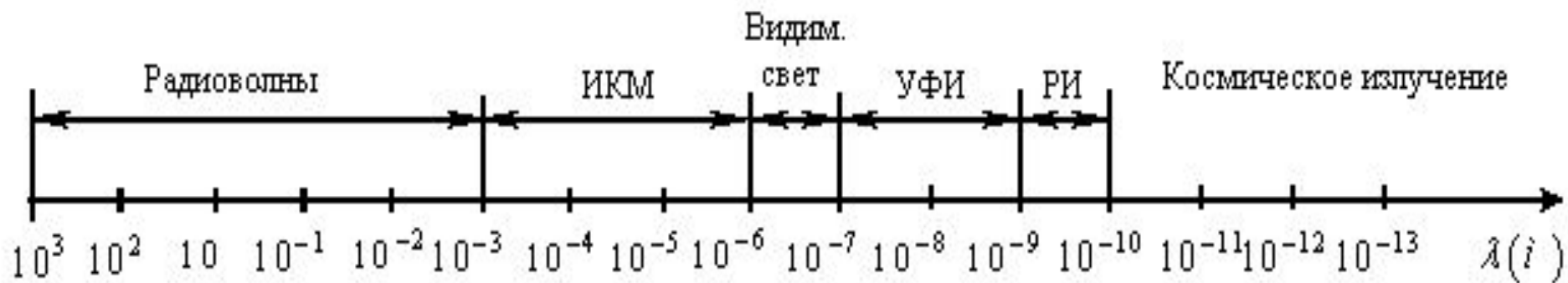


ВОСП

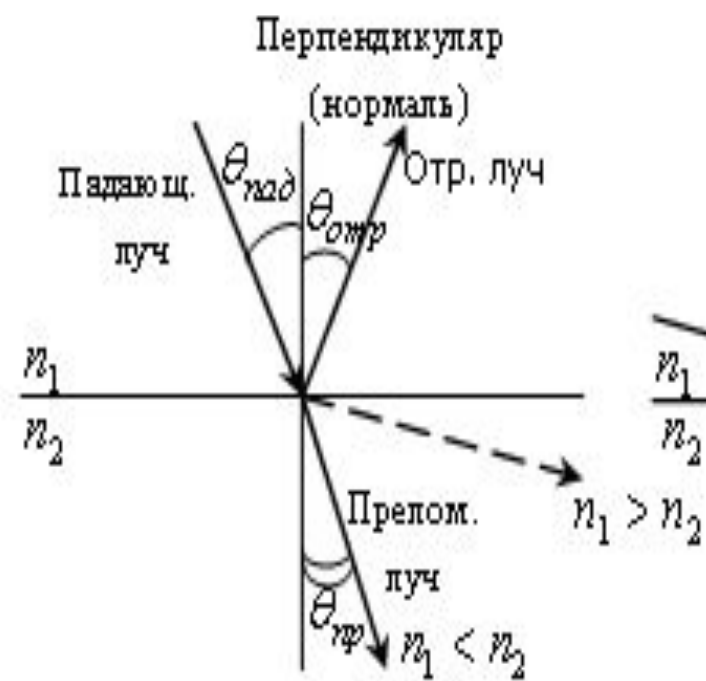
$$\lambda = \frac{c}{f}$$



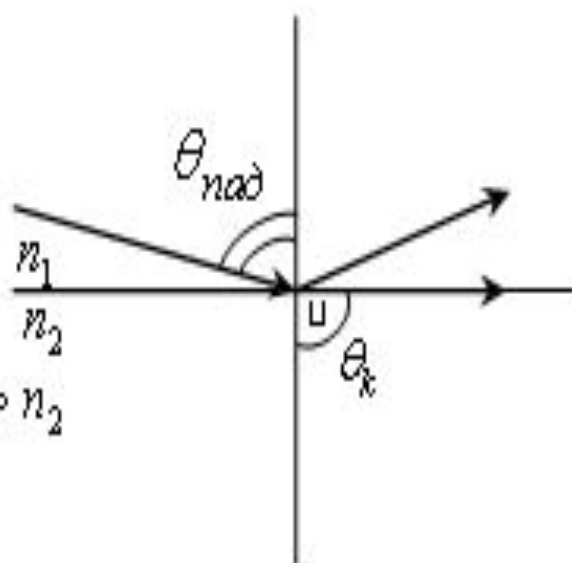
Энергия, запасенная в одном фотоне

$$E = h \cdot f$$

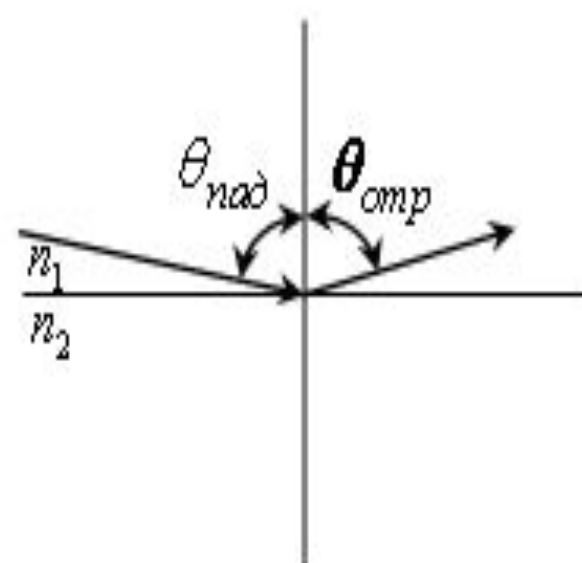
| Материал | Показатель преломления (n) | Скорость света (С, км/с) |
|-----------------|-----------------------------------|---------------------------------|
| Вакуум | 1,0 | 300000 |
| Воздух | 1,0003 | 300000 |
| Вода | 1,33 | 225000 |
| Кварц | 1,46 | 205000 |
| Стекло | 1,50 | 200000 |
| Алмаз | 2,5 | 120000 |



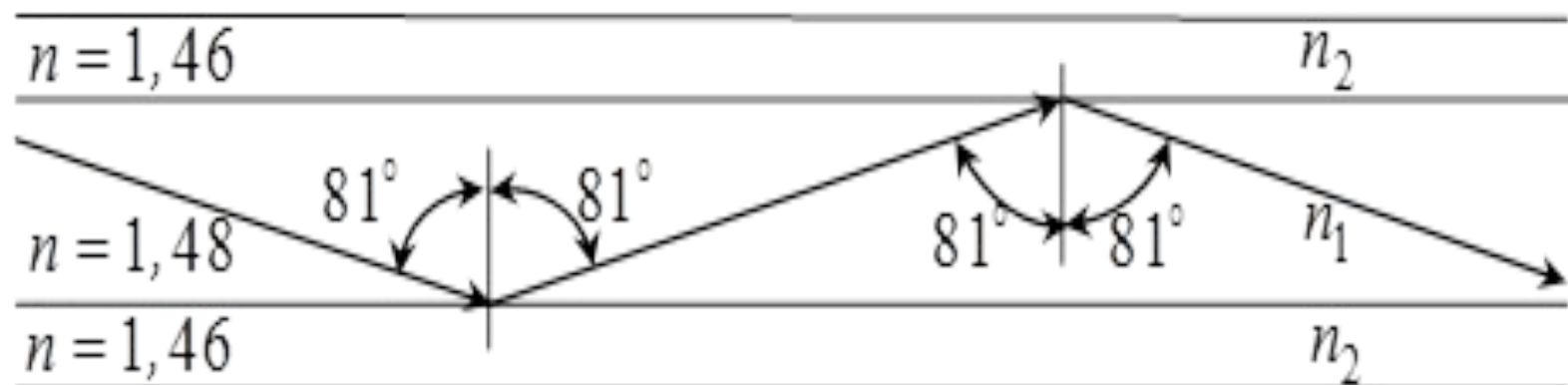
а)



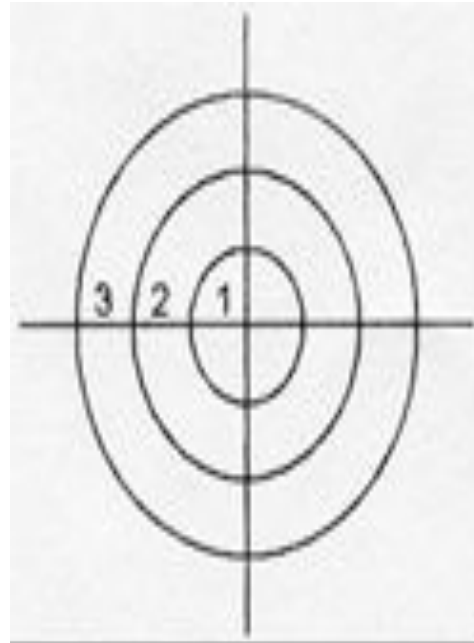
б)



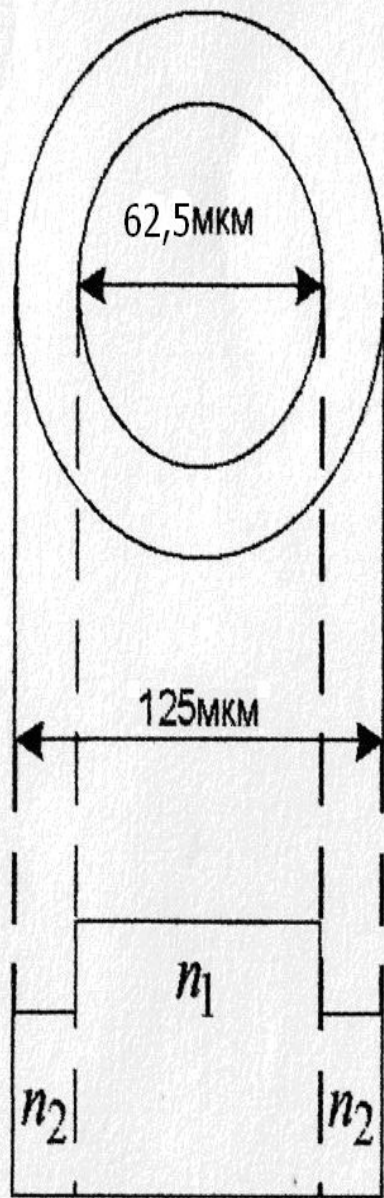
в)



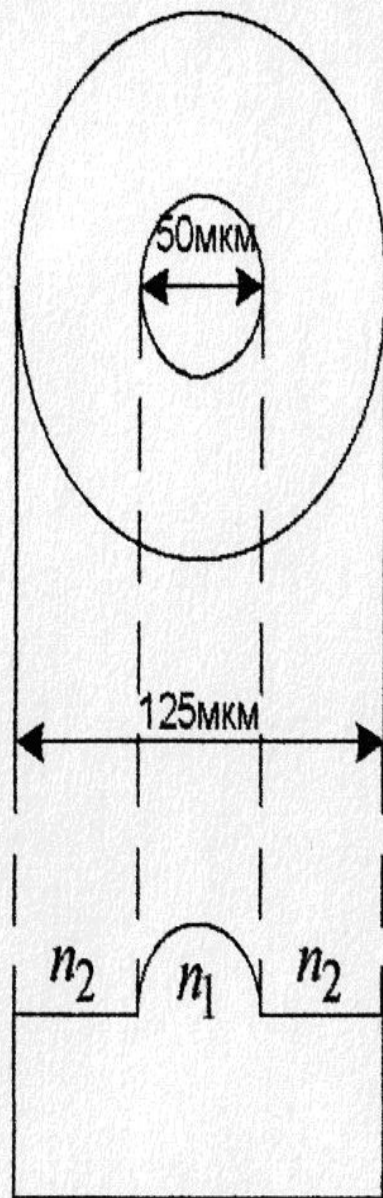
$$\theta_c = \text{arcSin}\left(\frac{1,46}{1,48}\right) = \text{arcSin}(0,9864) = 80,6^\circ$$



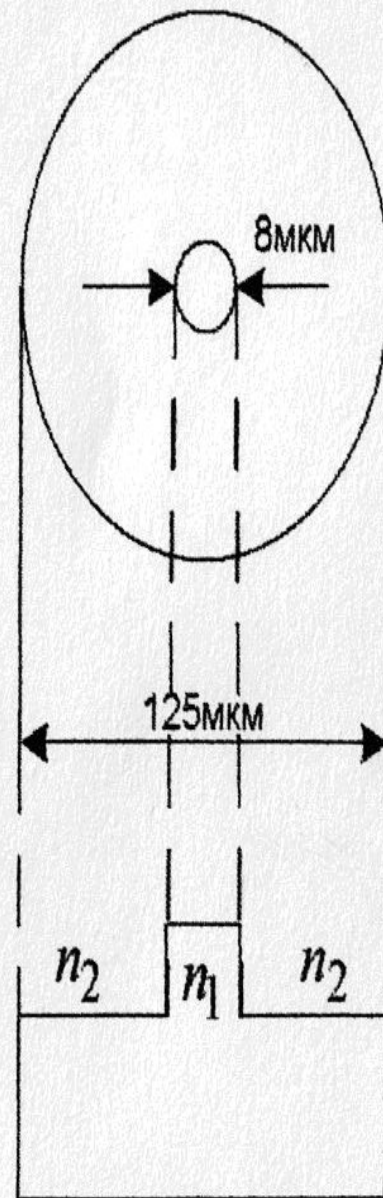
| Ядро (сердцевина), <i>мкм</i> | Оптическая оболочка, <i>мкм</i> |
|----------------------------------|------------------------------------|
| 62,5 | 125 |
| 50 | 125 |
| 8-10 | 125 |



a)

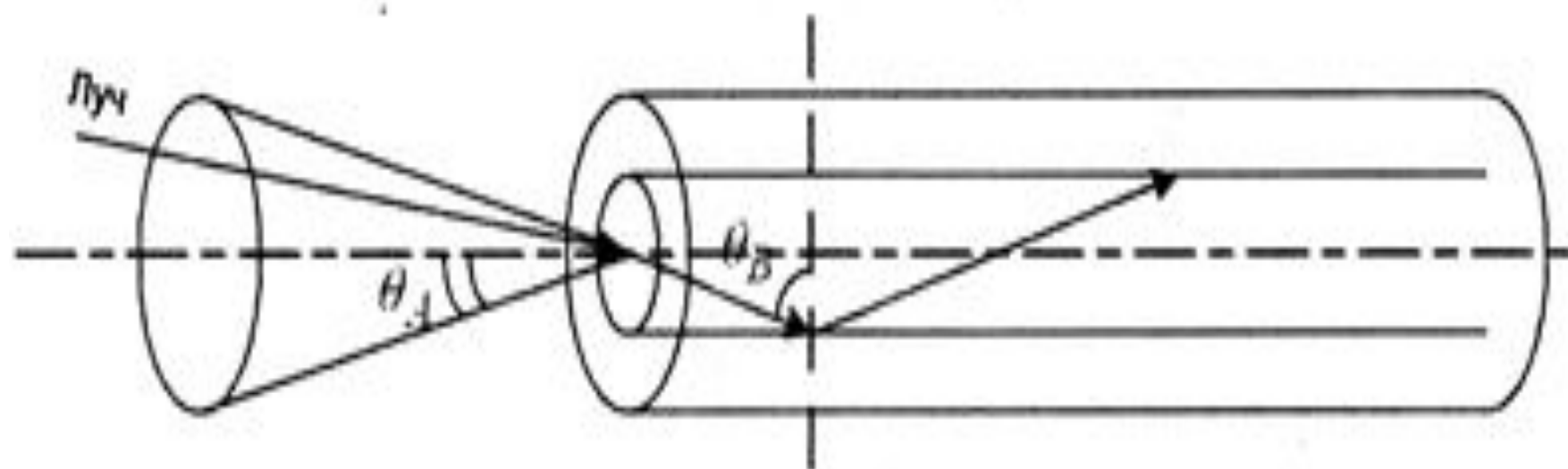


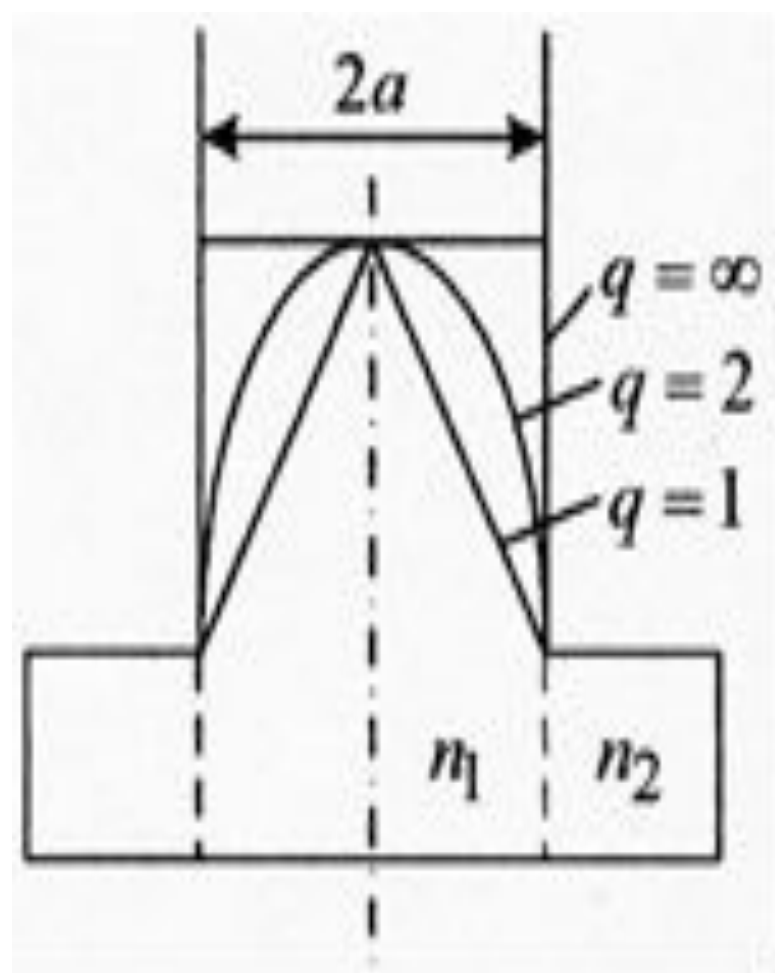
б)



B)

$$NA = \sin\theta_A$$



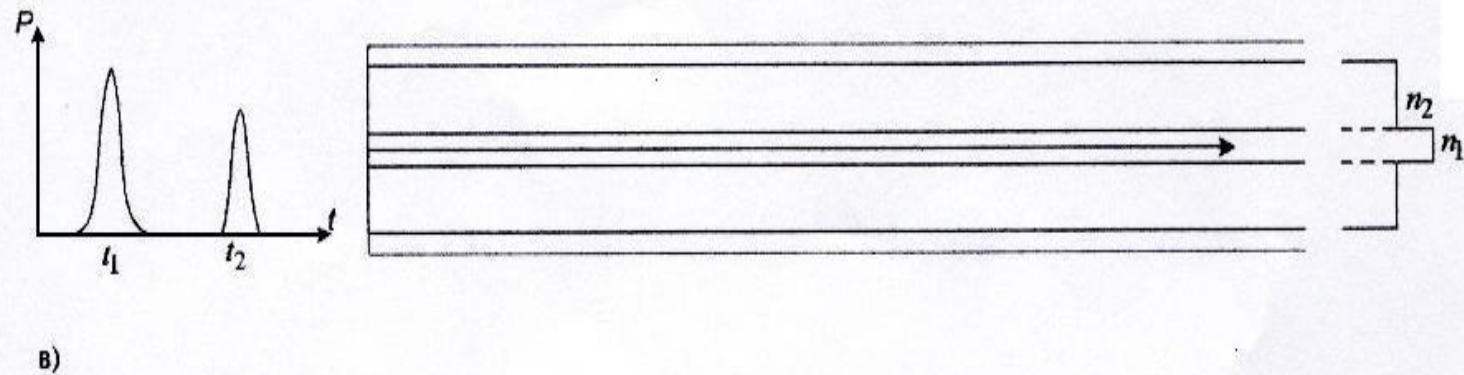
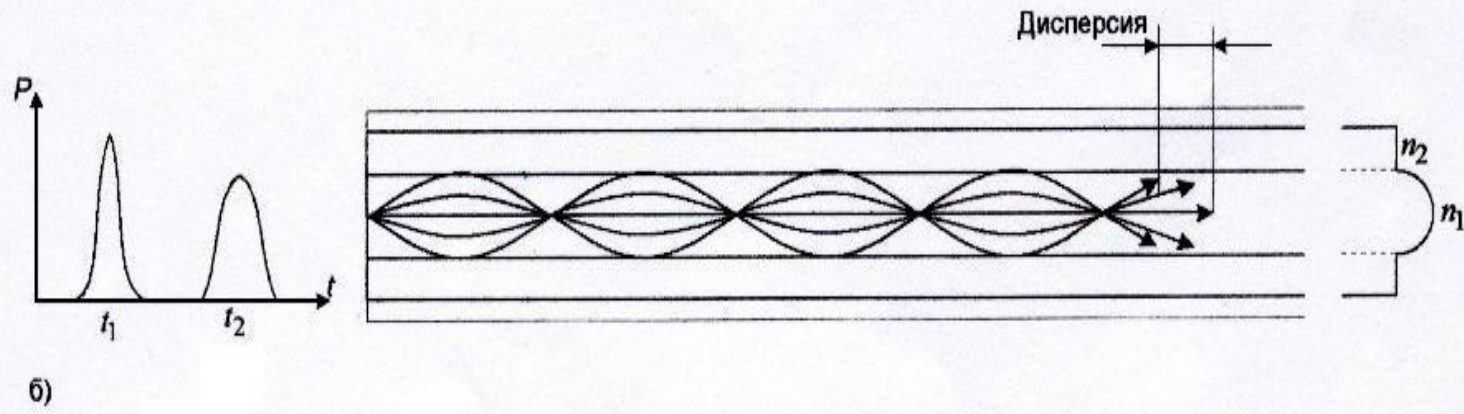
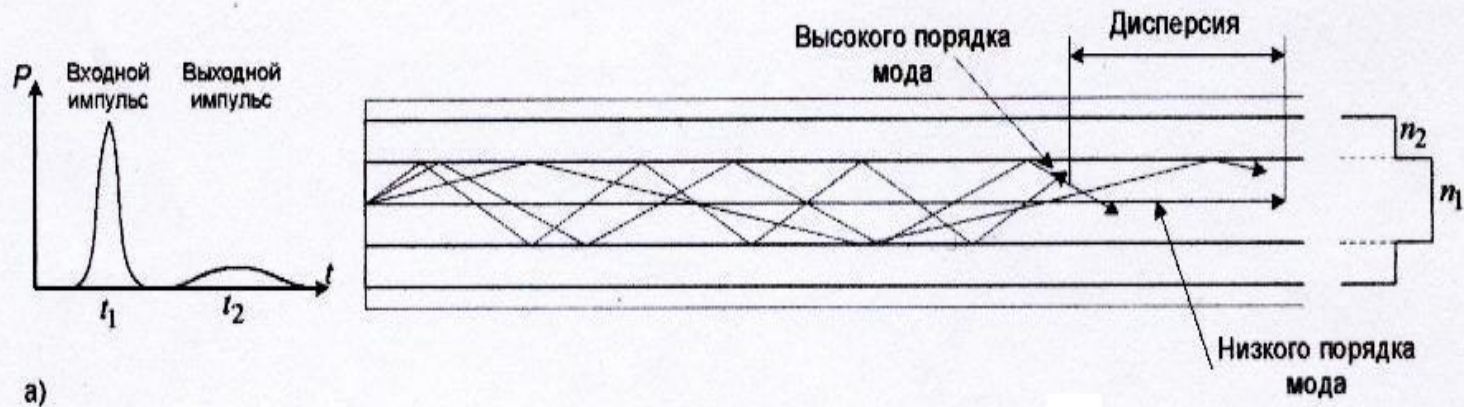


