_hkkyeb ijbgylv aZ gZqZeh dhhj^bgZdu dhhg_p\
nbdkbjh\Zgguc fhf_gl bjmkbb^Zevgu[Zgdby \ k_q_gbb
dhhj^bgZlhcbfo_xl hi_j_`_gb_ ih nZa_ gZ m]he .[hlghkl
dhgp_ ebgbb b hlklZ\Zgbb $\alpha(l-x)$ hZah_kbgZ_emvghe dhe_[Zgb
ebgbbol, ∂de l ±^ebgZ ebgbb GZijbf_j nZaZ gZijy`_gby
dhhj^bgZlhcbdklZo_l gZ m]he jbkmgh7d[i4b o $_2$ o$_1$² gZ
[hevrbc $\varphi_1 = \alpha(l - x_1)$ m]he jbkmg:h7d\ hl nZaiujy`gZgby b lhdZ \ g
ebgbbjbkmgh.dZ $\varphi_2 = \alpha(l - x_2)$

NZah\mx ihklhyggmx fh`gh \ujZablv q_bjk_cah^ye bbgamlh
qlh ijb jZkijhkljZg_gbb [_]ms_c \hegu igZbkZlkhlhlyglbk_lZ\
ih nZa_ gZijy`_gby beb lhdZ gZx = am]hce ehldlm^_ nZa
ihklhyggmx fh`gh \ujZablv $\varphi = \frac{2\pi}{\lambda} x$



Z±baf_g_gb_ gZij\y`g_ZgqbZye_ b^_Zevxgh,c±ebbagfb_g_gb_ gZij\yb^_gZbeyvgh
ebgbqbZjZkklhygqb(l-q) hl _gZqZeZ±ba\af_g_gb_ gZij\yb^_gbZyevghc qebZgb
jZkklhygbb(l-q) >(l-q) hl __ gZqZebZa f_g_gb_ gZijy`b^_gbZyevghc \ebg
jZaebqgu_ fhf_glu; \j_fb_agfb_g_gb_ gZij\y`j_gZbeyvgehbqgbbk ihl_jyf\b
jZaebqgu_ fhf_glu \j_f_gb

Jbkmghl7ed;_]msb_ \hegu gZijy`_gby b lhdZ

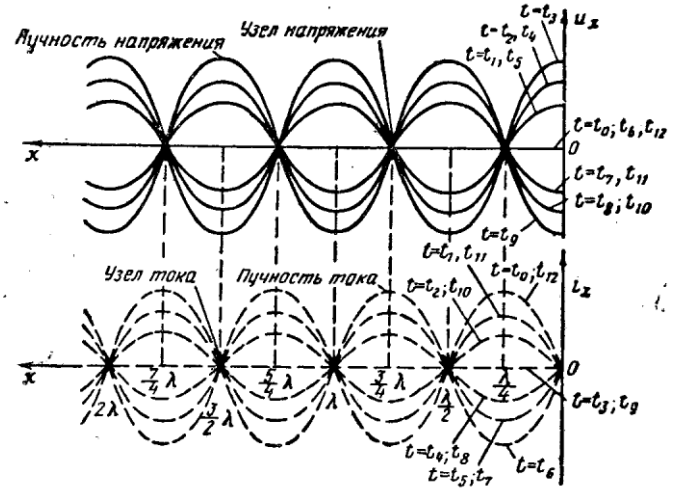
.

:. J_`bf klhyqbo \heg

Klhyqb_ \hegu ihemqZxlky \ b^_Zevghc ebgbb ij
mkeh\bc ebgby jZahfdgmlZ gZ dhgp_ ebgby aZfdgml
aZfdgmlZ gZ qbklh j_Zdlb\gh_ khijhlb\e_gb_