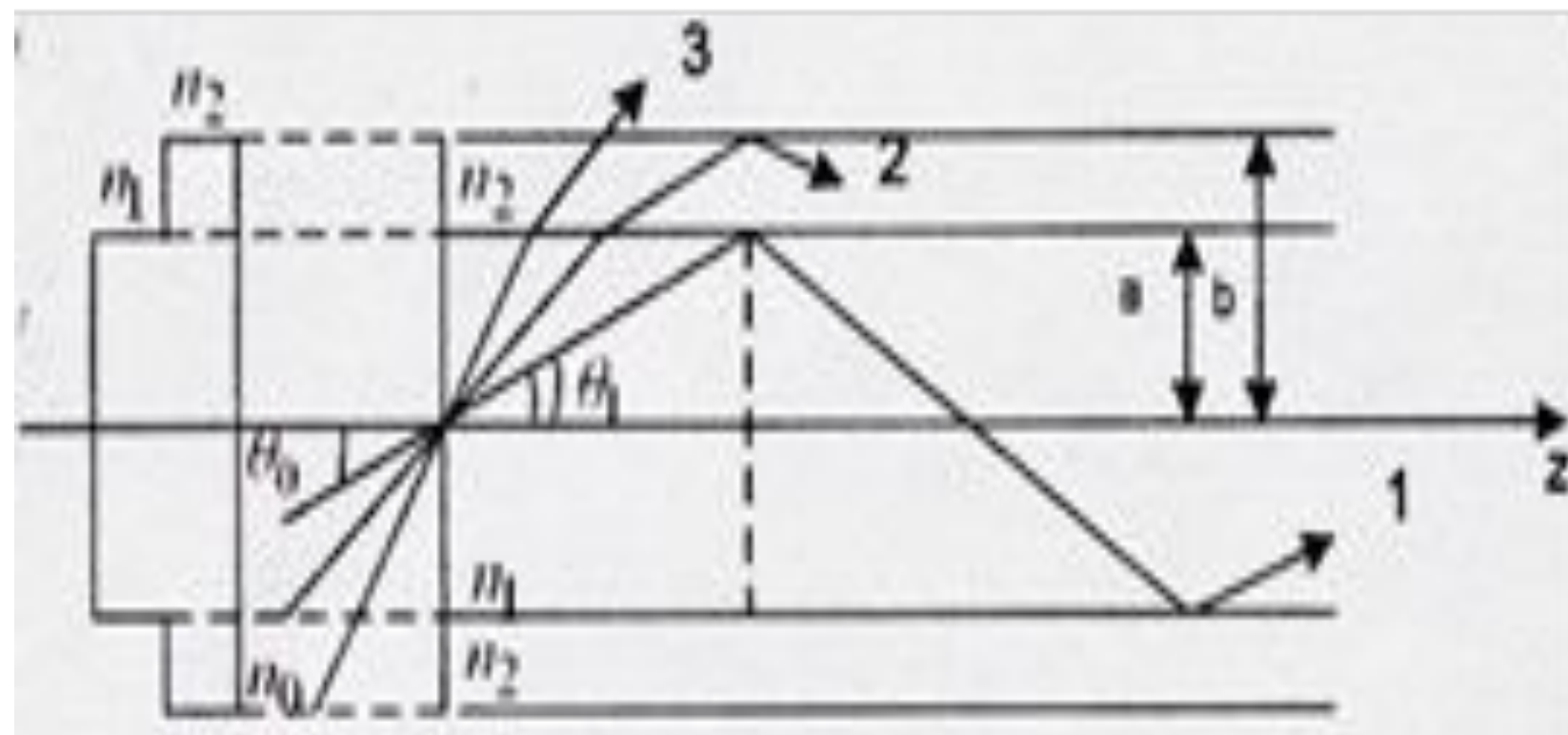
| Нормированная частота v | Число мод N_m | Типы мод |
|---------------------------|-----------------|---|
| 0-2,405 | 1 | HE_{11} -основная, фундаментальная мода (единственная допустимая для одномодового волокна) |
| 2,405-3,832 | 4 | $HE_{11}; H_{01}; EO_{01}; HE_{21}$ |
| 3,832-5,136 | 7 | $HE_{21}; H_{01}; E_{01}; HE_{21}; HE_{12}; EH_{11}; HE_{31}$ |
| 5,136-5,52 | 9 | $HE_{11}; H_{01}; E_{01}; HE_{21}; HE_{12}; EH_{11}; HE_{31}; EH_{21}$ HE_{41} |
| 5,52 | 12 | $HE_{11}; H_{01}; E_{01}; HE_{21}; HE_{12}; EH_{11}; HE_{31}; EH_{21}$ $HE_{41};$ $E_{02}; H_{02}; HE_{22}$ |
| 6,38-7,02 | 14 | $HE_{11}; H_{01}; E_{01}; HE_{21}; HE_{12}; EH_{11}; HE_{31}; EH_{21}$ $HE_{41};$ $H_{02}; E_{02}; HE_{22}; EH_{31}; HE_{51}$ |

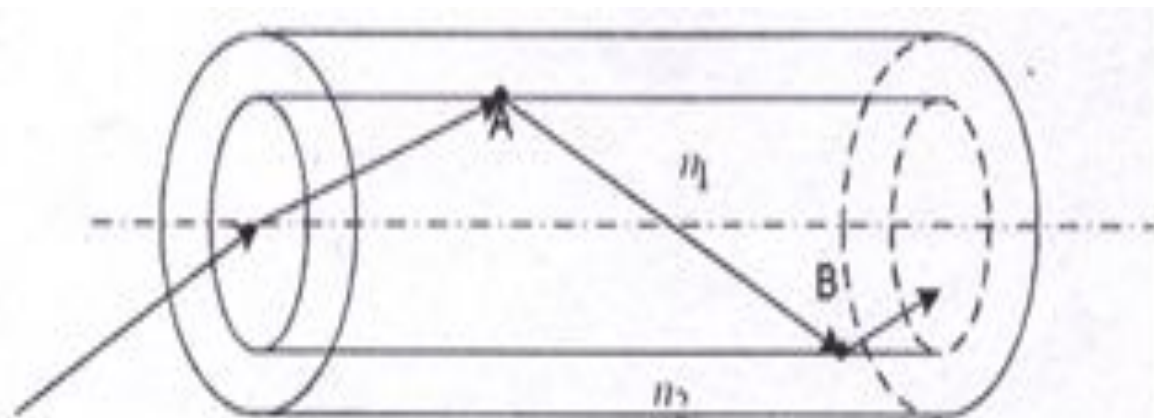
$$N_m = \frac{v^2}{2} = \frac{1}{2} \cdot \left(\frac{\pi d}{\lambda} \cdot NA \right)^2 = \frac{1}{2} \cdot \left(\frac{\pi d}{\lambda} \right)^2 \cdot (n_1^2 - n_2^2)$$

$$n(r) = \begin{cases} n_1 \left[1 - 2\Delta \cdot \left(\frac{r}{a} \right)^2 \right]^{\frac{1}{2}}, & 0 \leq r < a \\ n_2, & 0 \leq r < b \end{cases}$$

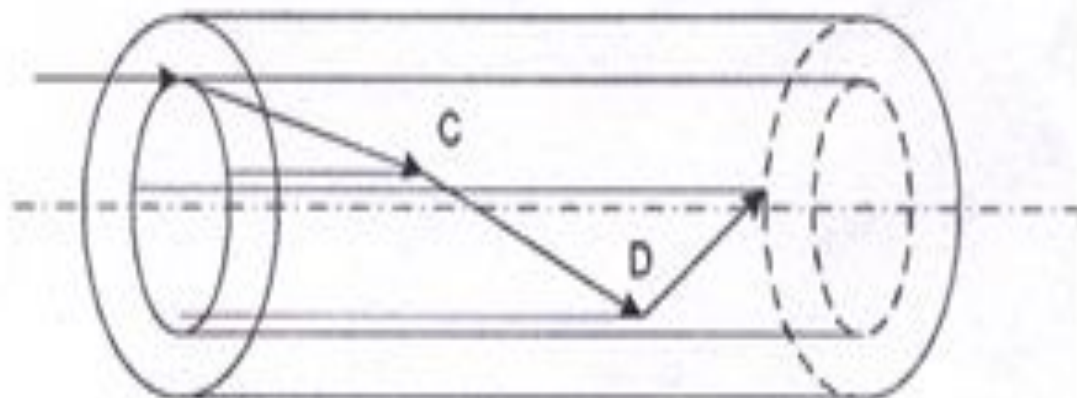
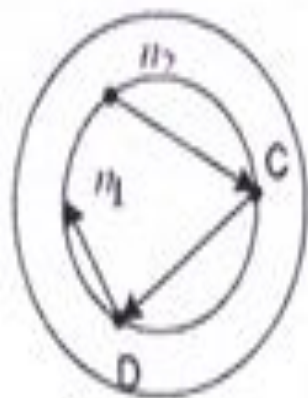
$$N_m = \frac{1}{4} \cdot \left(\frac{\pi d}{\lambda} \right)^2 \cdot (n_1^2 - n_2^2)$$



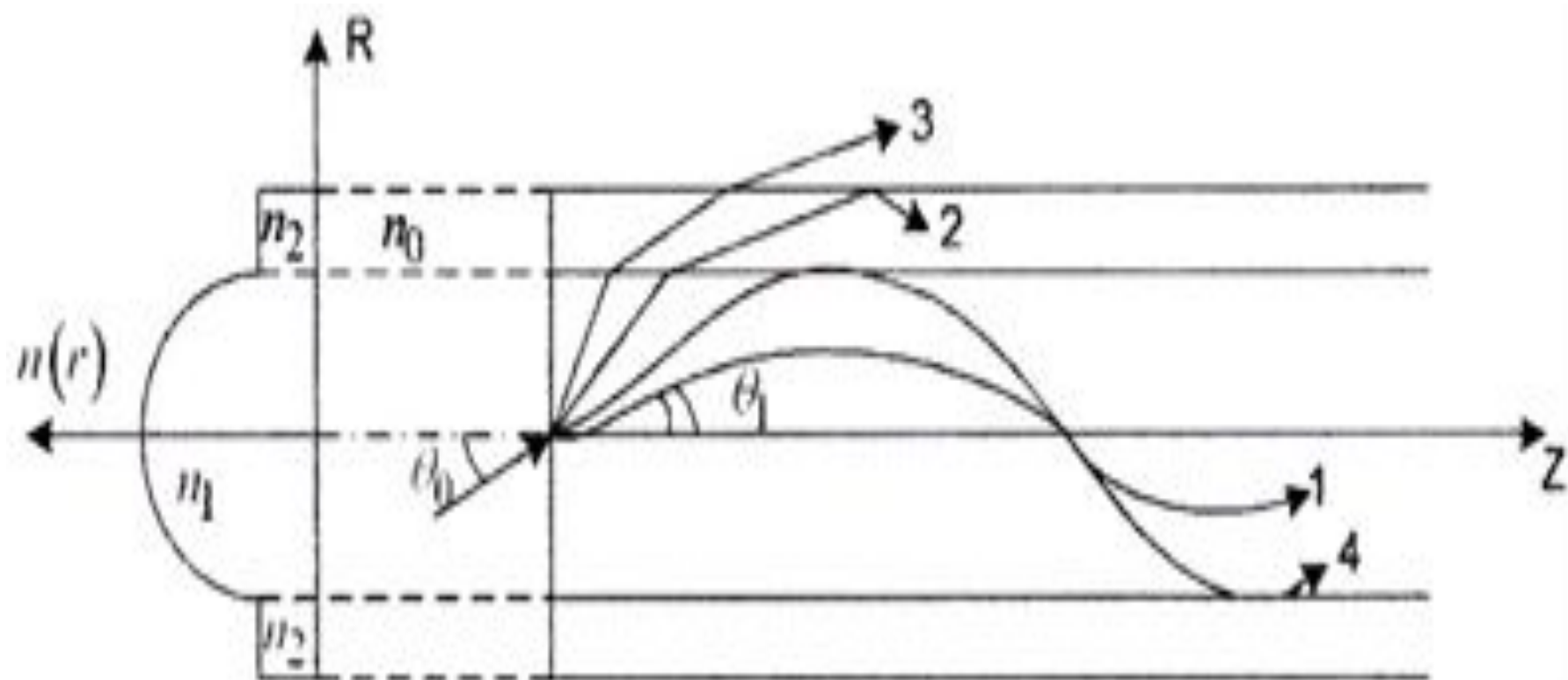


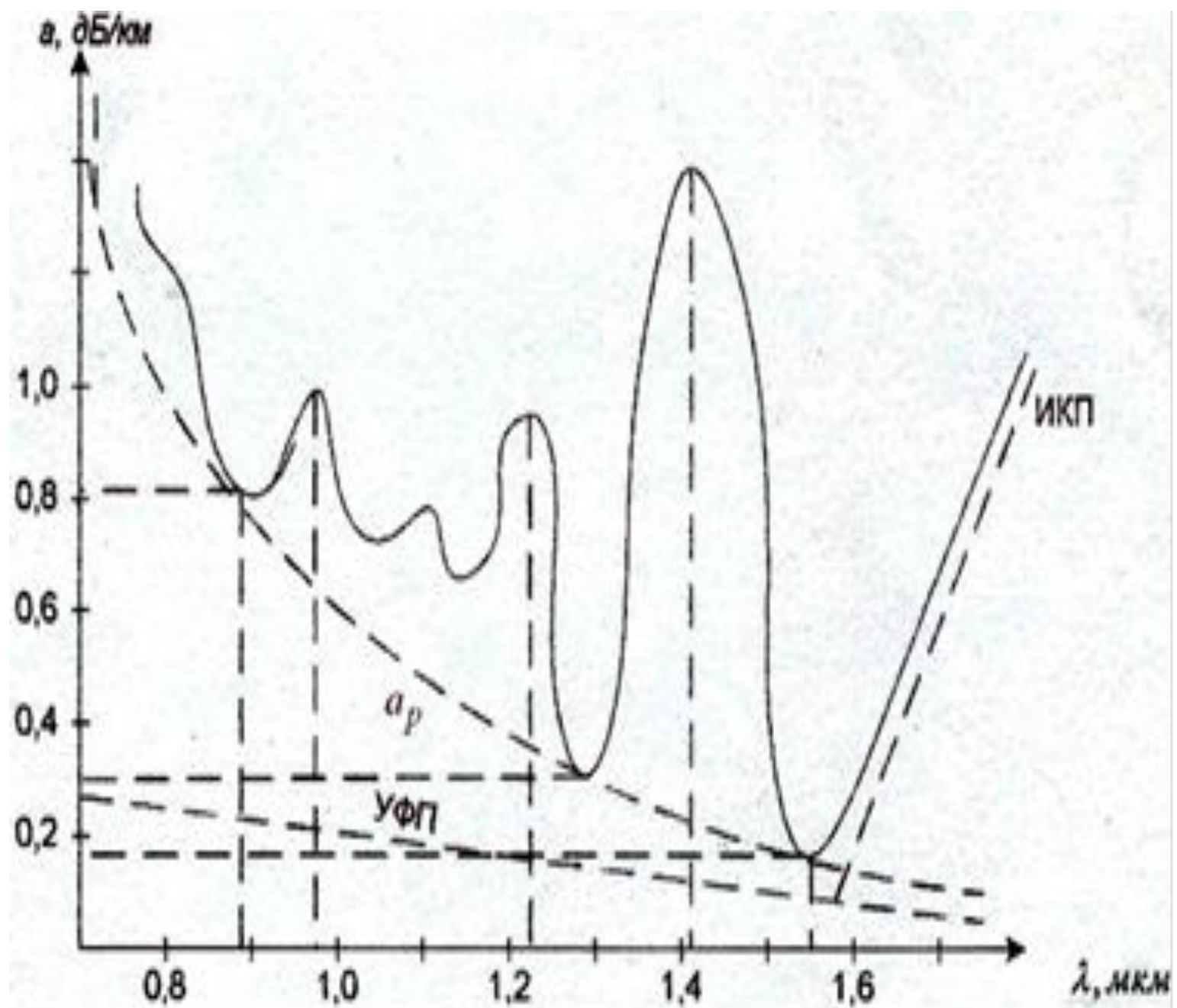


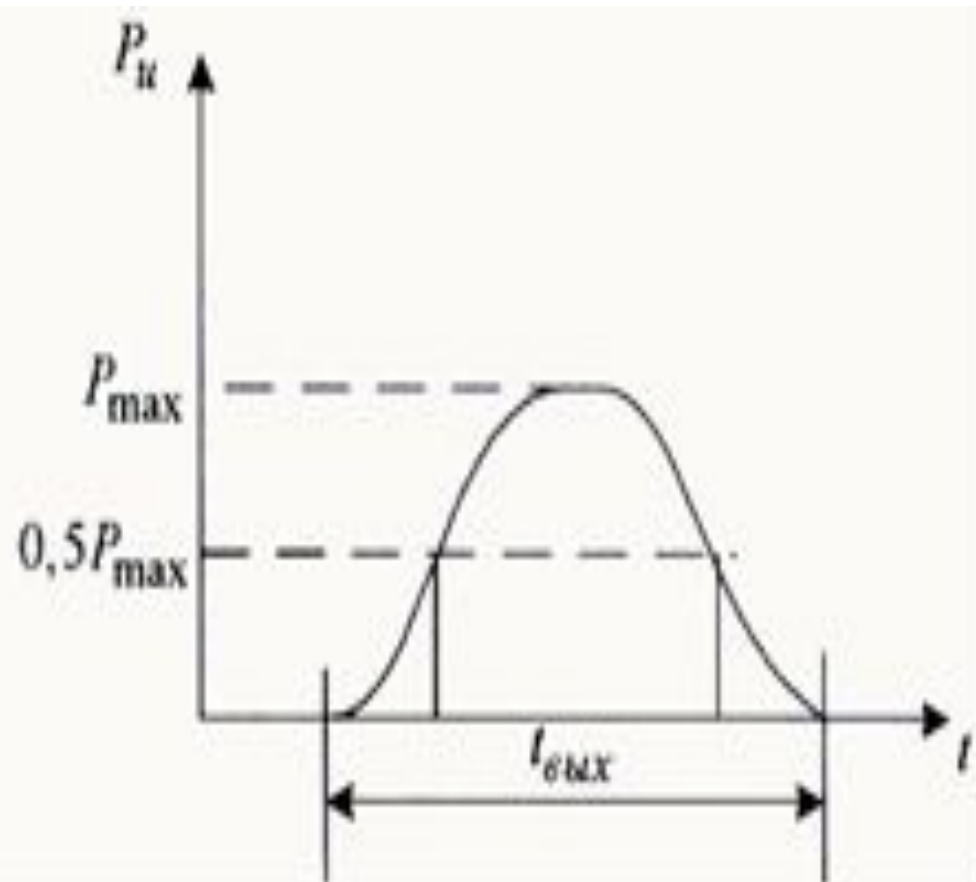
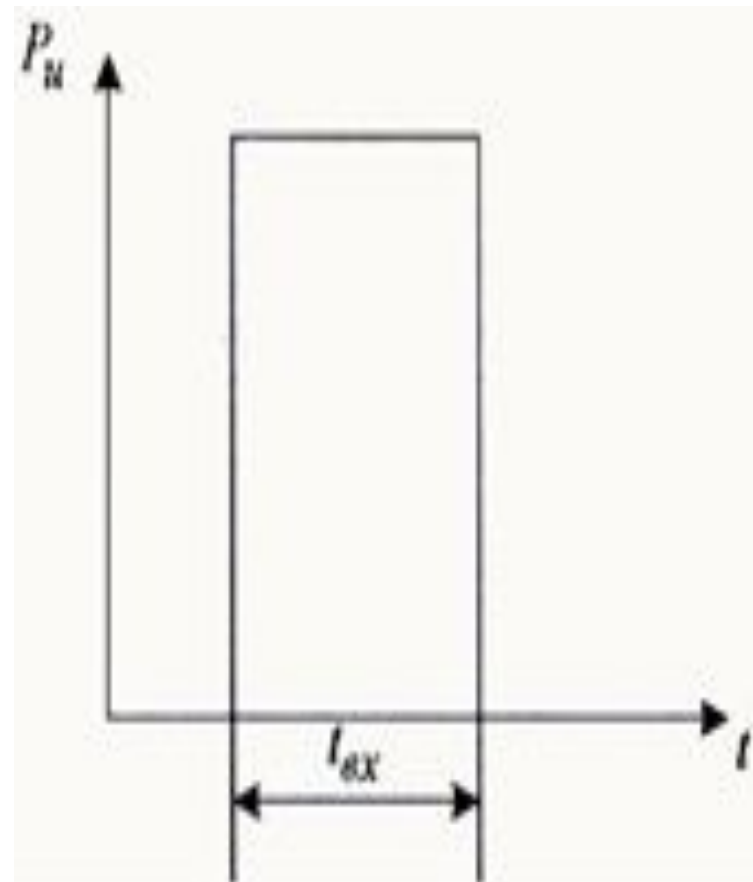
а. Меридиальные лучи



б. Косые лучи

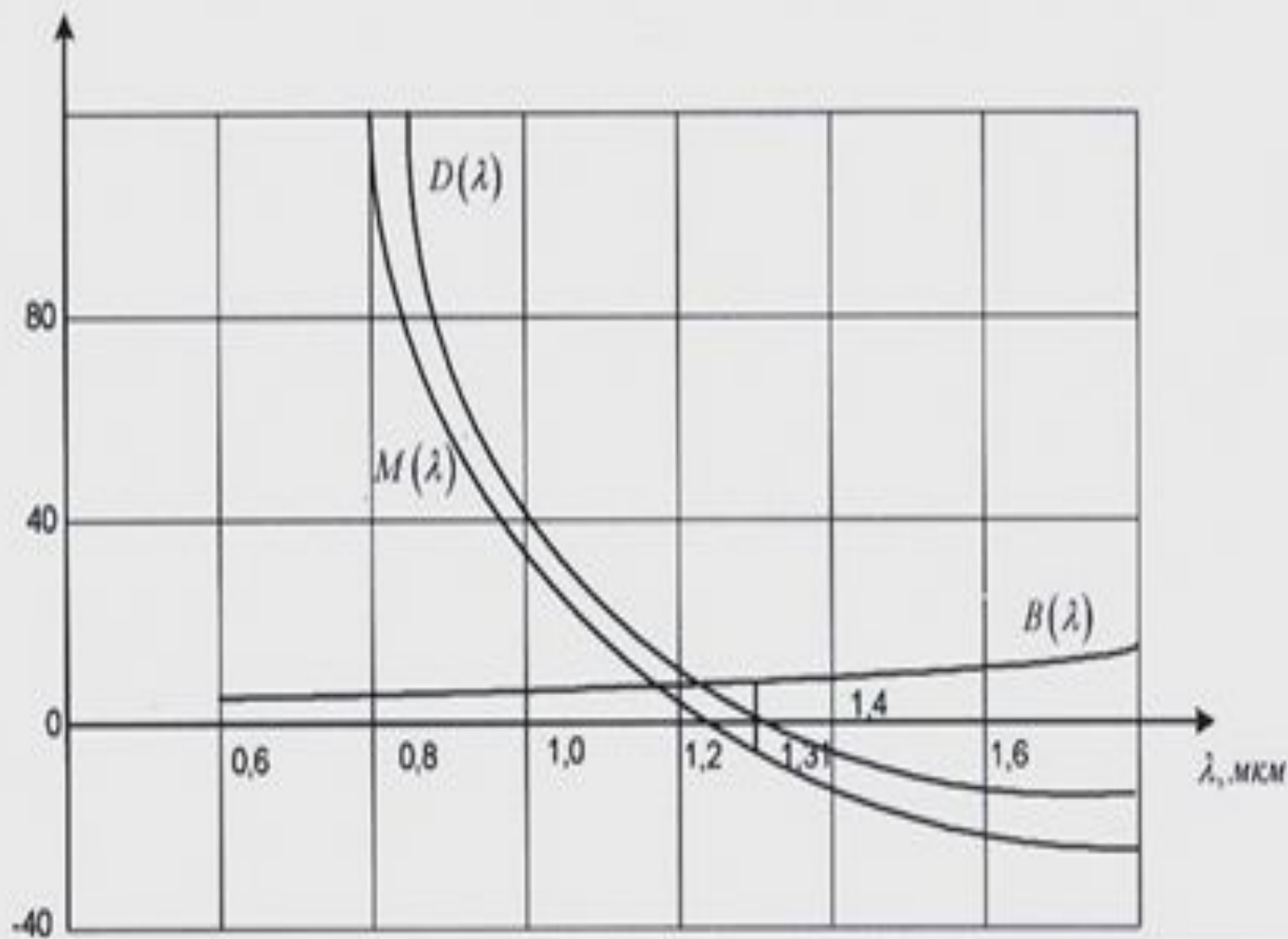


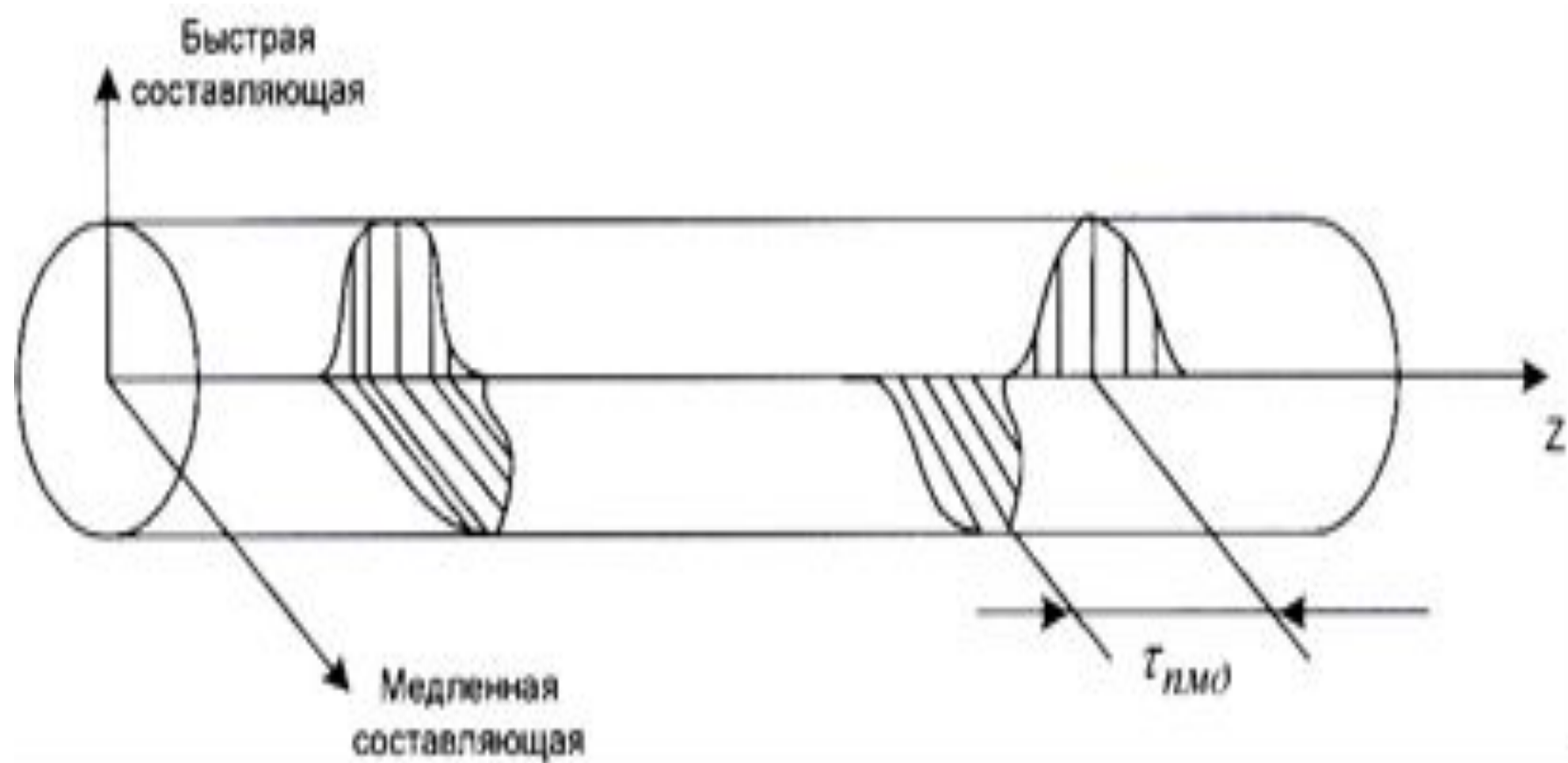


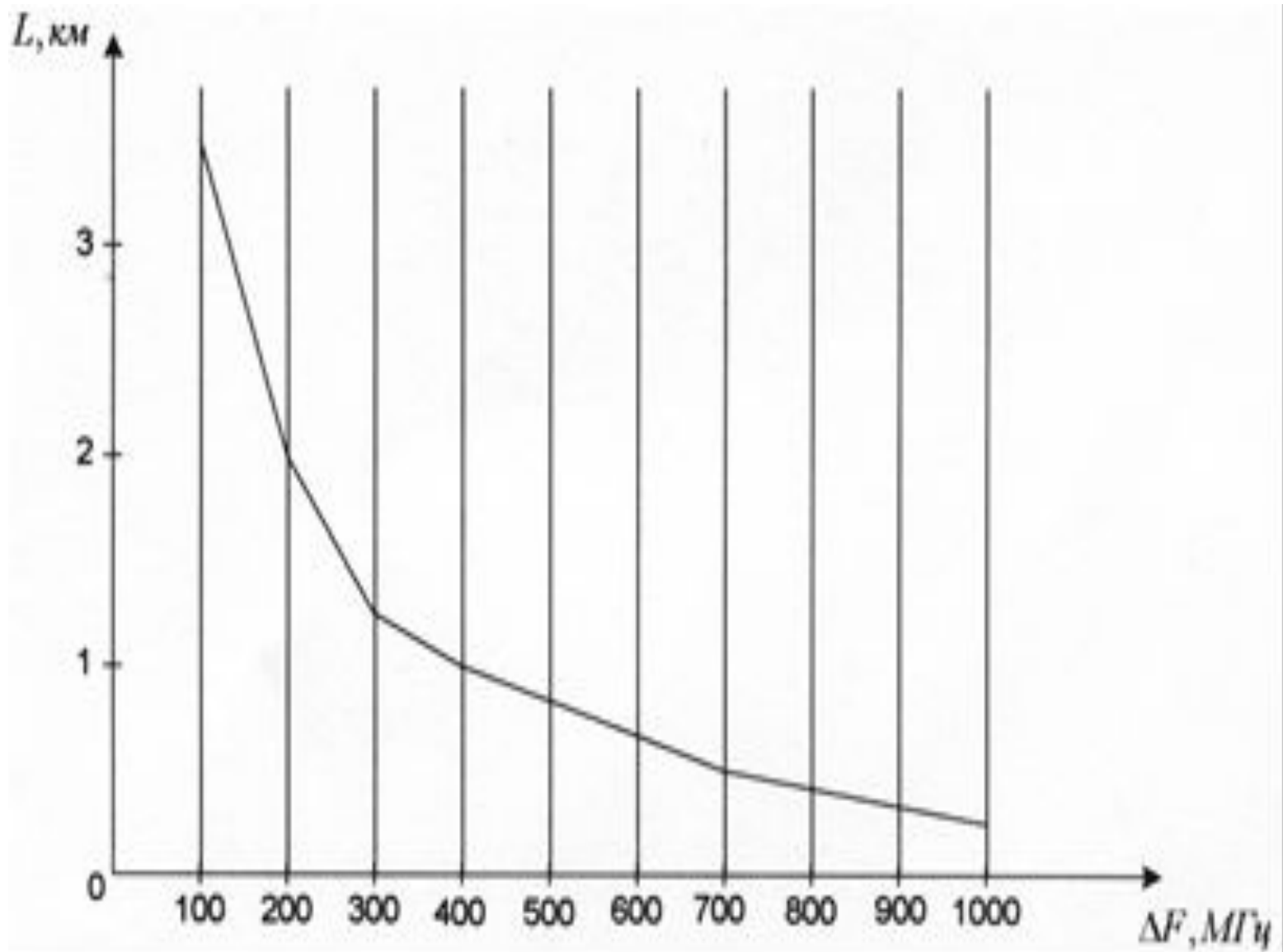


| | |
|---|--|
| <p>(850nm) I окно прозрачности</p> | <p>Длинная λ (850nm) →</p> <p>Короткая λ (845nm) →</p> |
| <p>(1300) II окно прозрачности</p> | <p>Длинная λ (1300nm) →</p> <p>Короткая λ (1295nm) →</p> |
| <p>(1560) III окно прозрачности</p> | <p>Короткая λ (1550nm) →</p> <p>Длинная λ (1560nm) →</p> |

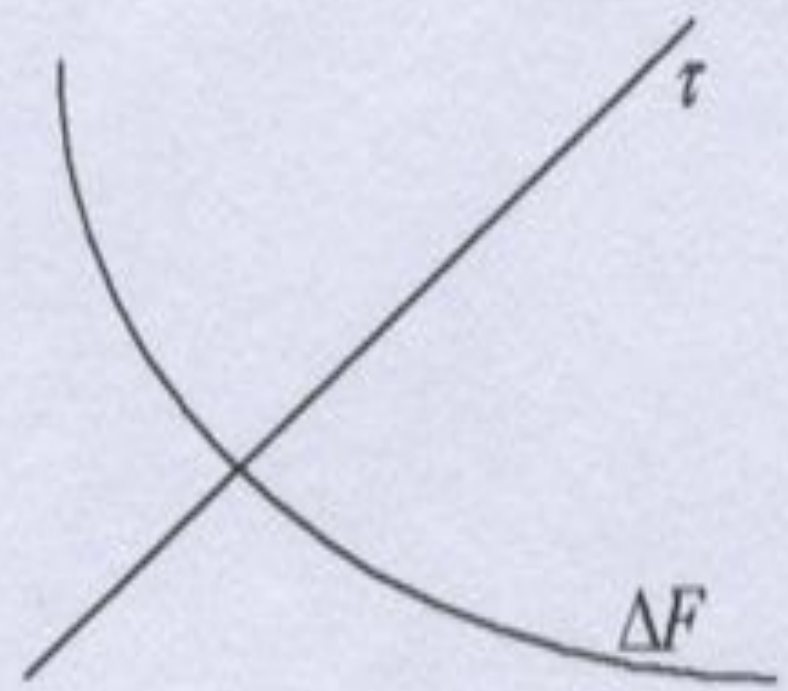
$D(\lambda), M(\lambda), B(\lambda), \text{PBC} / \text{KCM} \cdot \mu\text{M}$





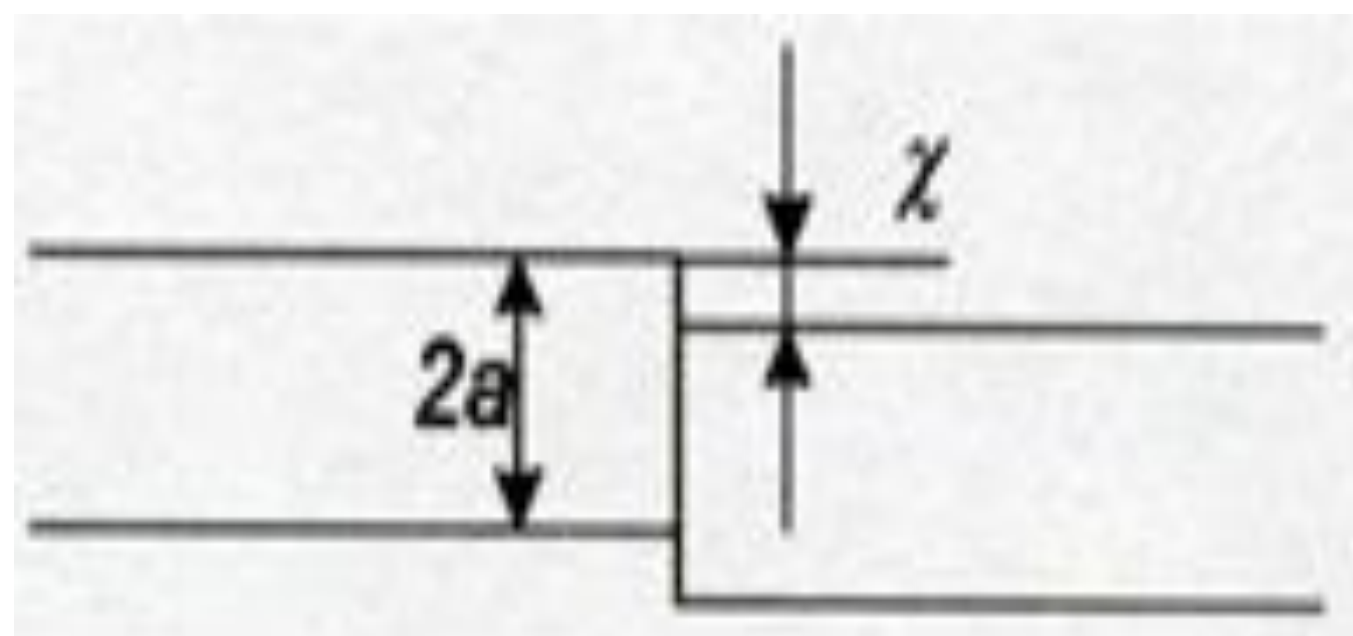


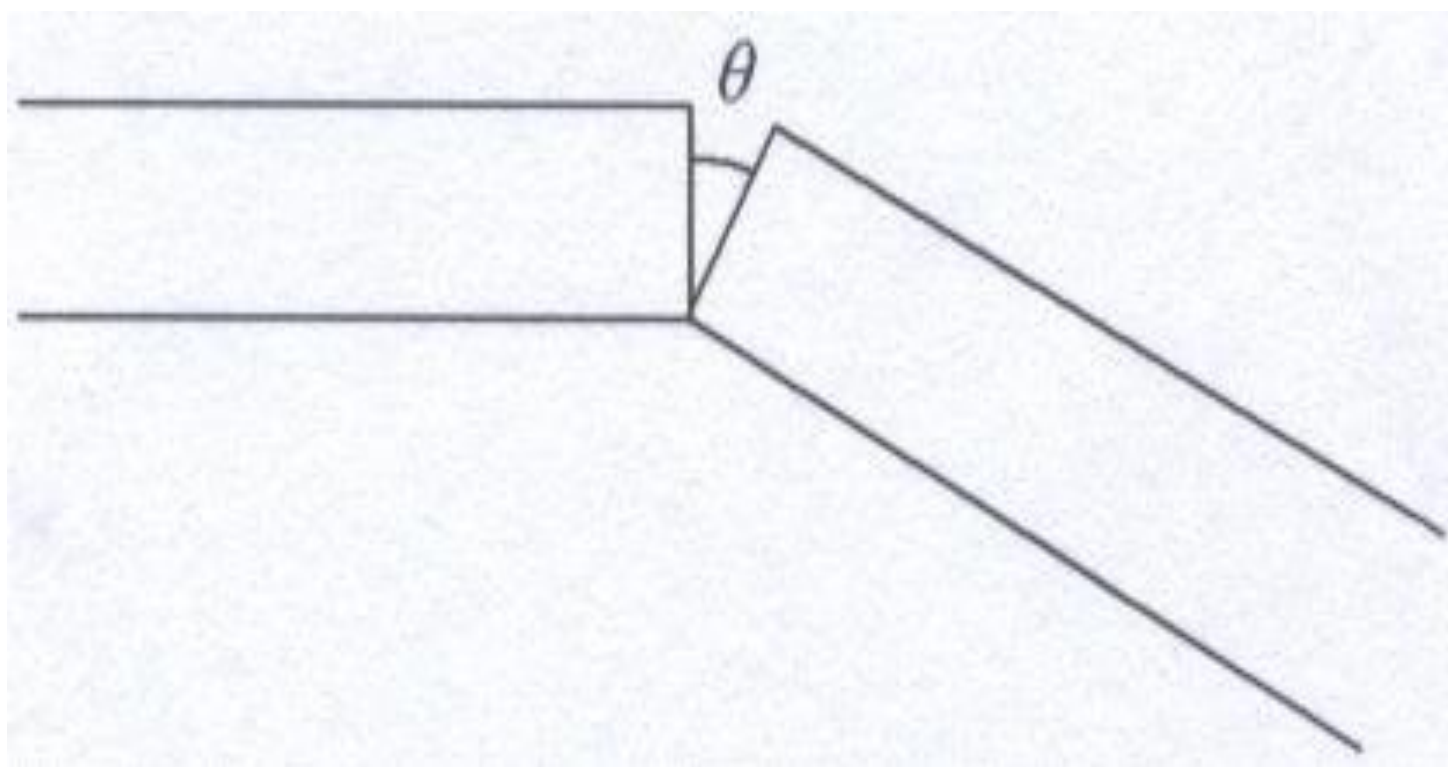
$\tau, \Delta F$

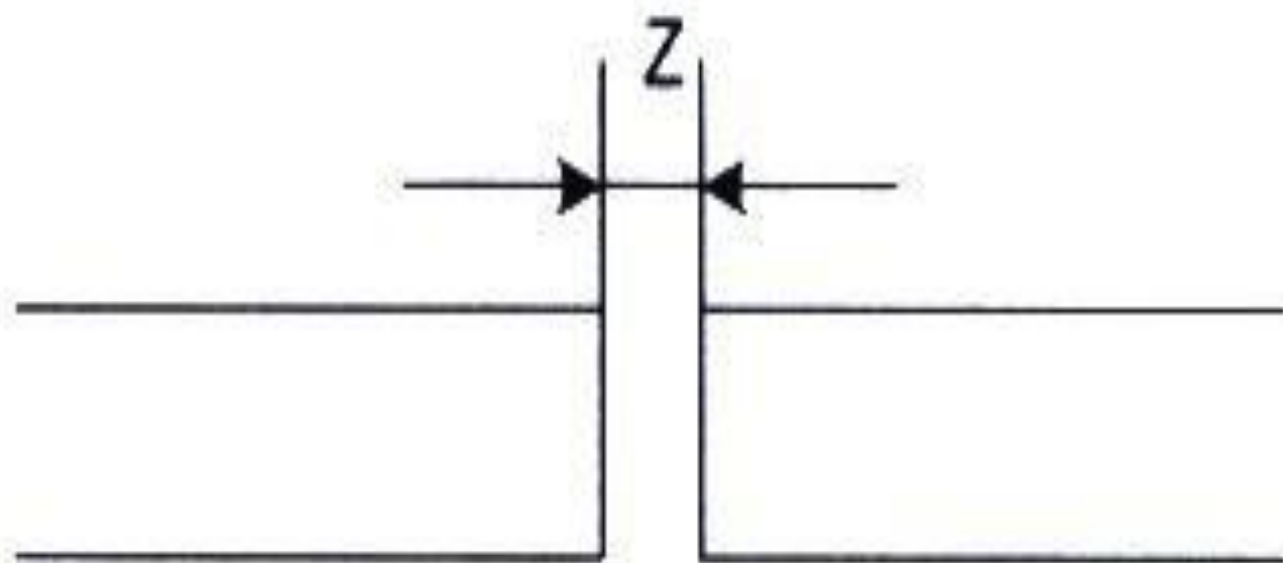


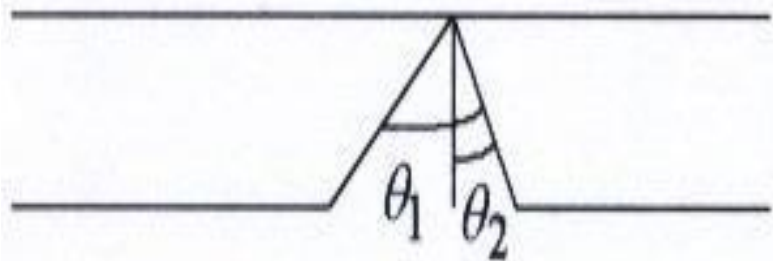
L

$$\alpha_{\text{CM}} = -10 \lg \eta_{\text{CM}}$$

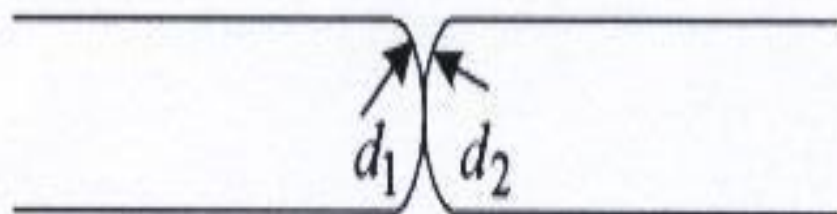




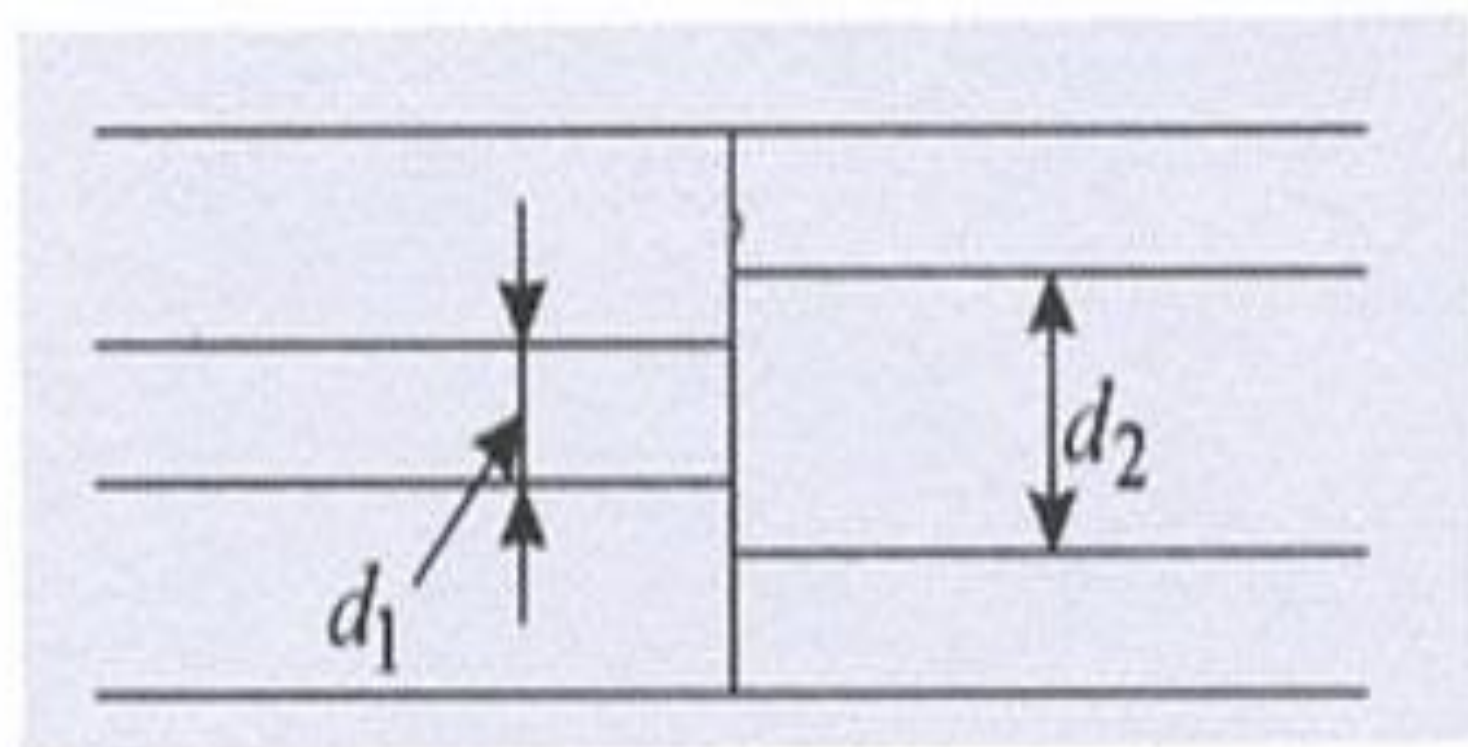


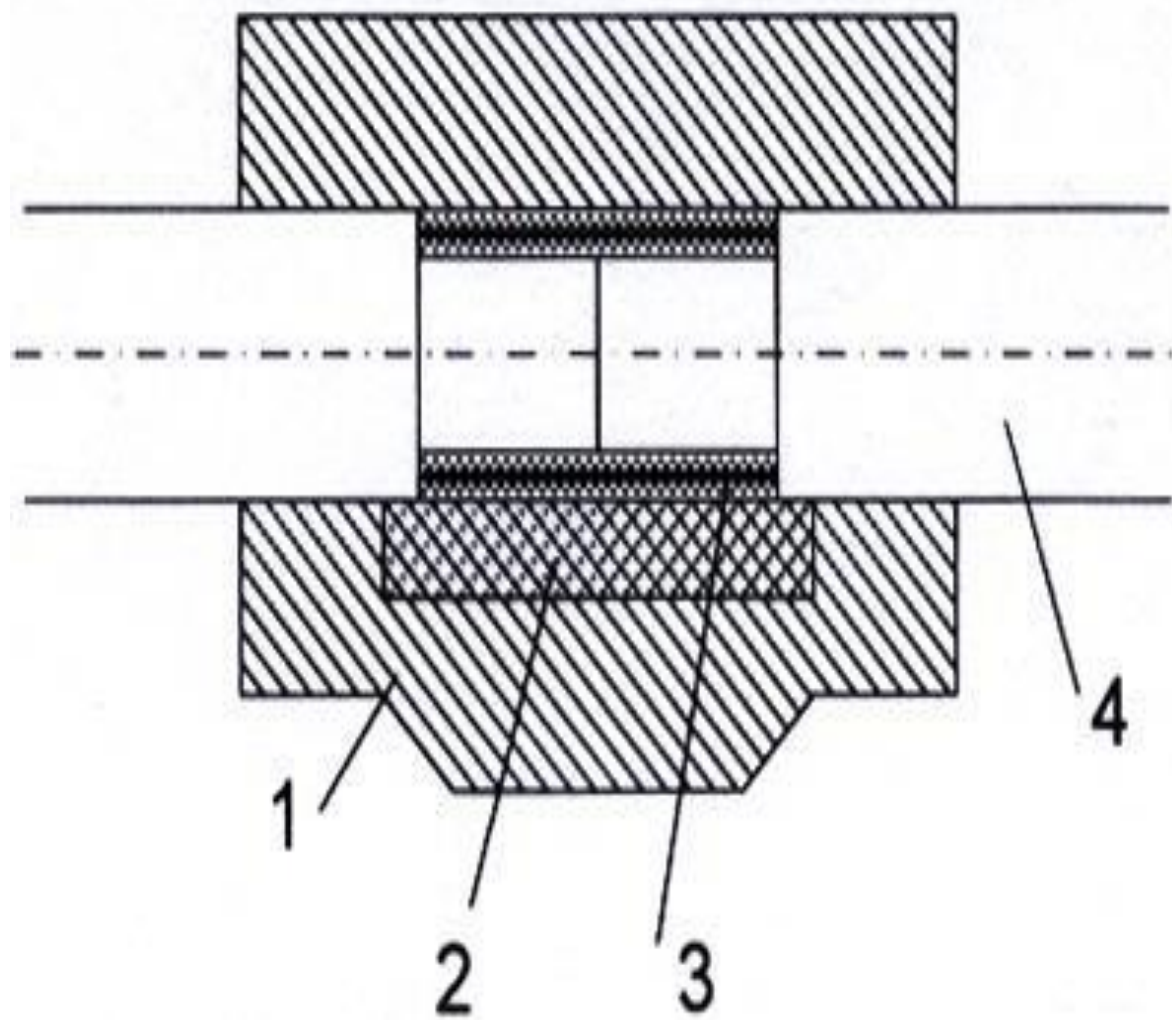


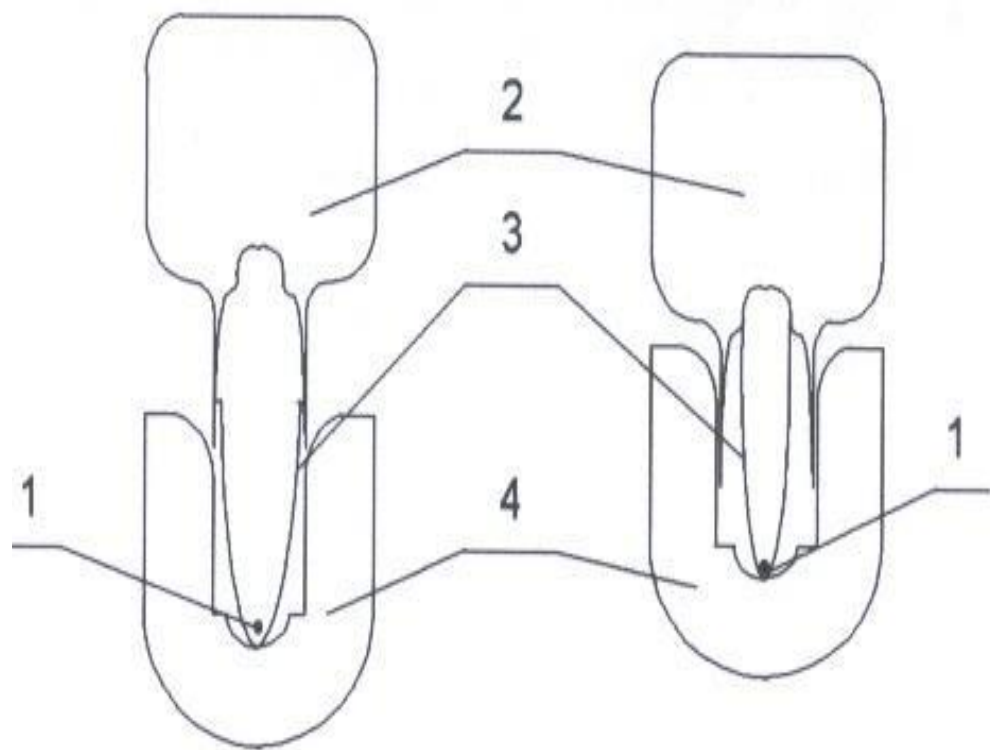
a.



b.