Линия, разомкнутая наконце. JZkkfhljbf oZjZdl_jy`_gbc
lhdh\ jZahfdgmlhc <ebgbb gZ dhgp_ ebgby aZfdgmlhc ebgby gZ dhgp_ keh`_gb
[_]msbo \heg iZ^Zxs_c b hbjZ`sdghc ^bgZdh\mx Zfi
gZijZ\e_gguo g,Zi\kejmqZxlkhyqb_ \hegd dZd \ dhgp_ jZ
ebgbb g_ fh`_l [ulv lhdiZ^Zxsdy]\hZegZ lhdZ ^hklb]Z_l
lhd j_adh kiZ^Z_l Z W>K\kZfuhZg^mdpbb dhlhjZy \ha[m
\hegm lhdZ LZd dZd W>K kZfhbg^mdpbb \k_]^Z bf
ij_iylkl\m_l baf_g_gbx hkgh\gh]h lhdZ jgh\kdvhgpj_`e_gg
\hegu gZijy`_gby lZdZy `_ dZd b m iZ^ZxiZ^ZxshZeygu
hljZ`_ggZy \hegu lhdZ bf_xl \ dhgpi_heb`gbo ajghZd
h[jZahf gZ jZahfdgmluo dhgpZo ebgbb kemqZxlky g
Zfieblm^hc imqigjyk_gbyZ b lhd k gme_\hc Zfieblm^hc

Hlf_lbf k\hckl\Z klhyqbo \heg gZ hkgh_]jZnb
baf_g_gby gZijy`_gby b lhdZ \^hev jZahfdgmlhc ebgbb
t_0, t_1 «t_{12} kf jbkm.5) hdho\Zlu\Zxsbo h^bdghe_j[bZhgjYbkmgl8d



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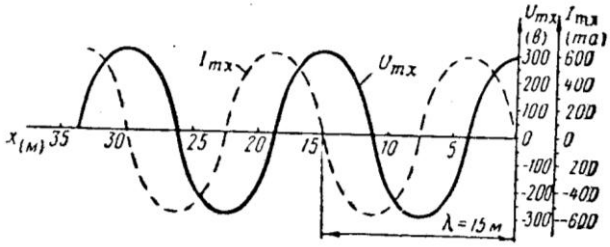
< dZ`^hf k_q_gbb ebgbb bf_xl f_klh kbgmkl
gZijy`_gby b lhdZ \h \j_f_gb GZijy`_gb_ gZijbf_j ihk
hl gm(te)y^h fZdkbfmfZ h^gh]h aZgZ_gdZrZ_lky ^h g^hkyb]Z
fZdkbfmfZ k ^jm]bf abgZdhfv klZgh\blky jZ\guf gmex

:fieblmdhe_[ZUmx bafgykxy \^hev ebgbb :jbkm
^ey gZijy`-gbyaZdhgm FRV .o ±sZQ^ey lhdZqghklb fZ
Zfieblm^u gZijy`_gby b maeu fbgbfmfu Zfieblm^u lh
ebgbb \ dhlhjuo FsRVQ .o



Jbkmgh9d Baf_g_gb_ Zfieblm^u gZijy\^hgbyjZalhfdZm
ebgbb

3. Hlghr_gb_ Zfieblm^gh]h agZq_gby gZijy`_gby
Zfieblm^ghfm agZq_gbx lhdZ \ _]h imqghklb jZ\gh \
ebgbb

$$\frac{\left(U_{mx}\right)_{max}}{\left(I_{mx}\right)_{max}} = \frac{U_{m2}}{\frac{U_{m2}}{\rho}} = \rho$$

4. NZaZ gZijy`_gby \h \k_o k_q_gbyo ebgbb h\k_gZdhjZ
gZijy`_gb_ jZ\gh gmex beb ^hklb]Z_l fZdkbfmfZ \ h^bg b
fZdkbfmfu ^ey jZagjZale_bq_gub cihkdhevdmdhZfie[ZbhmeZbgbb
baf_gy._Lhkyì_kZfhf_h`ghkdZaZlvlhd_GZijbf_j kh]hkZkg:dm\
ex[hf k_q_gbbobdhd jZ_g gmex \ fjh_ff_gdbu t_3, t_9 ^hklb]Z_
fZdkbfmfZ h^gh]ht a$t_{0,12}$ dZ^ijjb]h]h agZt_6 ijb

5. < ex[hc lhqd_ ebgbb f_`^m gZijy`_gb_f b lhdhf
nZa_ gZ *f* lhwlhfm dh]^ZgZ hjy\k_gdb_ebfZdlkbfZevgh
gme(tx= t_3, t_9), b gZh[htj=ht$_0$, t_6, t_{12} AgZqbl ^ey klhyqbo \heg o
ih nZa_ f_`^m gZijy`_gb_f b lhdhf \h \j_f_gb
ljhkljZgkl_gguc k^\b] \ujZ`Z_lky \ lhf qlh \ gkhkqlygb
gZijy`_gby gZ[ex^ZxlkymaeulhdZ Z ijb maeZo g
imqghklb +hdhZgh_ khijhlb\e_gb_ jZahfdgmlhc ebgbb [_

$$Z_{ex} = \frac{\dot{U}_x}{\dot{I}_x} = \frac{\dot{U}_2 \cos(\gamma x)}{j\frac{\dot{U}_2}{\rho}\sin(\gamma x)} = -j\rho \cdot ctg(\gamma x)$$