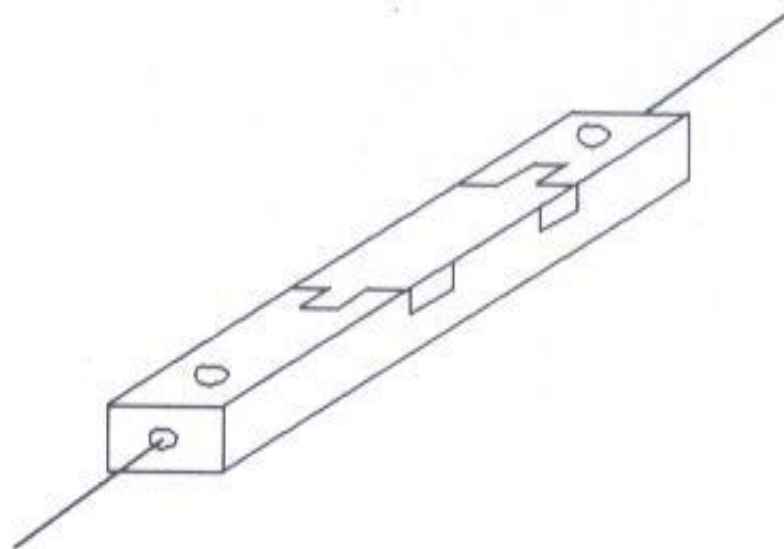






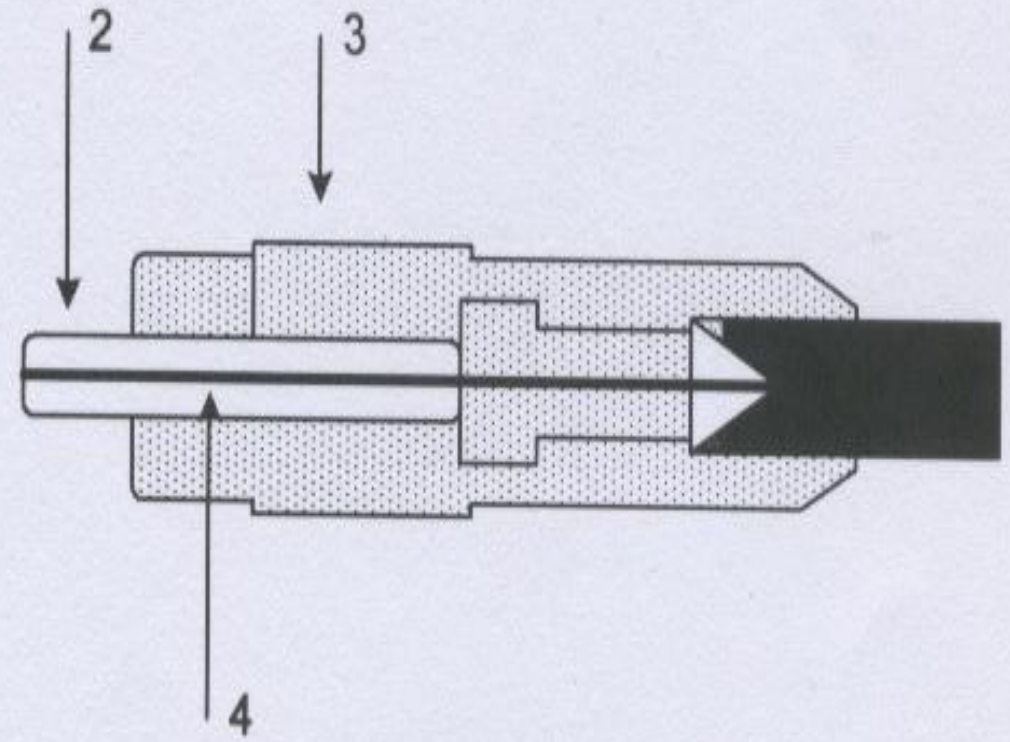
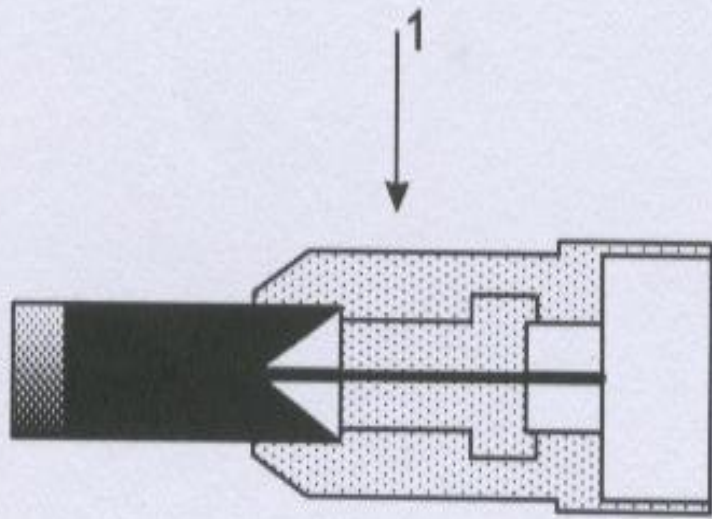
a)

б)

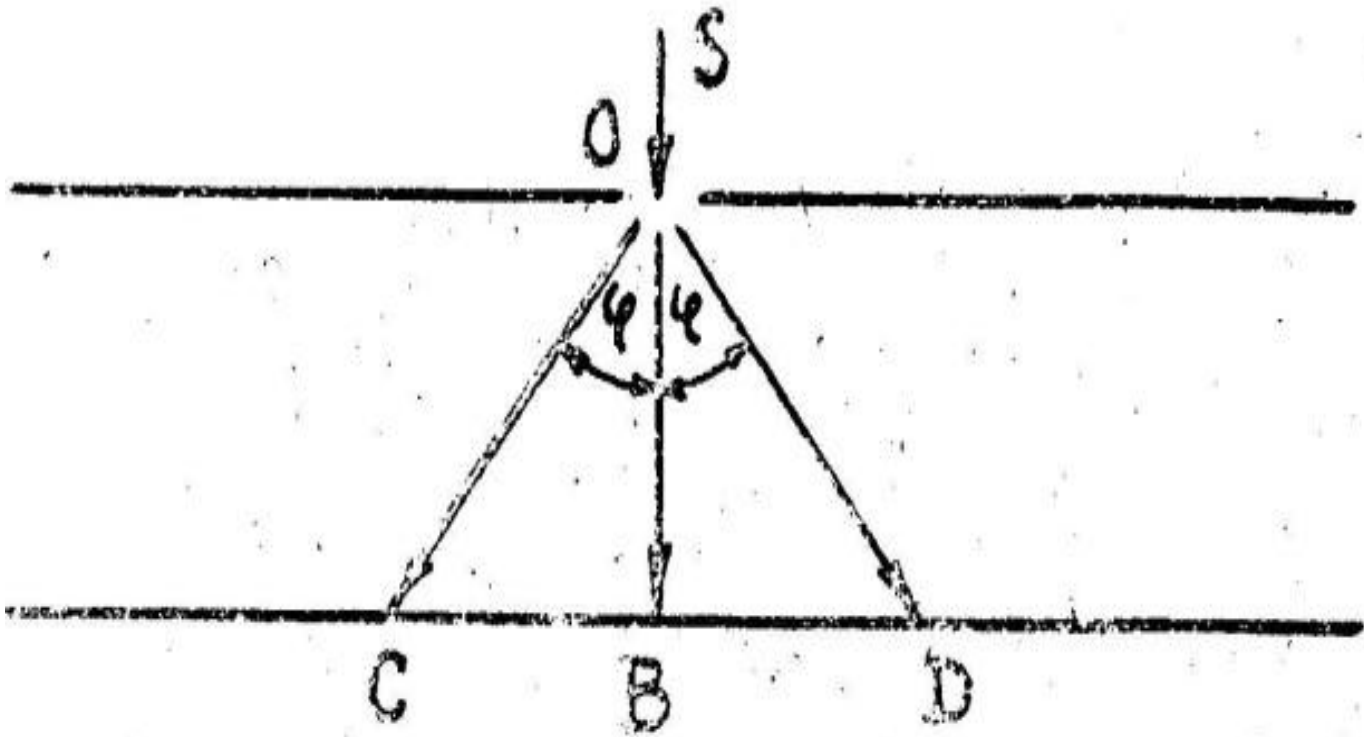


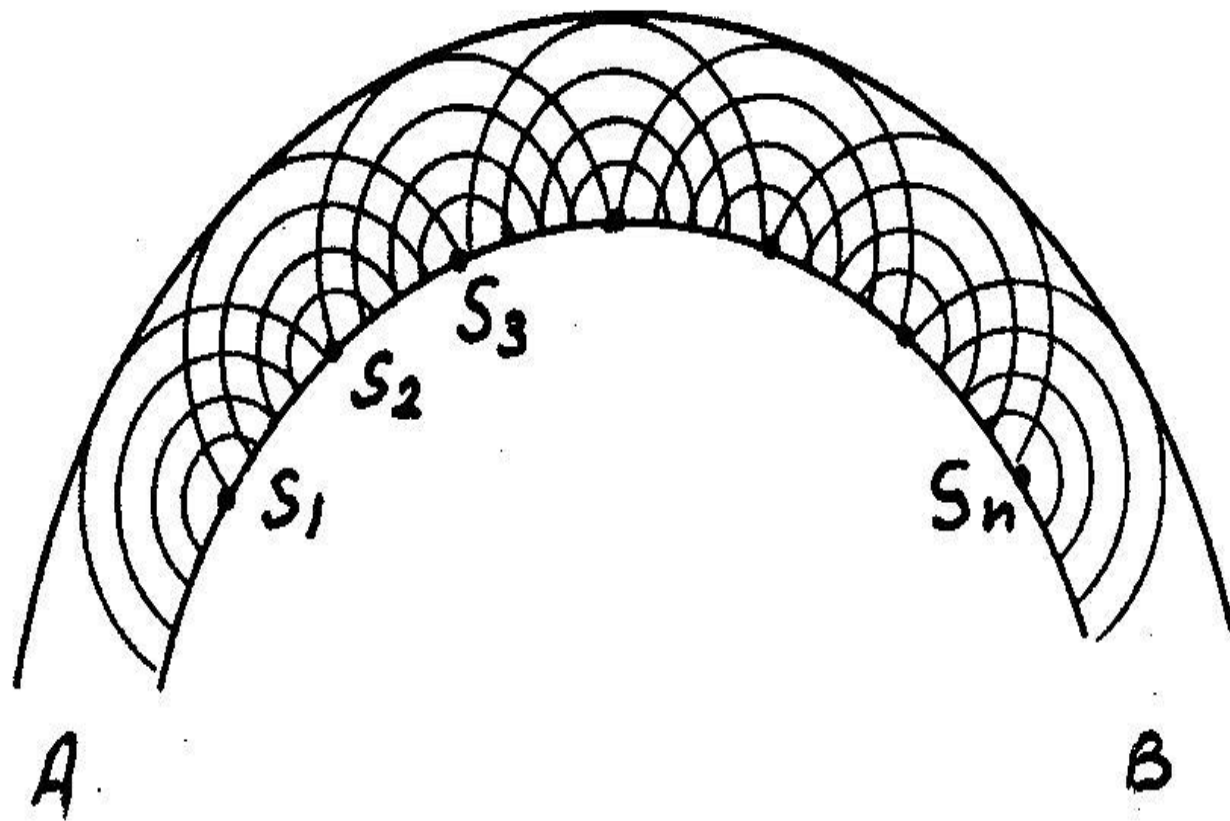
в)

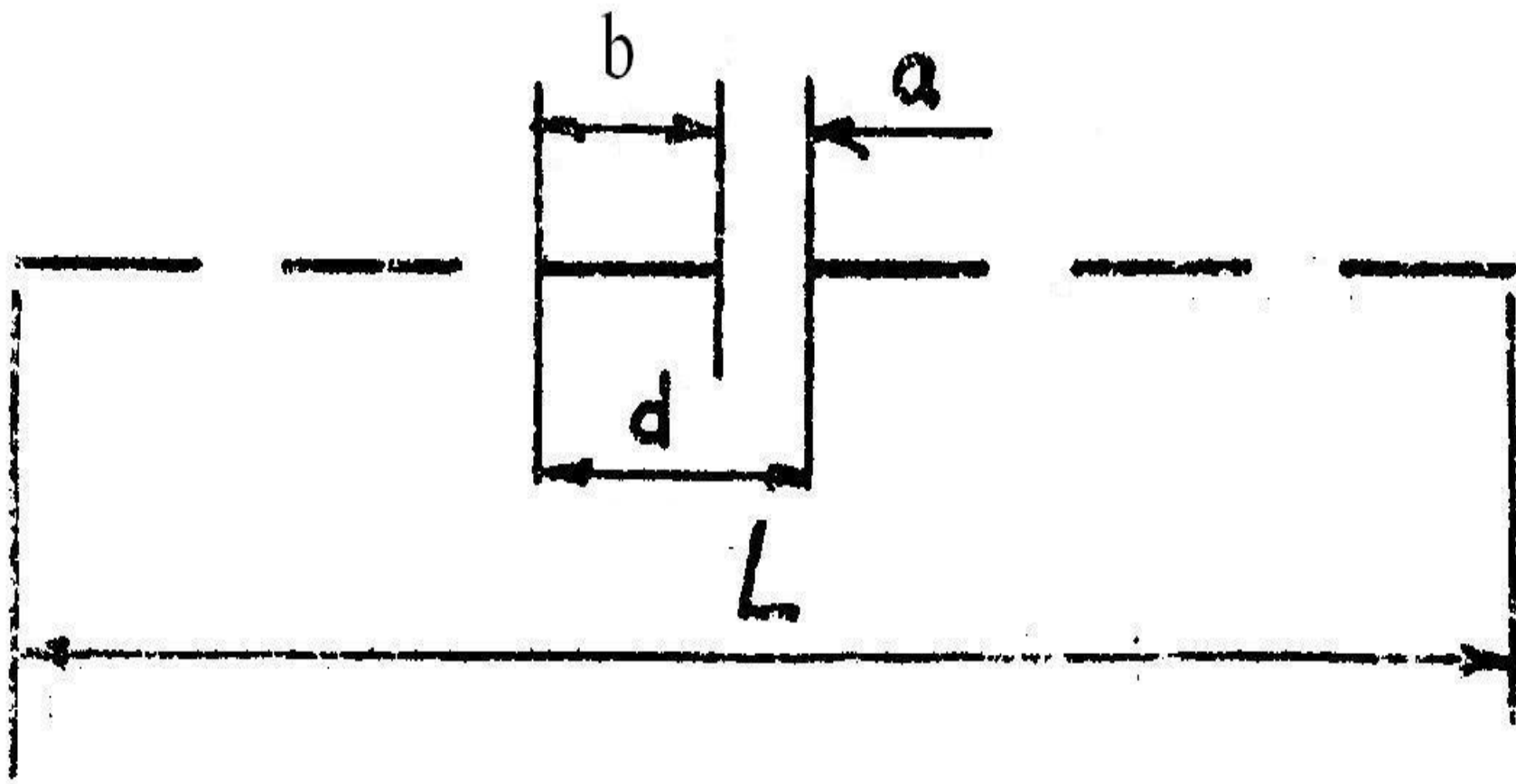


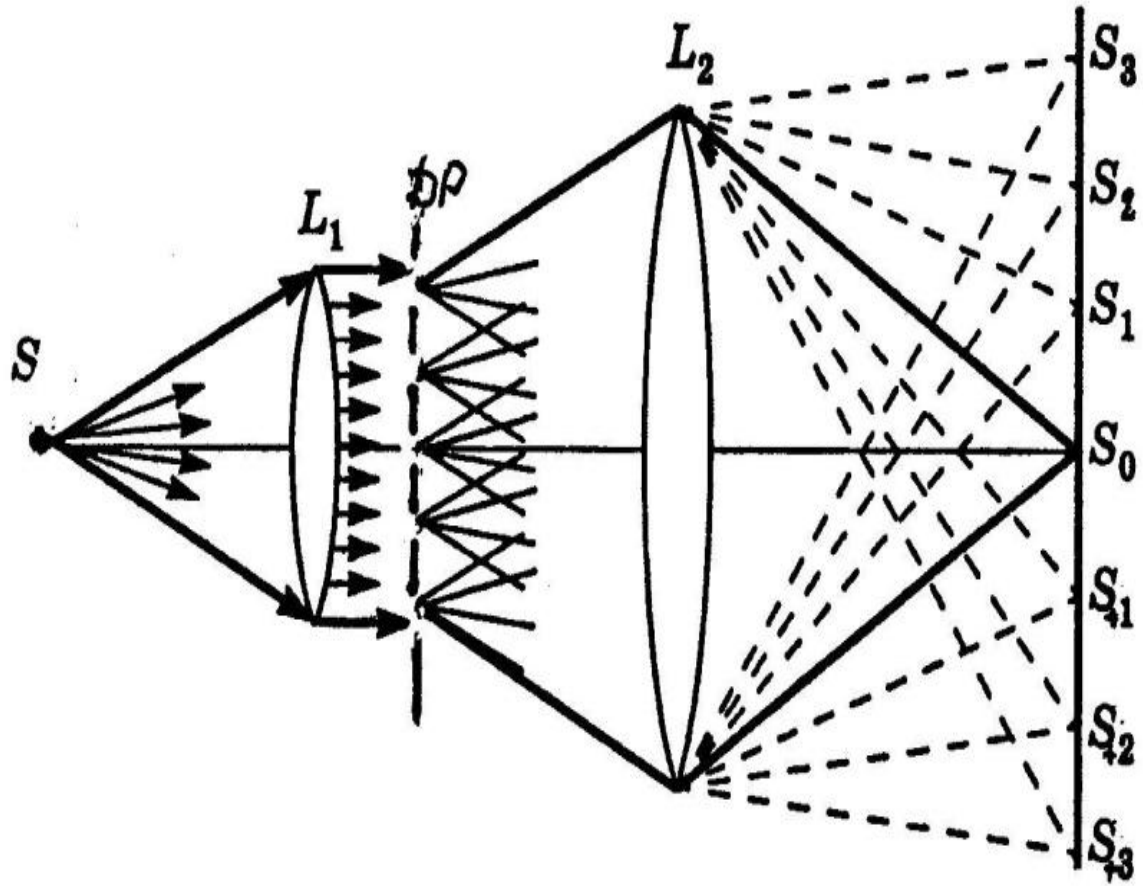








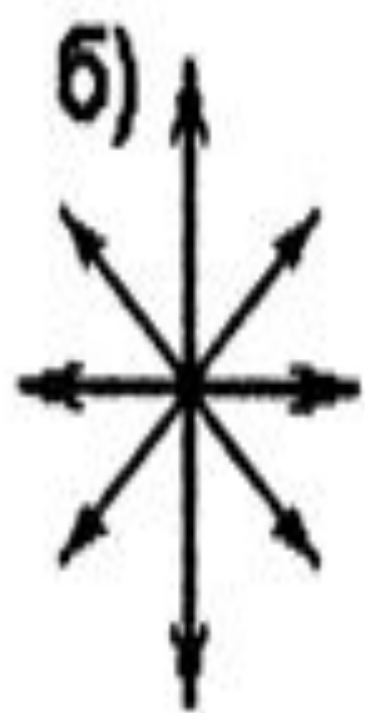
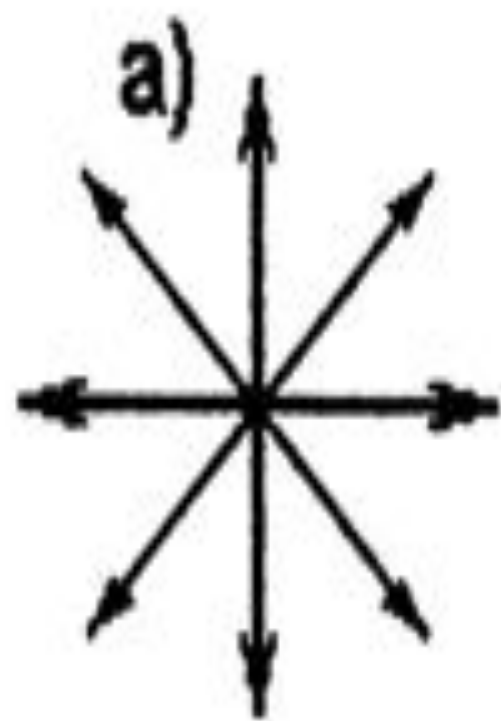


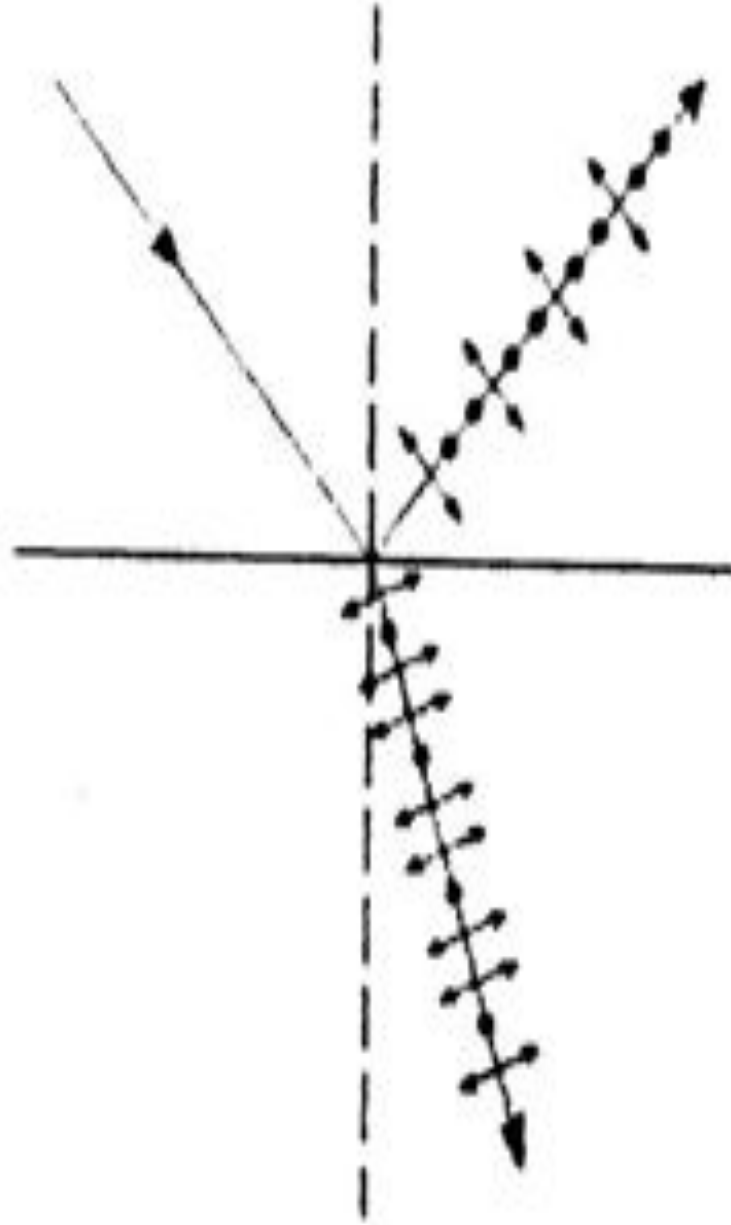


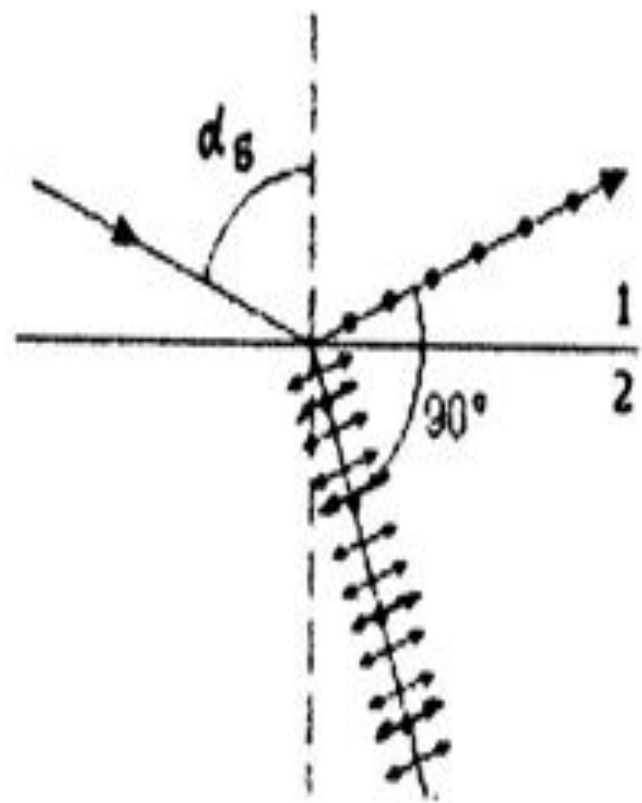
$$d \sin \varphi_m = m \lambda, \quad m=0, 1, 2, 3, \dots$$

$$a \sin \varphi_m = m\lambda, \quad m=1, 2, 3, \dots, m \neq 0$$

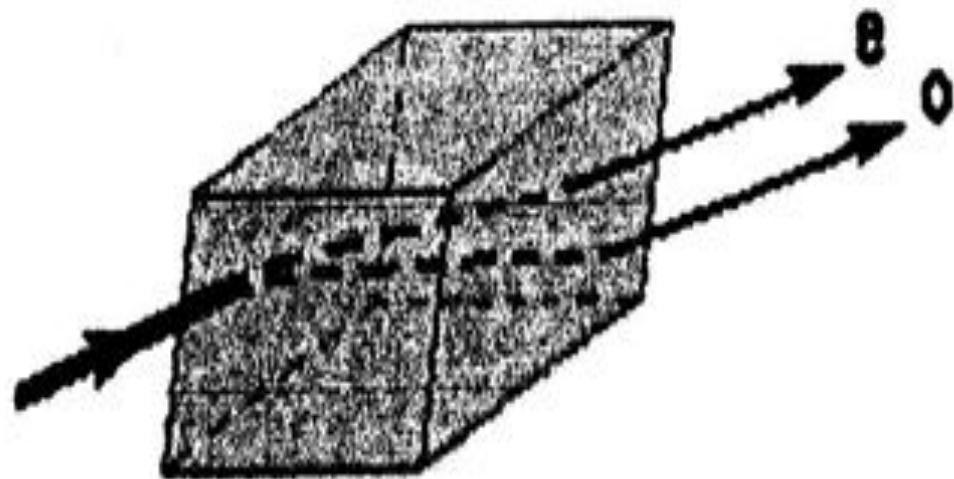
$$a \sin \varphi_m = \frac{m}{N} \lambda, \quad m=1, 2, 3, \dots, m \neq 0$$



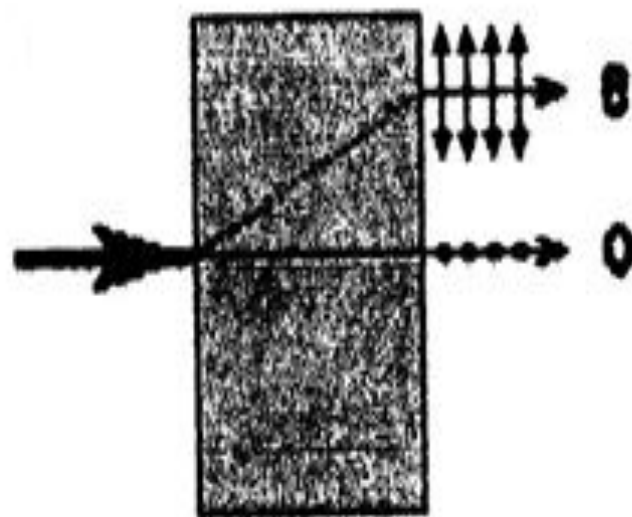




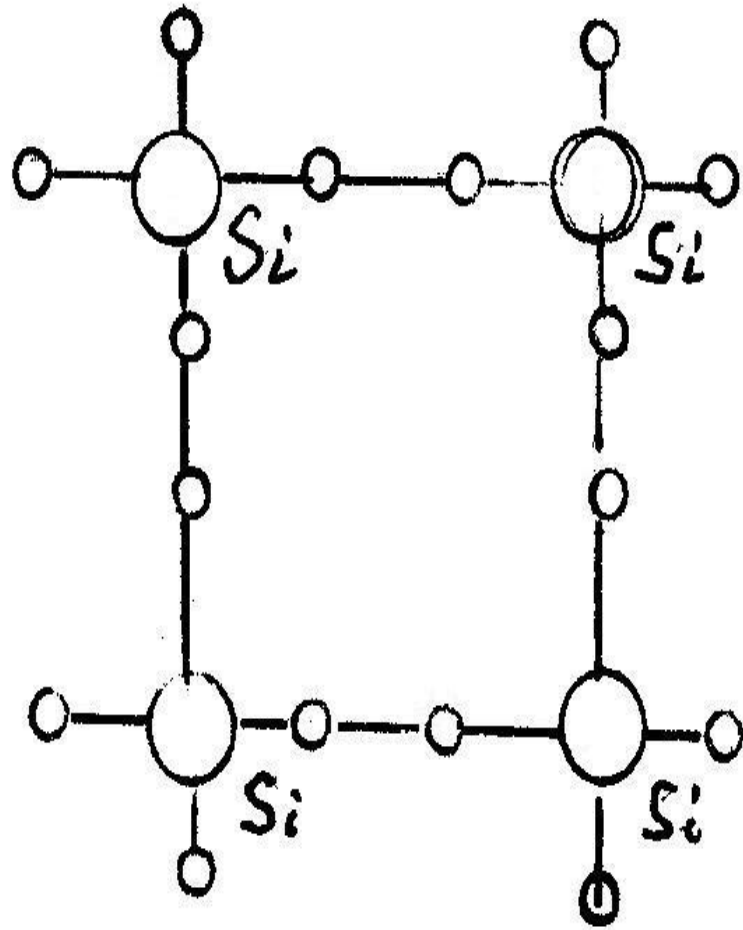
$$\operatorname{tg} \alpha_6 = n_{21} = \frac{n_2}{n_1}$$



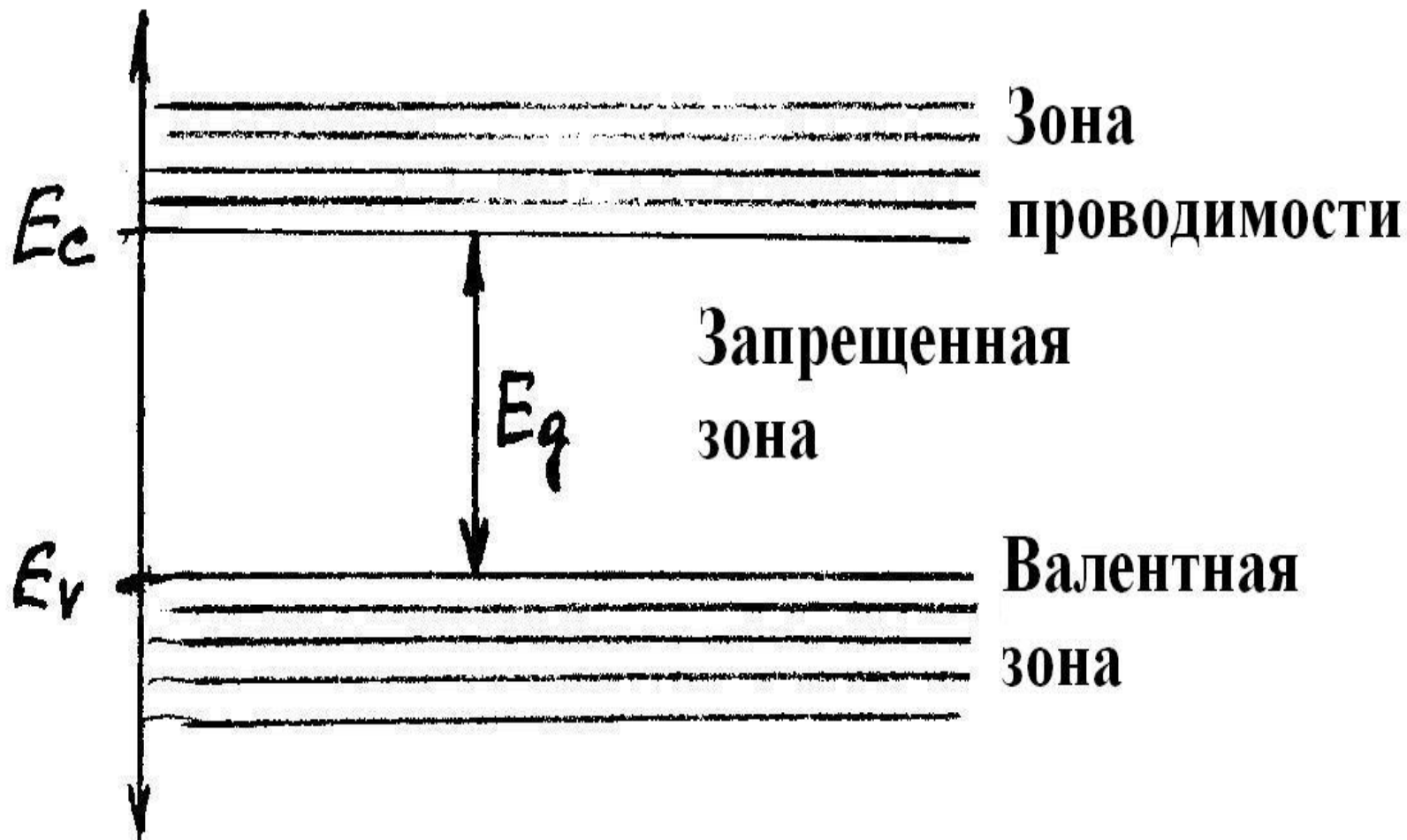
a)



б)

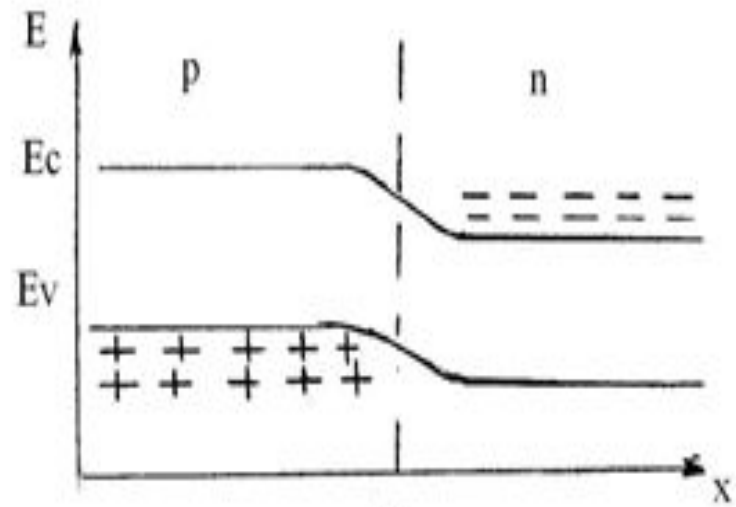


- **3 группа** – Бор (B), Алюминий (Al),
Галлий (Ga), Индий (In), Талий (Tl);
- **4 группа** – Кремний (Si), Германий
(Ge);
- **5 группа** – Азот (N), Фосфор (P),
Мышьяк (As), Сурьма (Sb), Висмут
(Bi)

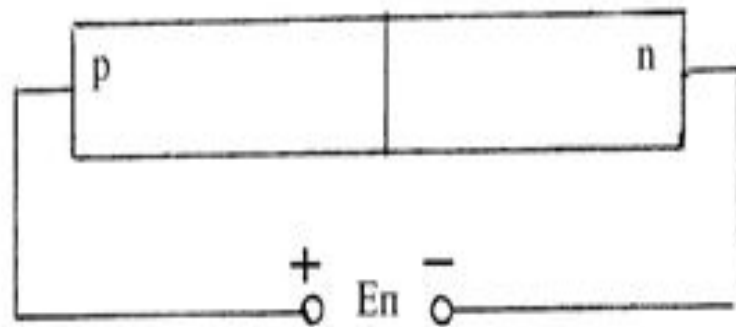


| | | | | | | | | | | | |
|-----------------|------|------|------|------|------|------|------|------|------|------|------|
| Материал | Ge | Si | AlP | AlAs | AlSb | GaP | GaAs | GaSb | InP | InAs | InSb |
| E_g , эВ | 0,66 | 1,11 | 2,45 | 2,16 | 1,58 | 2,28 | 1,42 | 0,73 | 1,35 | 0,36 | 0,17 |
| λ , мкм | 1,88 | 1,15 | 0,52 | 0,57 | 0,75 | 0,55 | 0,87 | 1,7 | 0,92 | 3,5 | - |

$$I = \frac{cn}{4\pi} E^2, \text{ Вт/см}^2$$



a)

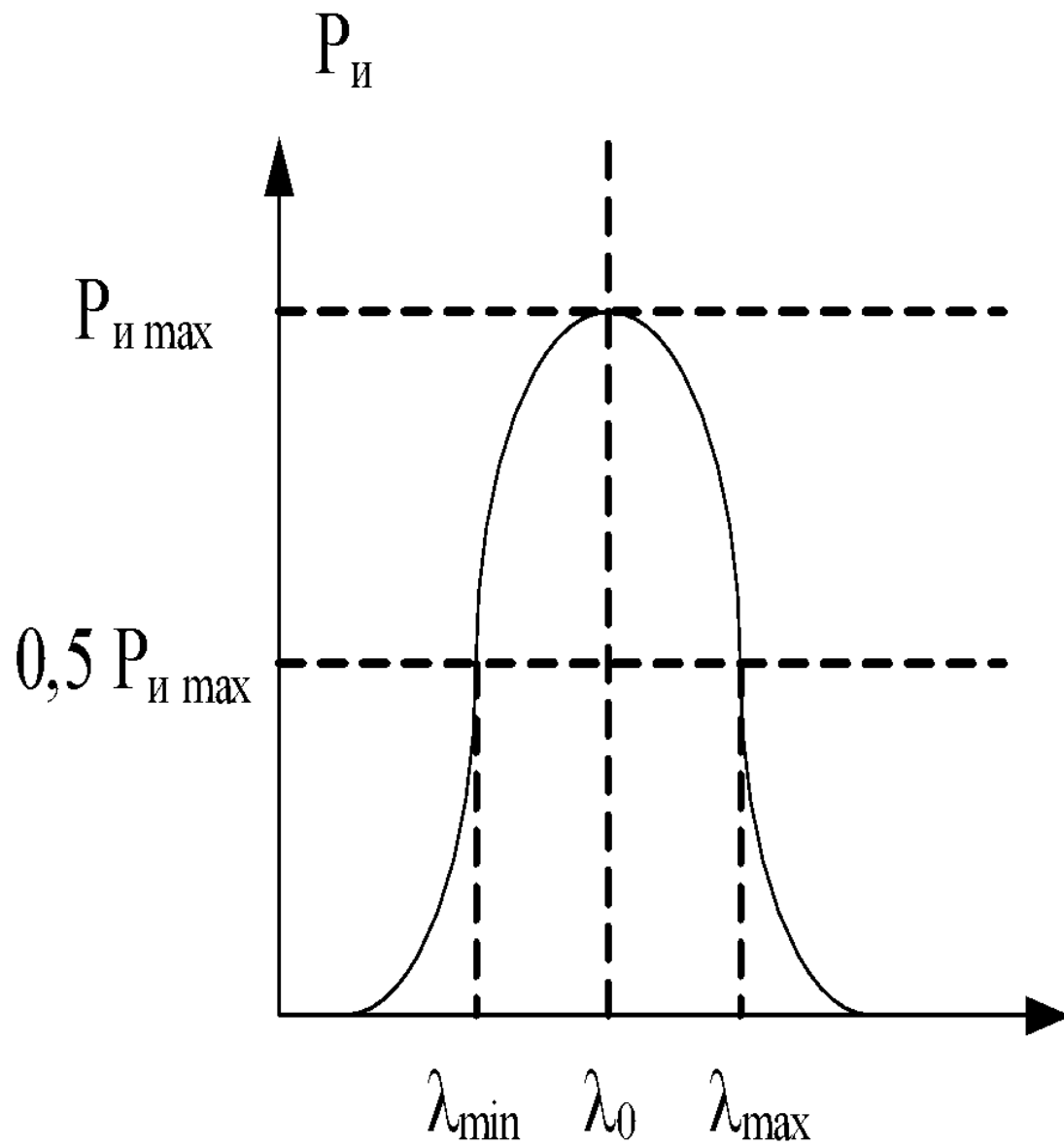


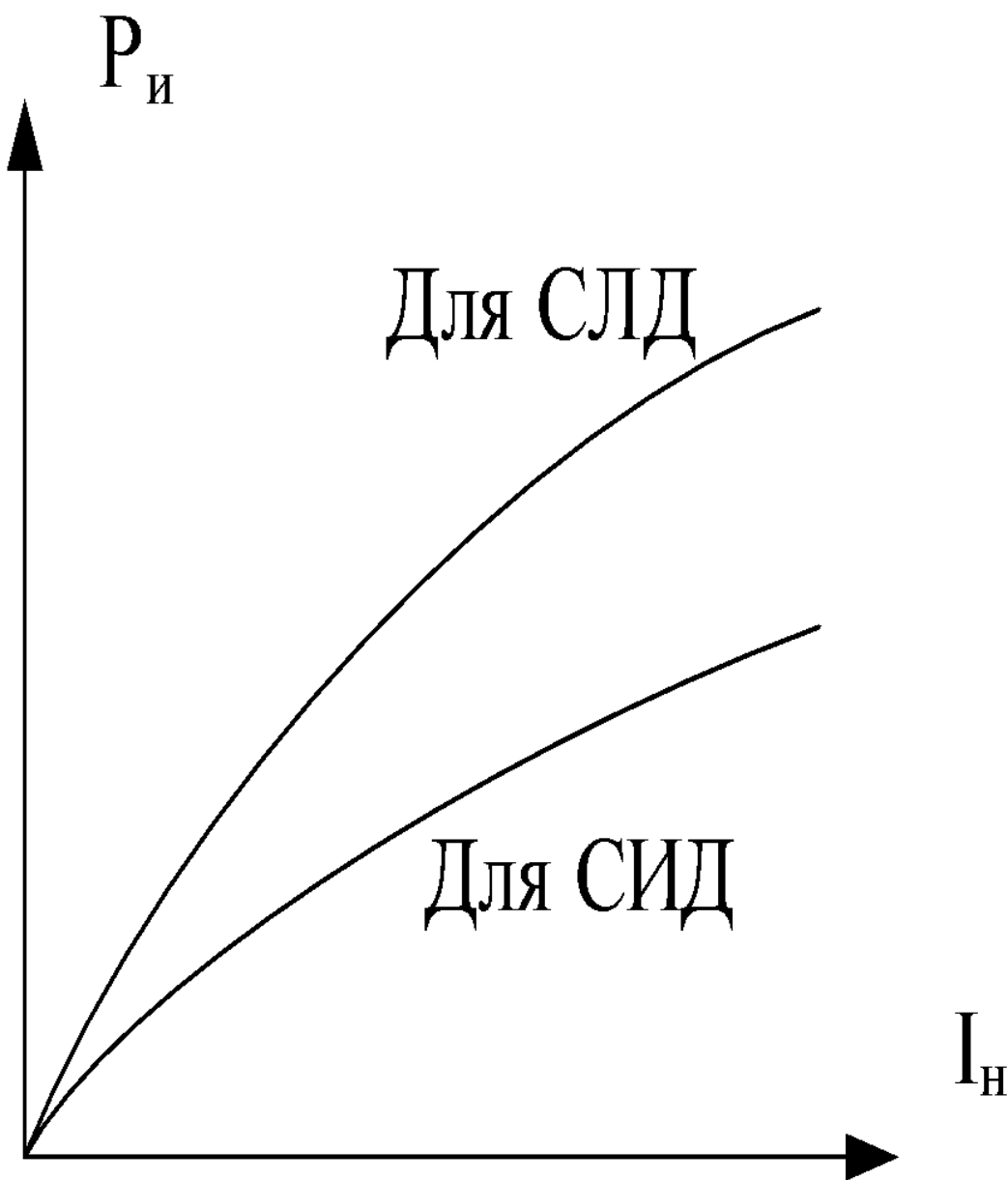
b)