Wlh khijhlb\e_gb_ bf__l j_Zdlb\guc gZo ZqjZhdl_mjdZOa
fgh`bl_ev l _

$$Z_{ex} = jX_{ex}, \quad \text{где} \quad X_{ex} = -\rho \cdot ctg(\gamma x)$$

J_Zdlb\guc oZjZdl_j jZahfdgmlhc ebgbb dZd gZ
kh]eZkm_lky k l_f qlh ijb klhyqbo \hegZo f_`^m gZijy
k^\b] ih nZa_ gZ m]he *f* Hlkx^Z ke_^m_l qlh kj_
]_g_jZlh\jhjZahfdgmlmx ebgbx [_a ihl_jv jZ\gZ gmex

Baf_g_gb_ ^ebgu ebgbb gZ \uau\Z_l $\frac{2\pi}{\lambda}\frac{\lambda}{4} = \frac{\pi}{2}$ g_\gb
k\yab k q_fctgagoZdklZgh\blky h[jZlguf b \oh^gh_ khijh
ijhc^y q_j_a gme_\h_ beb [_kdhg_qgh [hevrh_ agZq_g
bg^mdlb\ghfm beb gZh[hjhl Wlh iha\hey_l ml_j`^Zlv
wd\b\Ze_glgZ dhe_[Zl_evghfm q$_1$ g^mbm_ eb$_2$ ghjZlgh$_3$
gZoh^blky \ j_ahgZgk_ ihke_^h\Zl_evghf beb iZjZe
agZq_gbyo [khijhlb\e_gb_ wd\b\Ze_glgh]h dhglmjZ ijl
_fdhklghc beb bg^mdlb\guc oZjZdl_j

Краткие выводы

1. ?keb ebgbb gZ]jm`_gZ$_2 j lh mkeh\by jZkijhkljZg_g
dhgp_ ebgbb g_ gZ<mebZgxblkykms_kl\mxl lhevdh .[_]msb_
^ey [_]ms_c \hegu lhdZ kij_^kbZkhy_ldlb\gh_ khijhlb\e_g
\hegh\hfm_j]by iZ^Zxs_c \hekguxih]ehsZ_lky \ gZ]jmac

2. ?keb b^_ZevgZy ebgby aZfdgmlZ gZdhjhldh beb
mkeh\by jZkijhkljZg_gby \ dhgp_ ebgbb j_adh baf_
ijhbkoh^bl ihegh_ hljZ`_gb_ iZ^dZ]ksg_cjZ\hegu < j_ar
\hagbdZqxbklh klhyqb_ \hegu b]_g_jZlhj gbdZdhc wg_j
bf__l f_klh lZd`_ \ b^_Zevghc ebgbb aZfdgmlhc gZ j_
dZd ihke_^g__ g_ ih]ehsZ_l wg_j]bb

?keb \ ebgbb bf_xlky ihl_jb lh g_aZ\bkbfh h
[_]msZy \hegZ hl]_g_jZlhjZ dhfi_gkbjm_l wlb ihl_jb

?keb ebgby \ bhf^q_bZkevgZy aZfdgmlZ gZ dhfie
beb gZ Zdlb\gh_ khijhlb\e_gb_ g_ jZ\gh_ \hegh\hfm
[_]msb_ b klhyqb_ \hegu QZklv wg_j]bhehsZ_lky_c \ghZe
khhl_lkl\m_l [_]ms_c \heg_ Z ^jm]Zy qZklv hljZ
khhl_lkl\m_l klhyq_c \heg_

<oh^gh_ khijhlb\e_gb_ ebgbb jZ[hlZxs_c \²j_`
qbklh Zdlb\gh_ b jZ\gh \hegh\hfm khijhljZ[hlZxs_c \?jkèb
klhyqbo \heg dh^gh__ \khijhlb\e_gb_ bf__lZjZdlb\gmx
gZebqbb [_]msbo b klhyqbo \heg \ ebgbb _y\eyh^ky
dhfie_dkgufkhl^_j`bl Zdlb\gmx b j_Zdlb\gmx khklZ\eyxs