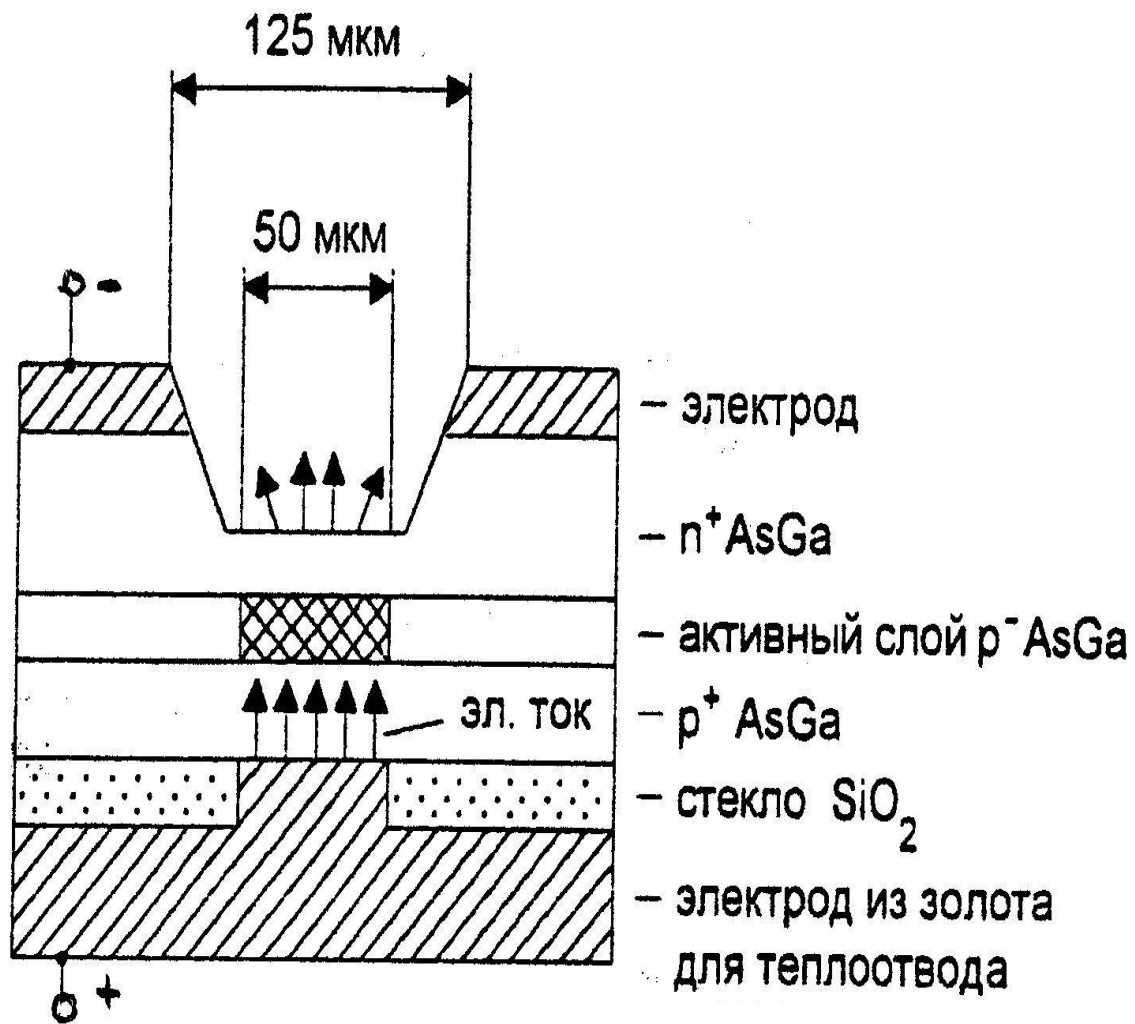
$$E_{\phi} = E_c - E_v = hf \geq E_g,$$

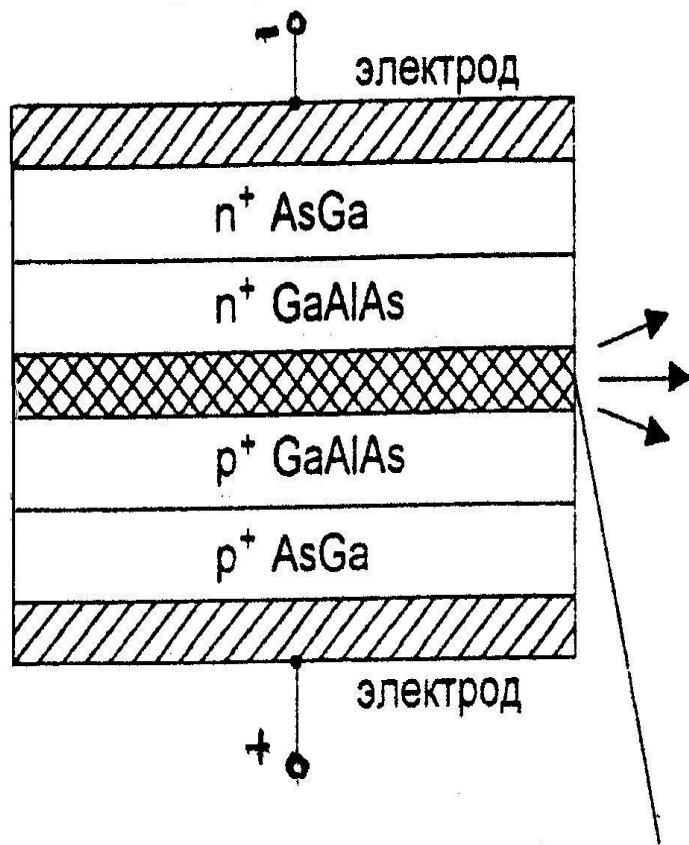
h – постоянная Планка, $h=6,626 \cdot 10^{-34}$ Дж·с

$$\lambda = \frac{hc}{E_g}$$

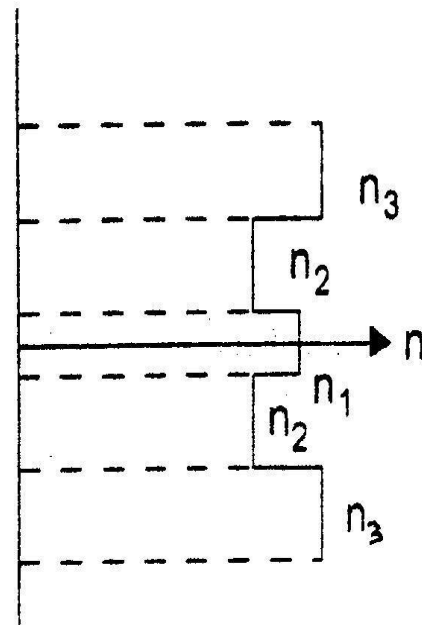








активный слой
 $p^- \text{AsGa}$
 (зона излучения)

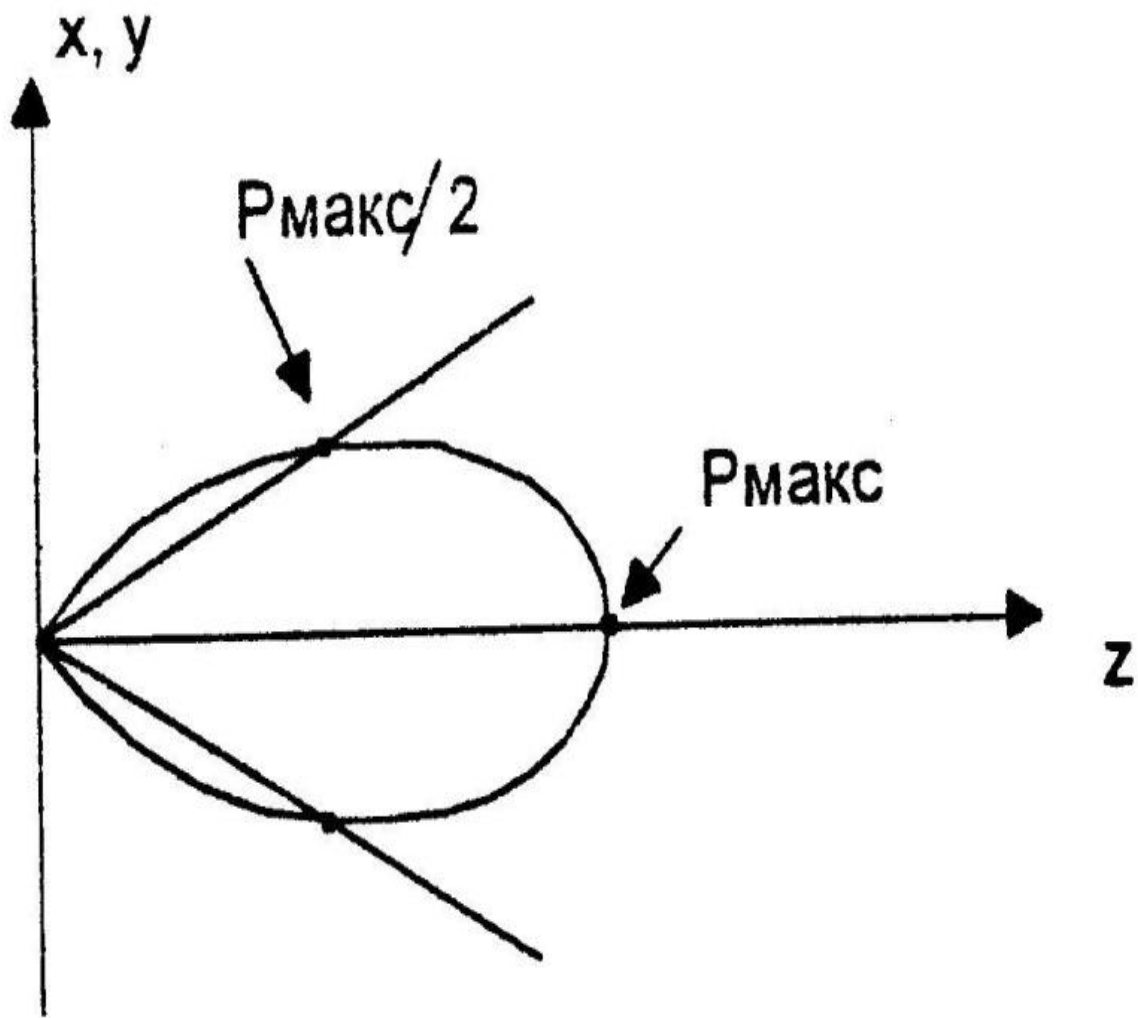


Показатели преломления слоев полупроводника

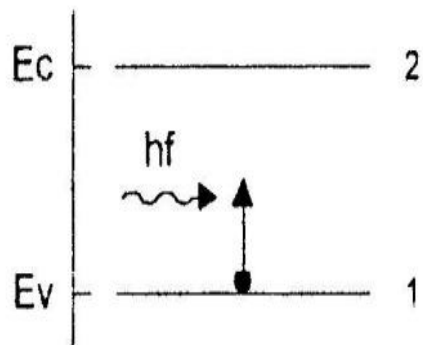
$$n_1 = 3,56$$

$$n_2 = 3,53$$

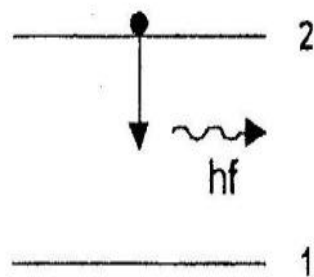
$$n_3 = 3,58$$



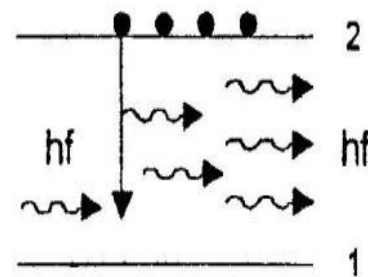
$$\eta_{\text{внеш}} = \frac{P_{\text{изл}}}{P_{\text{реком}}}$$



Поглощение
фотонов



Спонтанное
излучение



Стимулированное
излучение

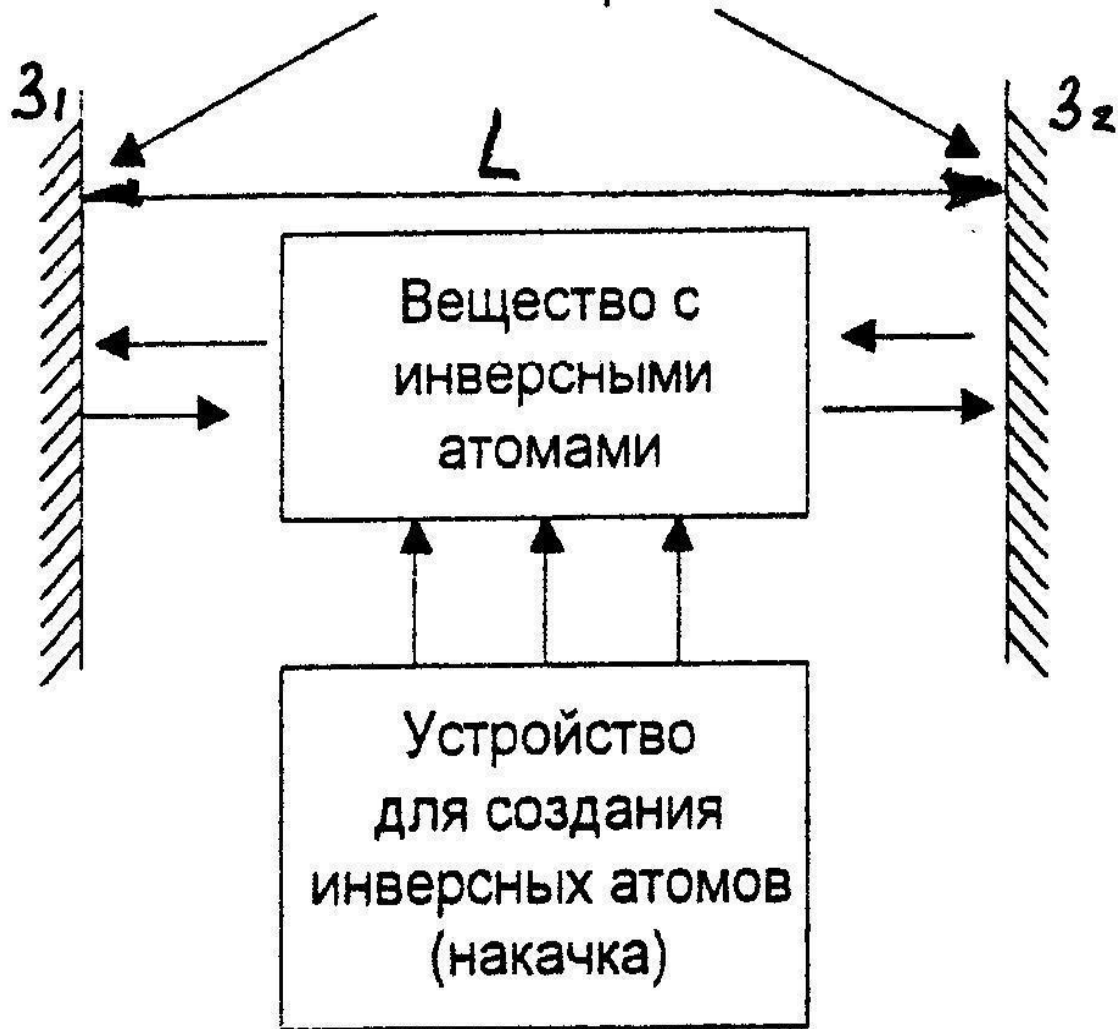
$$N_V = N_c e^{-(E_c - E_v)kt}$$

$$B_{12} N_v E(f) = A_{21} N_c + B_{21} N_c E(f)$$

$$\frac{B_{21} N_c}{B_{12} N_v} > 1$$

$$\frac{B_{21}}{A_{21}} E(f) > 1$$

Система для увеличения
плотности фотонов

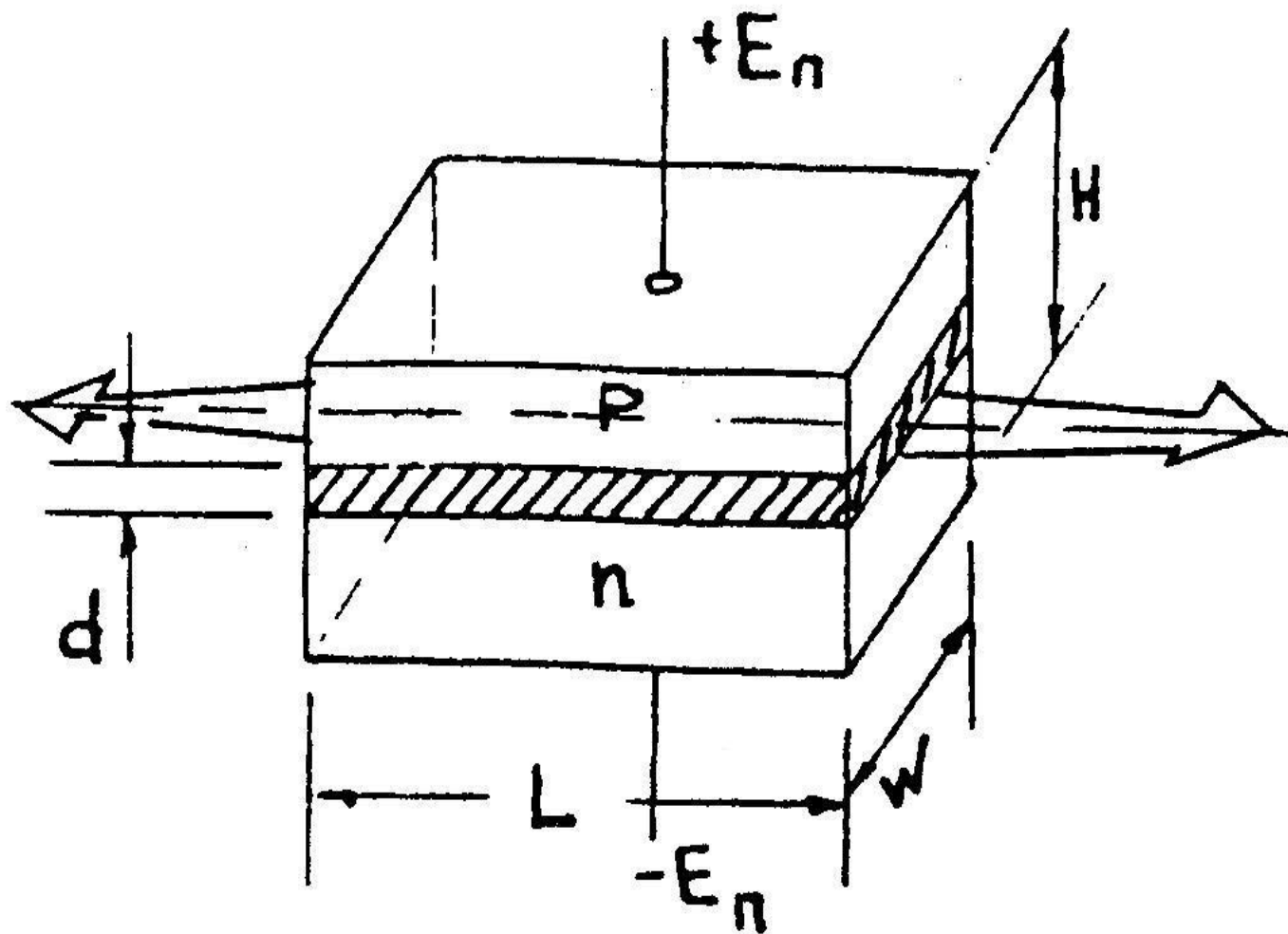


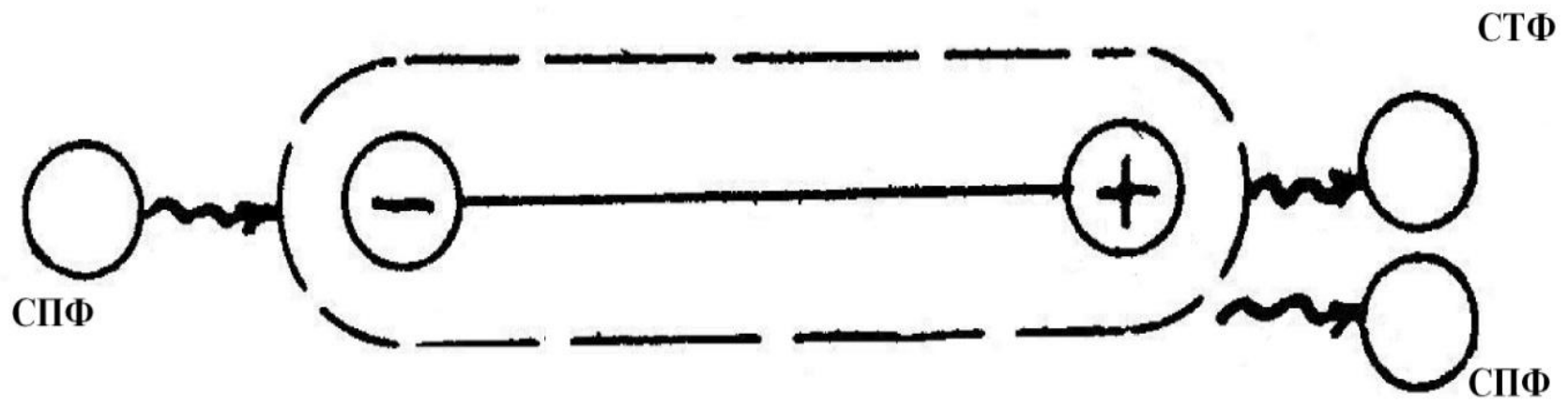
$$L = \frac{\lambda}{2} m, \text{ где } m=1, 2, 3, \dots$$

$$\Delta f_m = f_m - f_{m-1} = \frac{c}{\lambda_m} - \frac{c}{\lambda_{m-1}} = \frac{c}{2L}$$

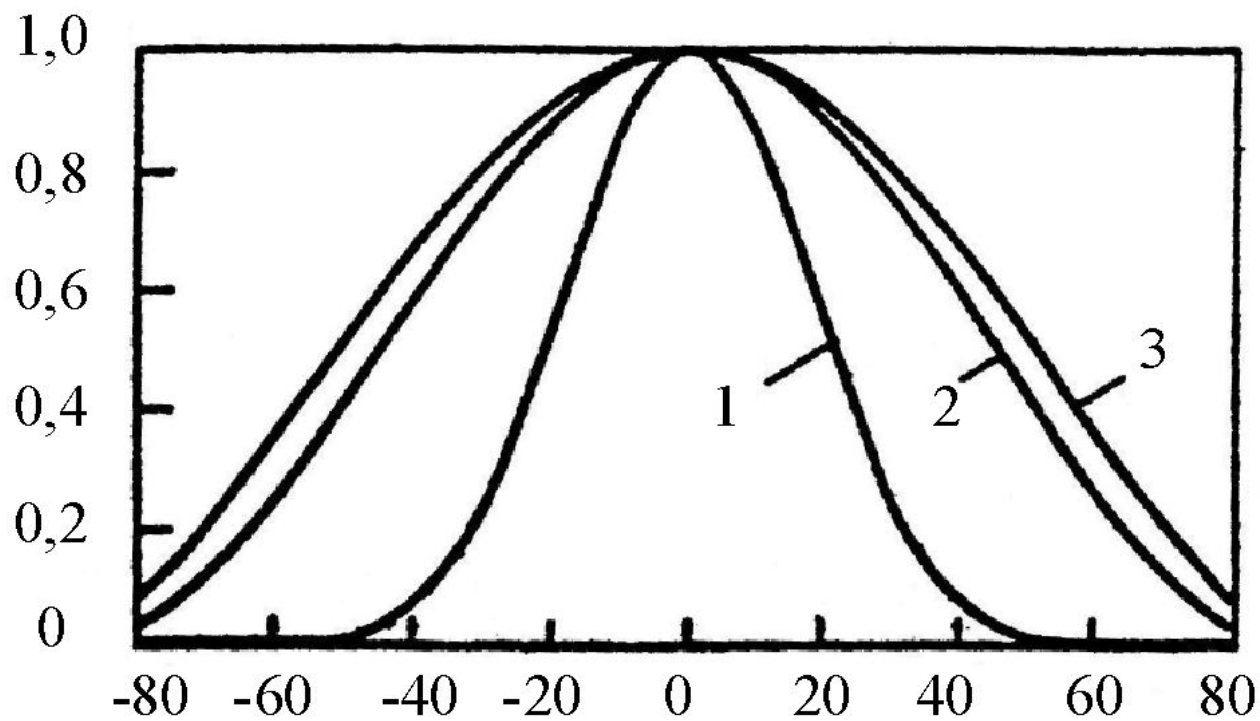
$$\Delta f_m = \frac{c}{2L \cdot n}$$

$$Q = \frac{\pi L n}{\lambda \ln R}$$



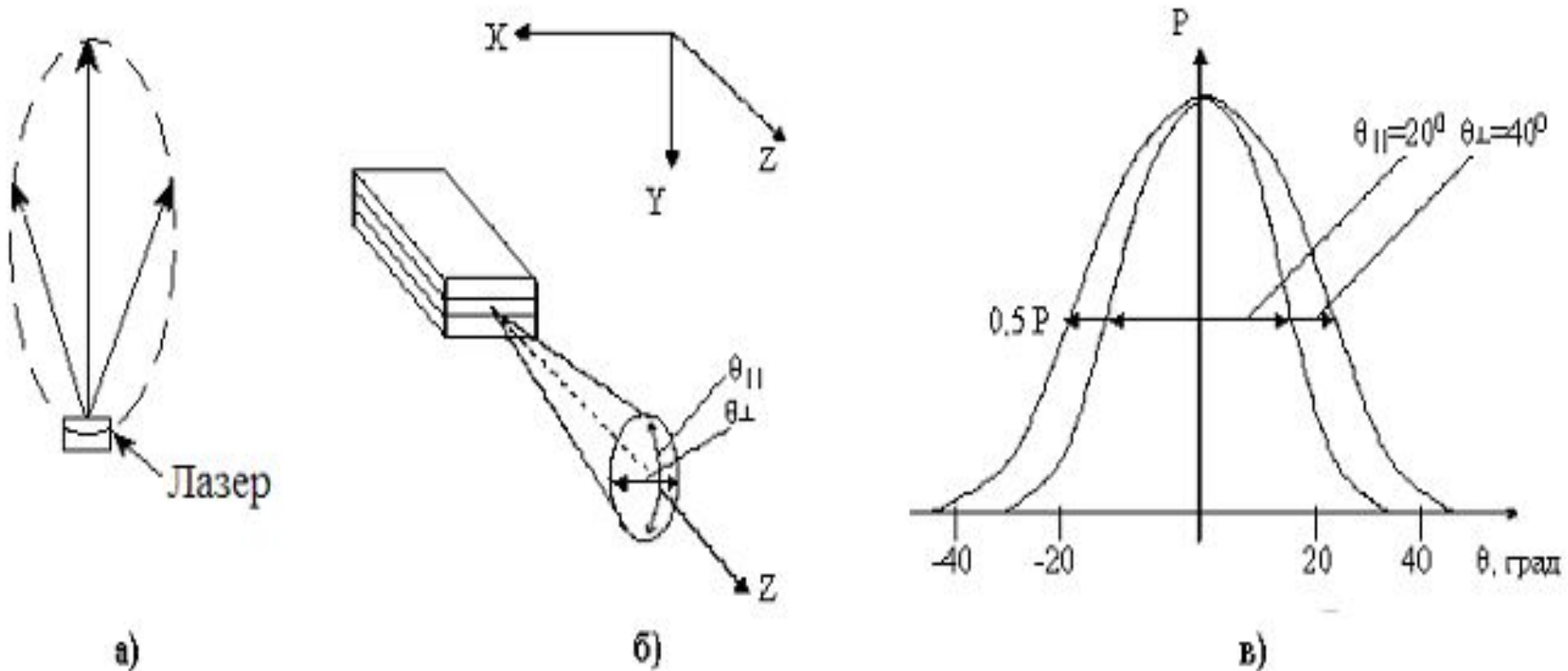


Относительная интенсивность



Градусы от нормали

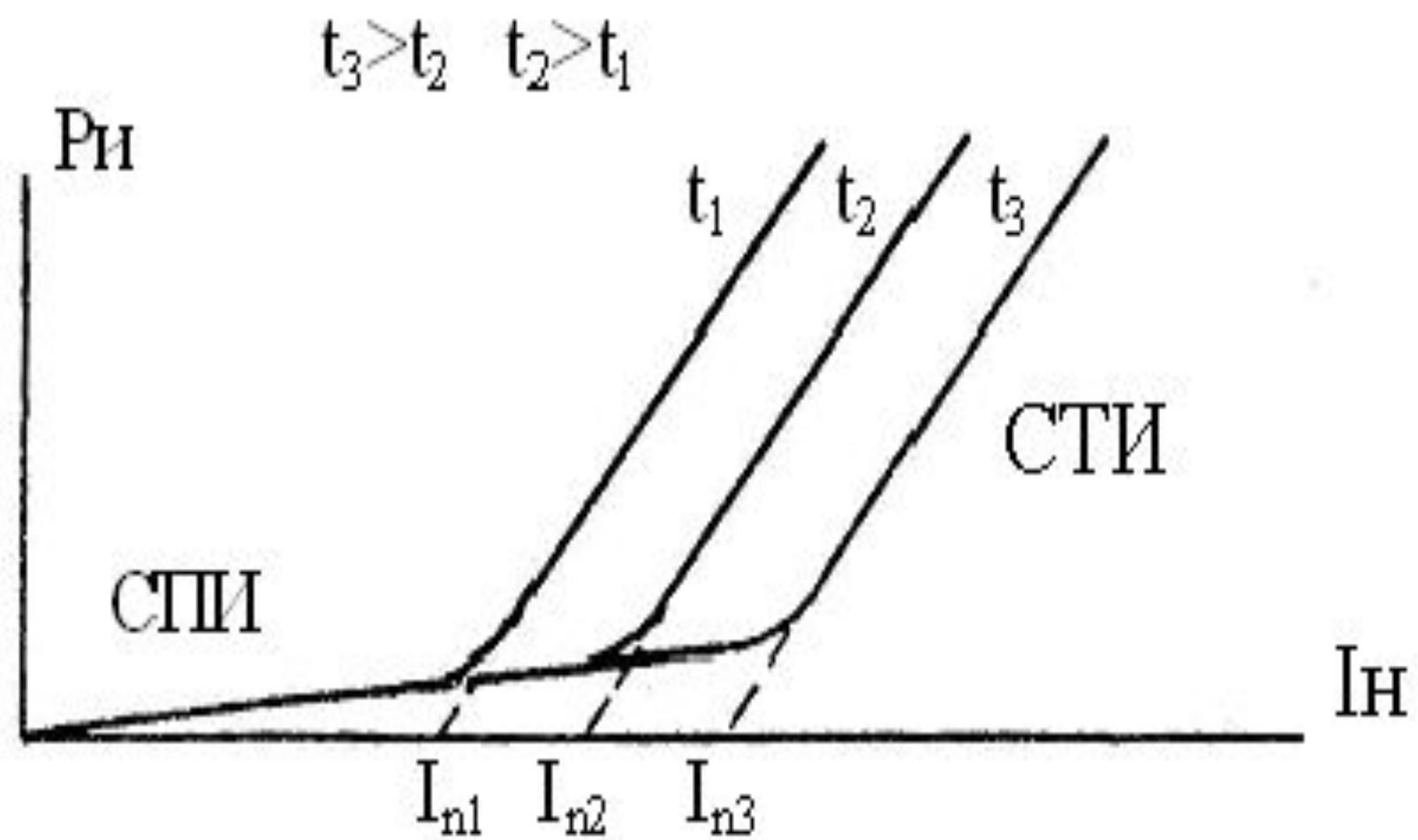
Диаграмма направленности оптического излучения ЛД

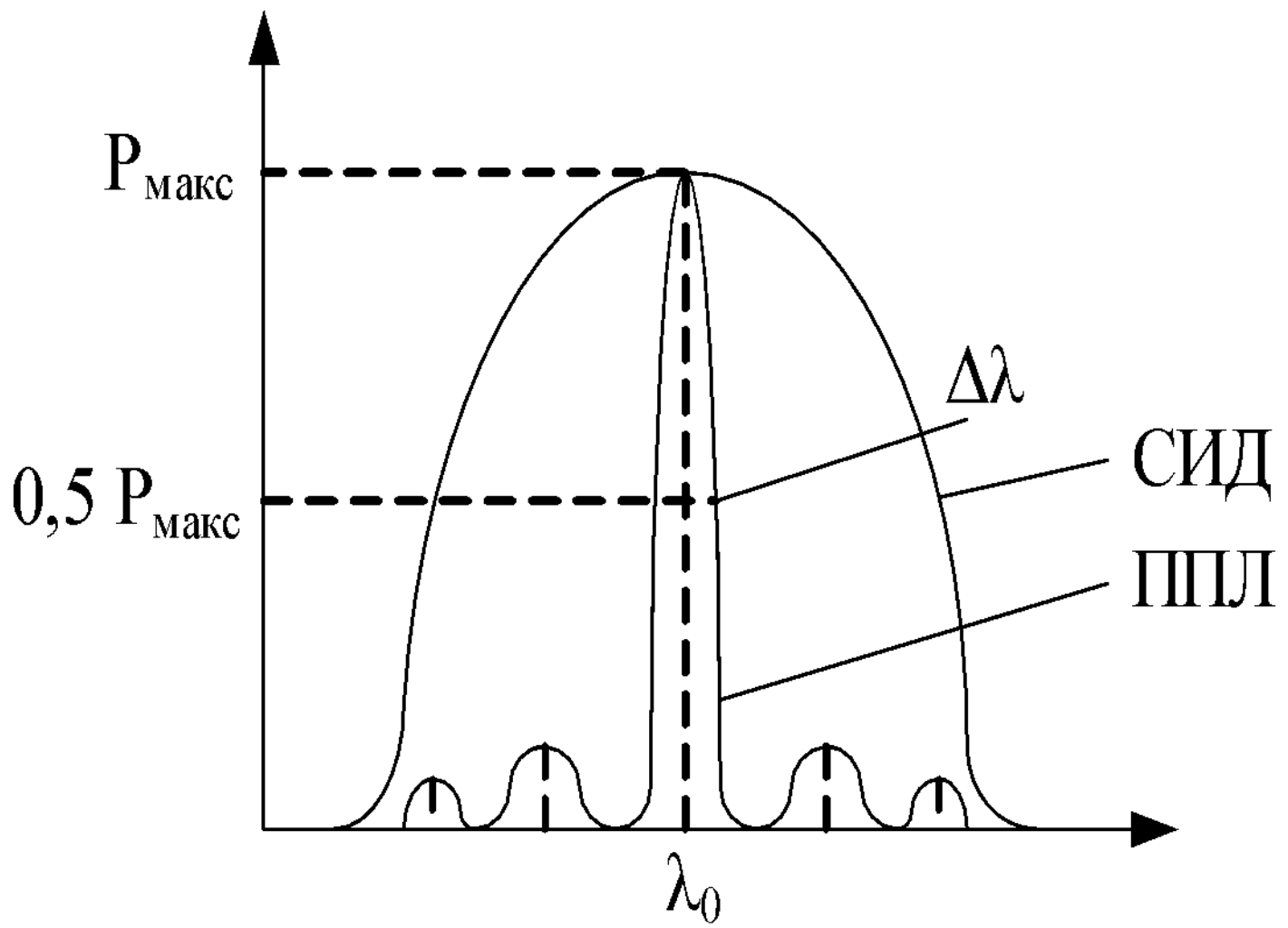


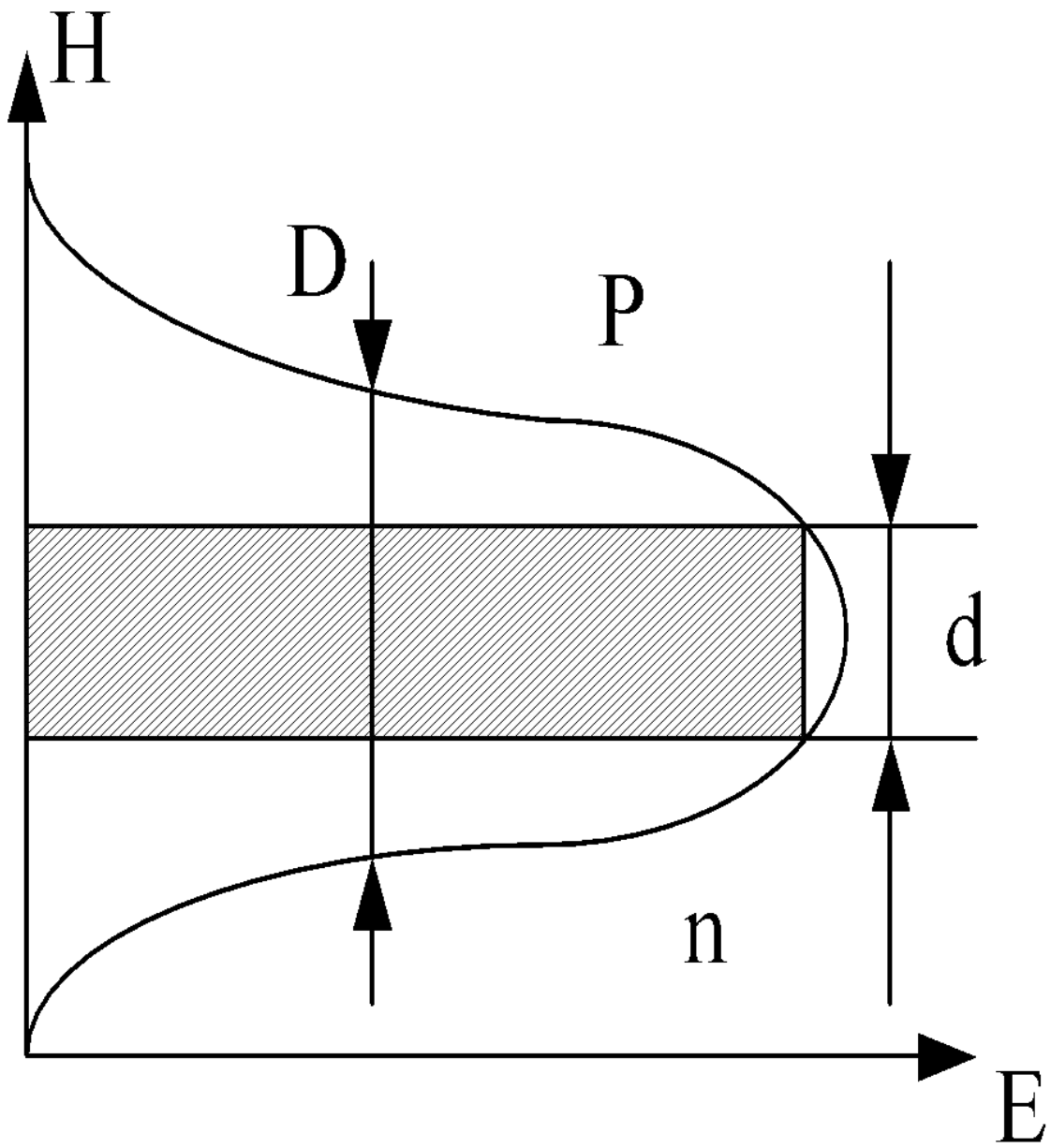
а – диаграмма направленности;

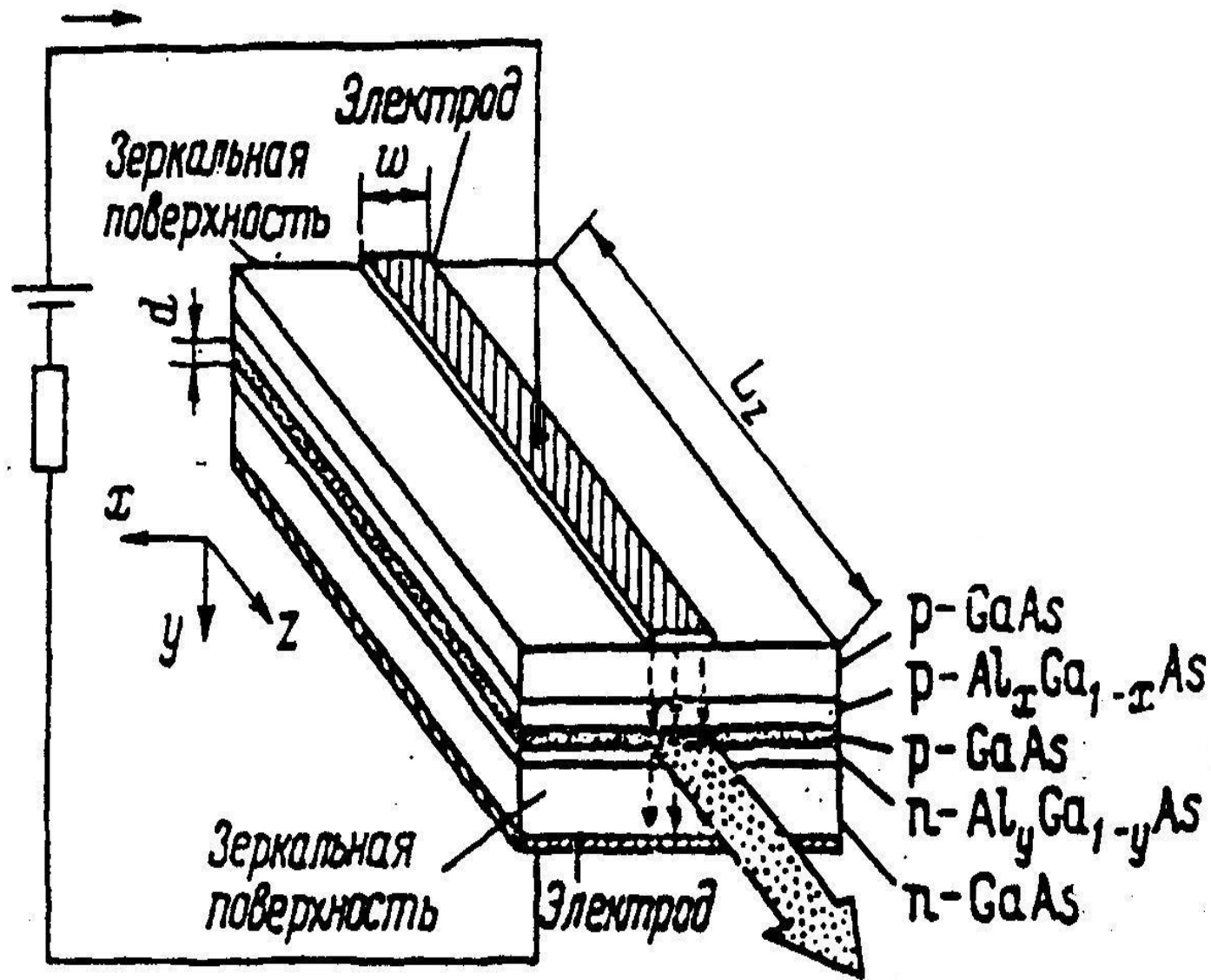
б – зависимость излучаемой мощности от угла во взаимно перпендикулярных направлениях;

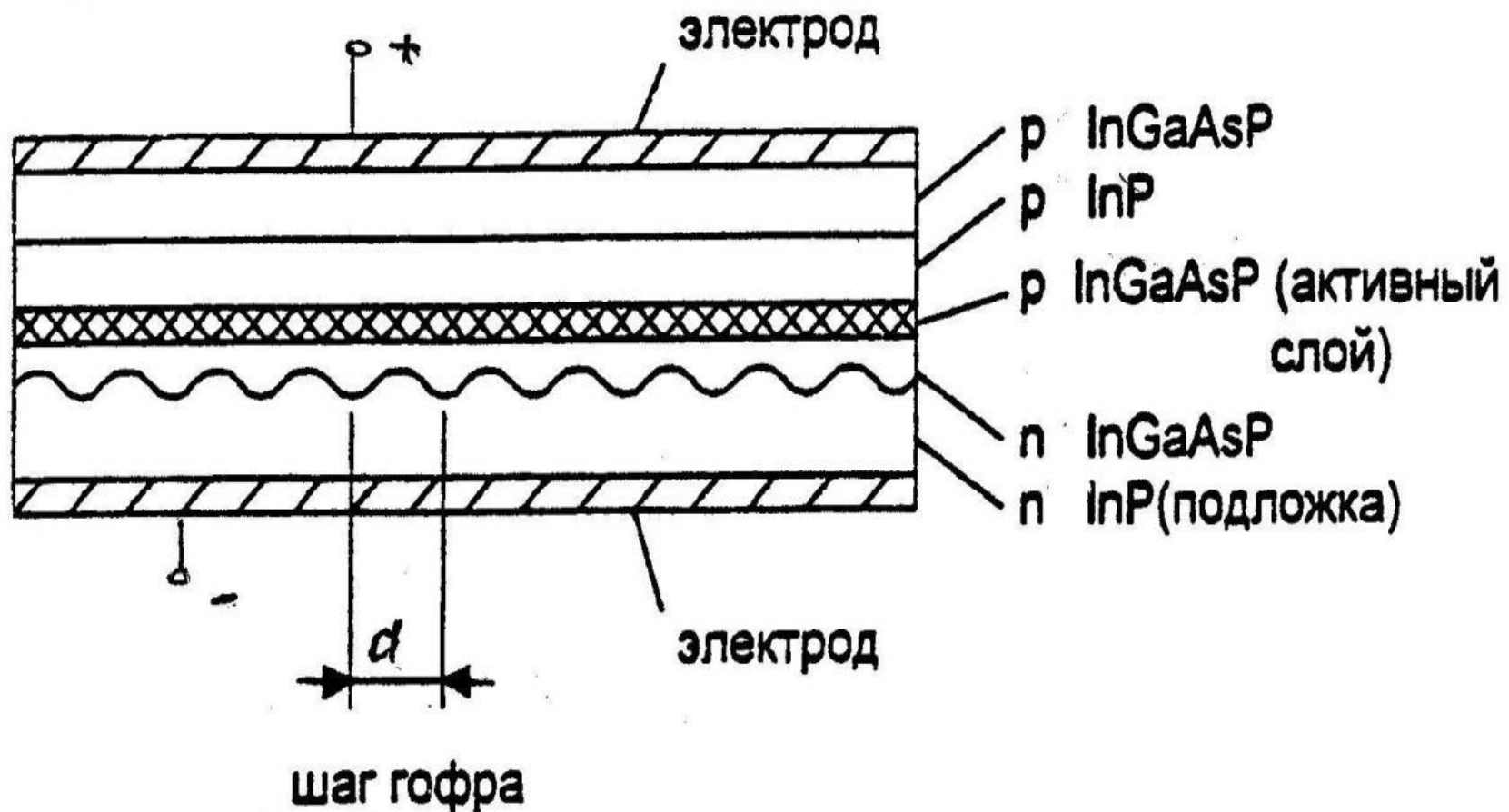
в – конус излучения











условие Вульфа-Брэгга

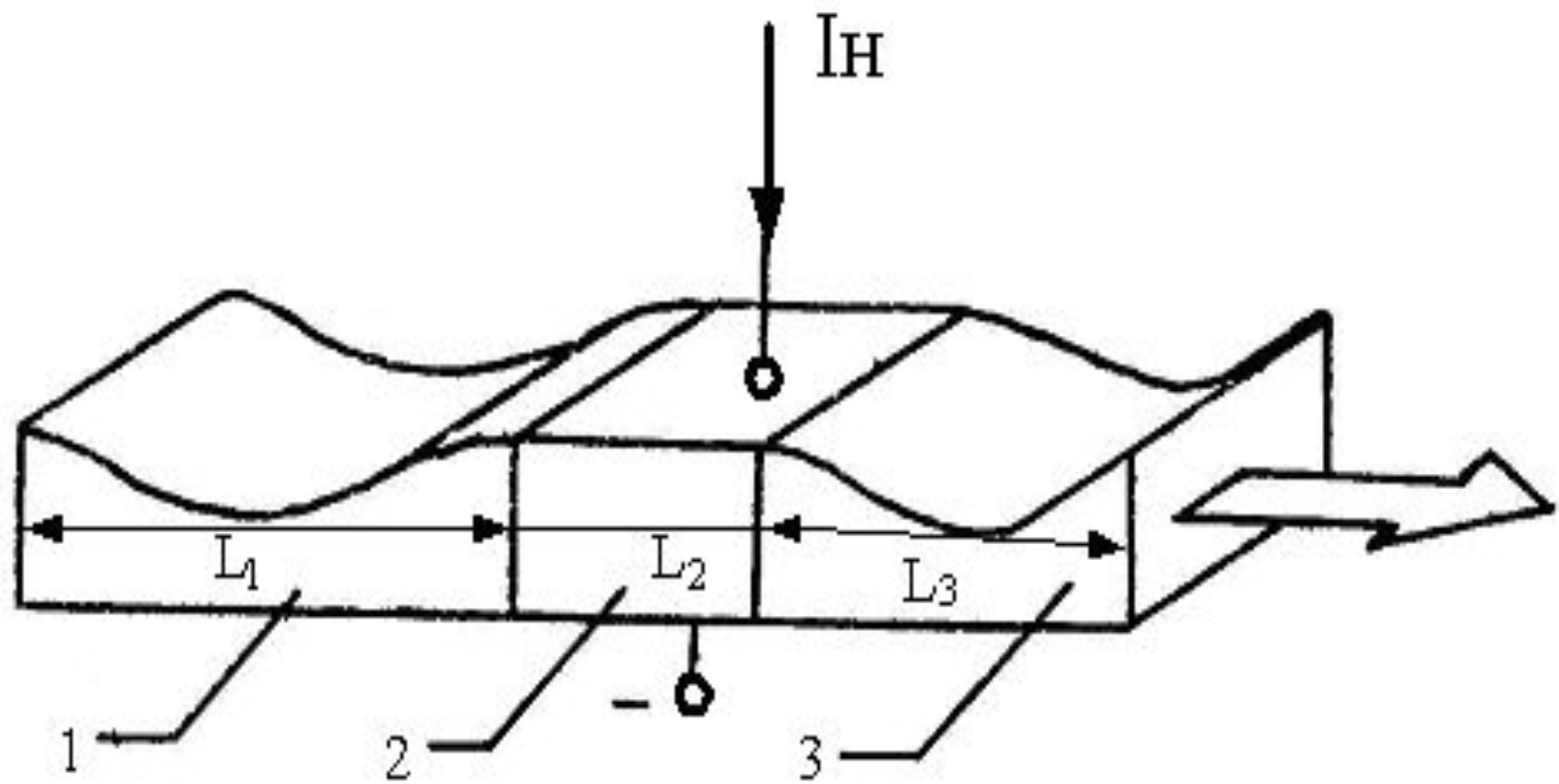
$$dn_{\vartheta} (\sin\theta + 1) = m\lambda_0$$

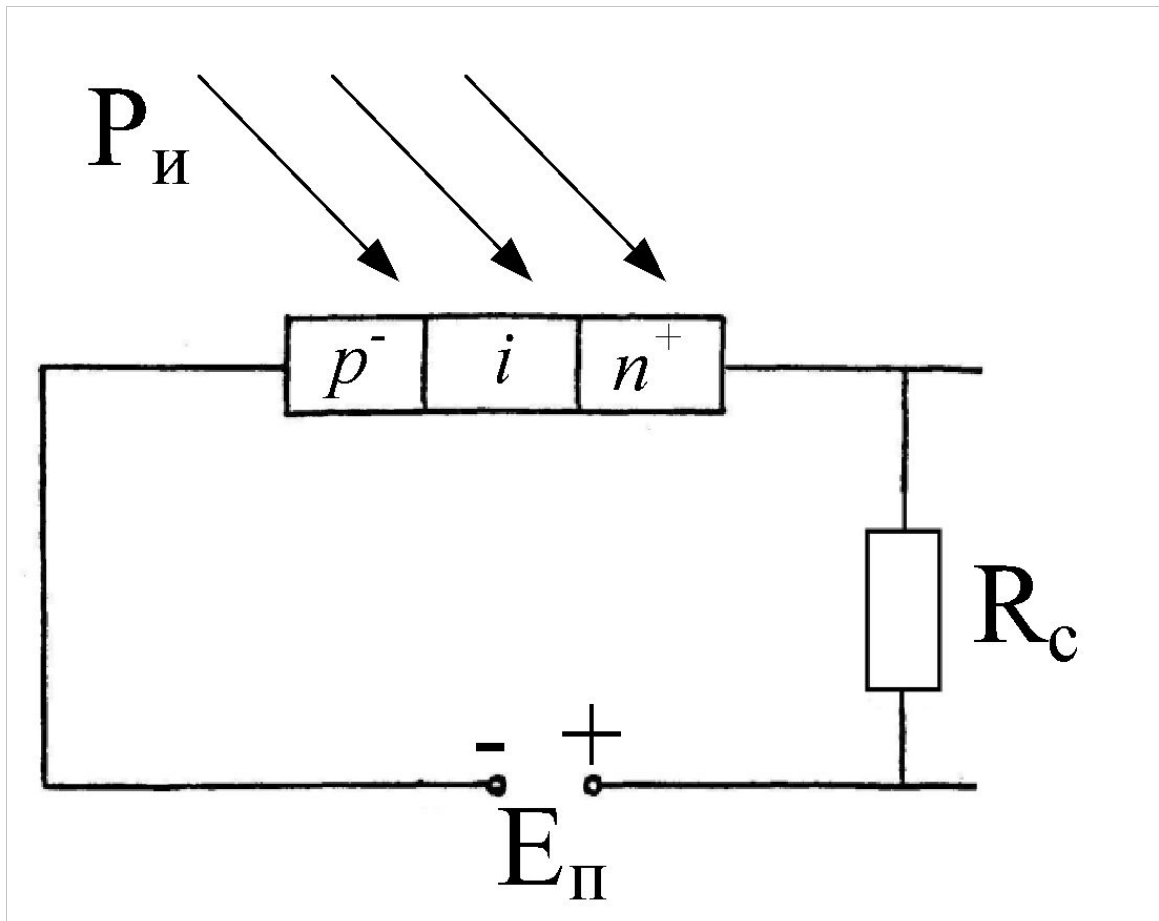
условие Брэгга (при $\theta = \pi/2$)

$$2dn_{\vartheta} = m\lambda_0$$

$$\lambda_0 = \lambda_B = 2dn_{\vartheta}$$

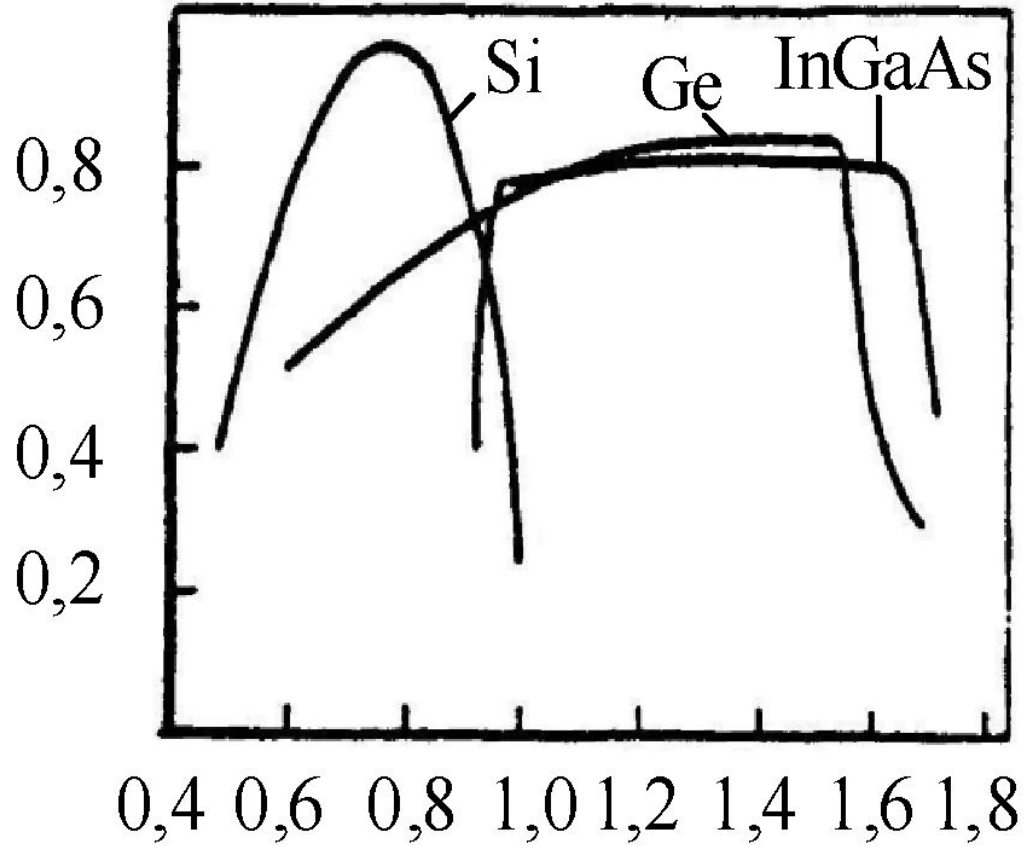
$$f = f_B - \left(m + \frac{1}{2} \right) \frac{c}{nL}$$

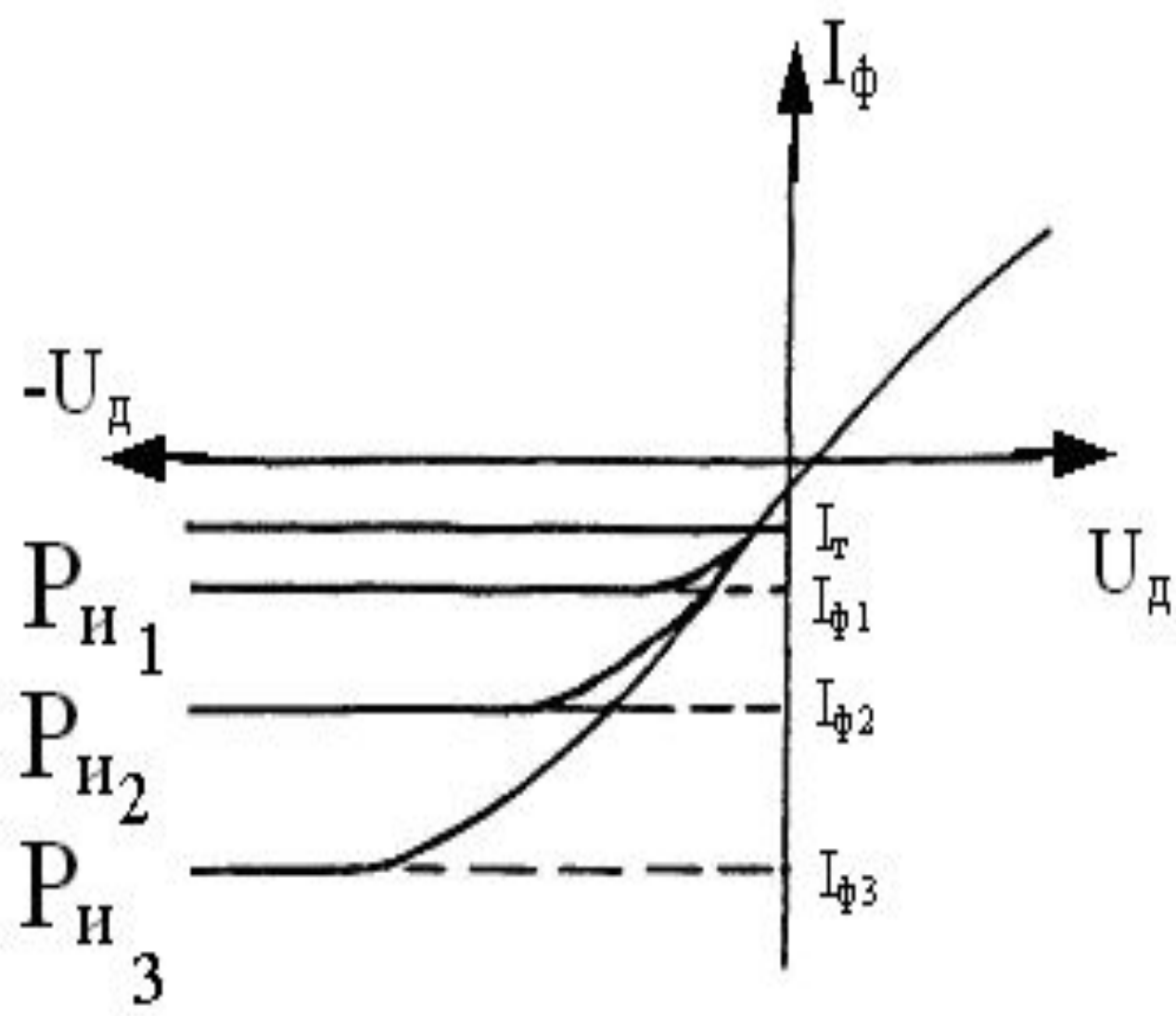


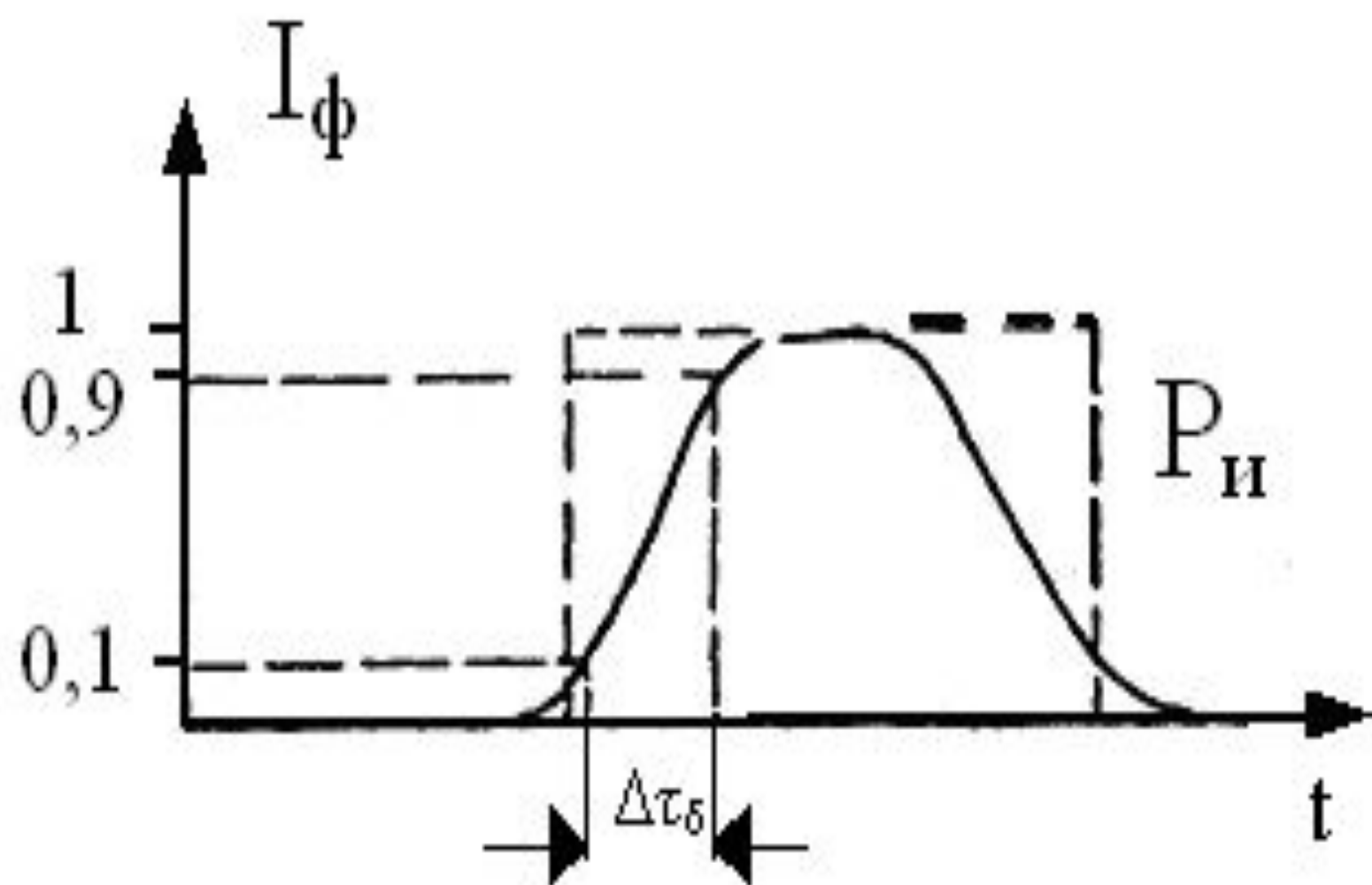


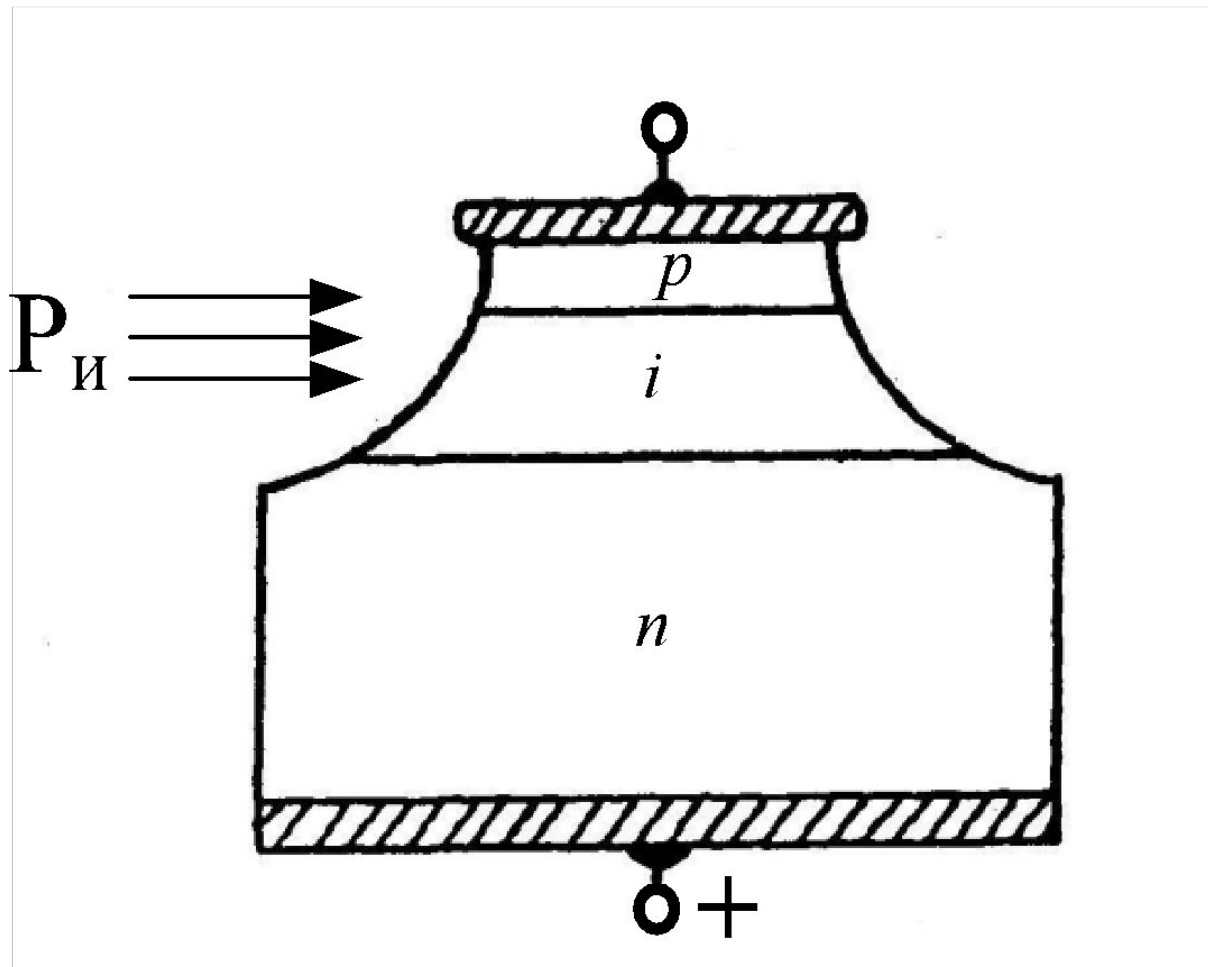
$$I_{\phi} = N_e q$$

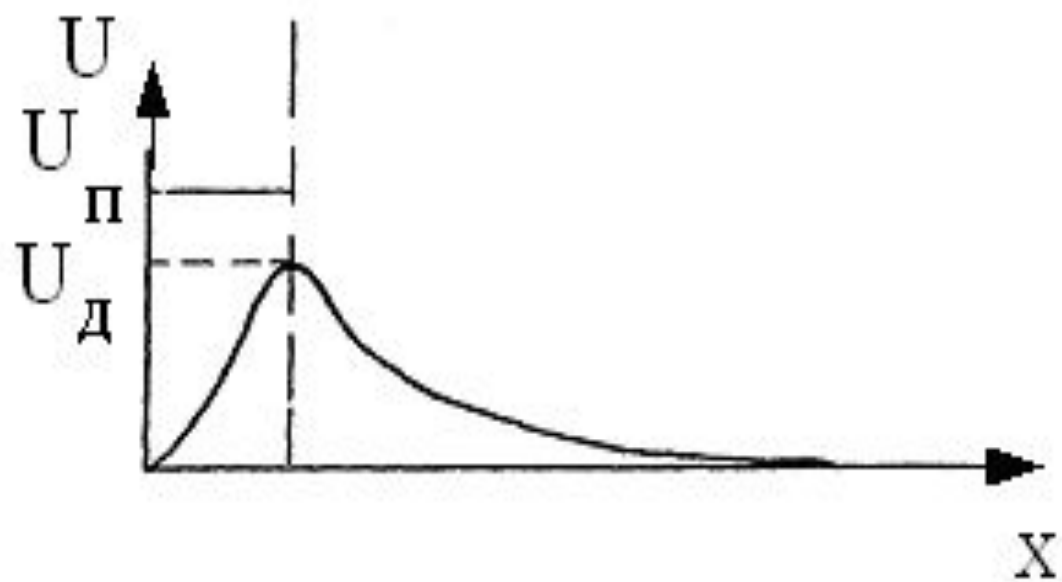
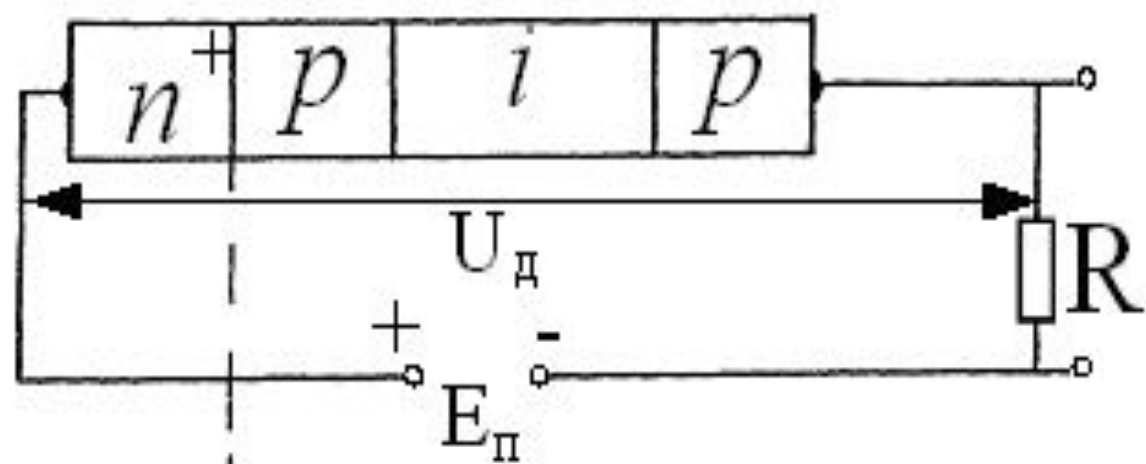
$S, A/B_T$

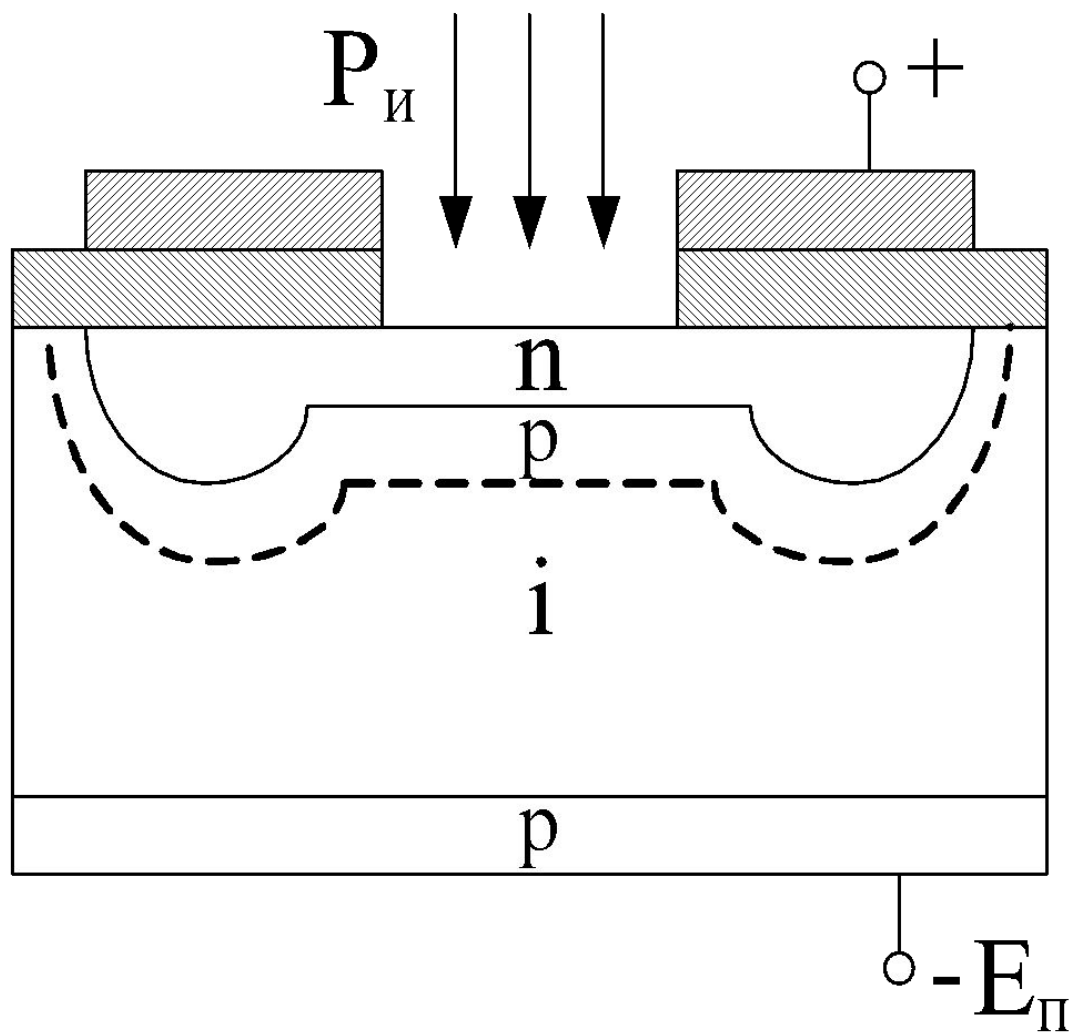












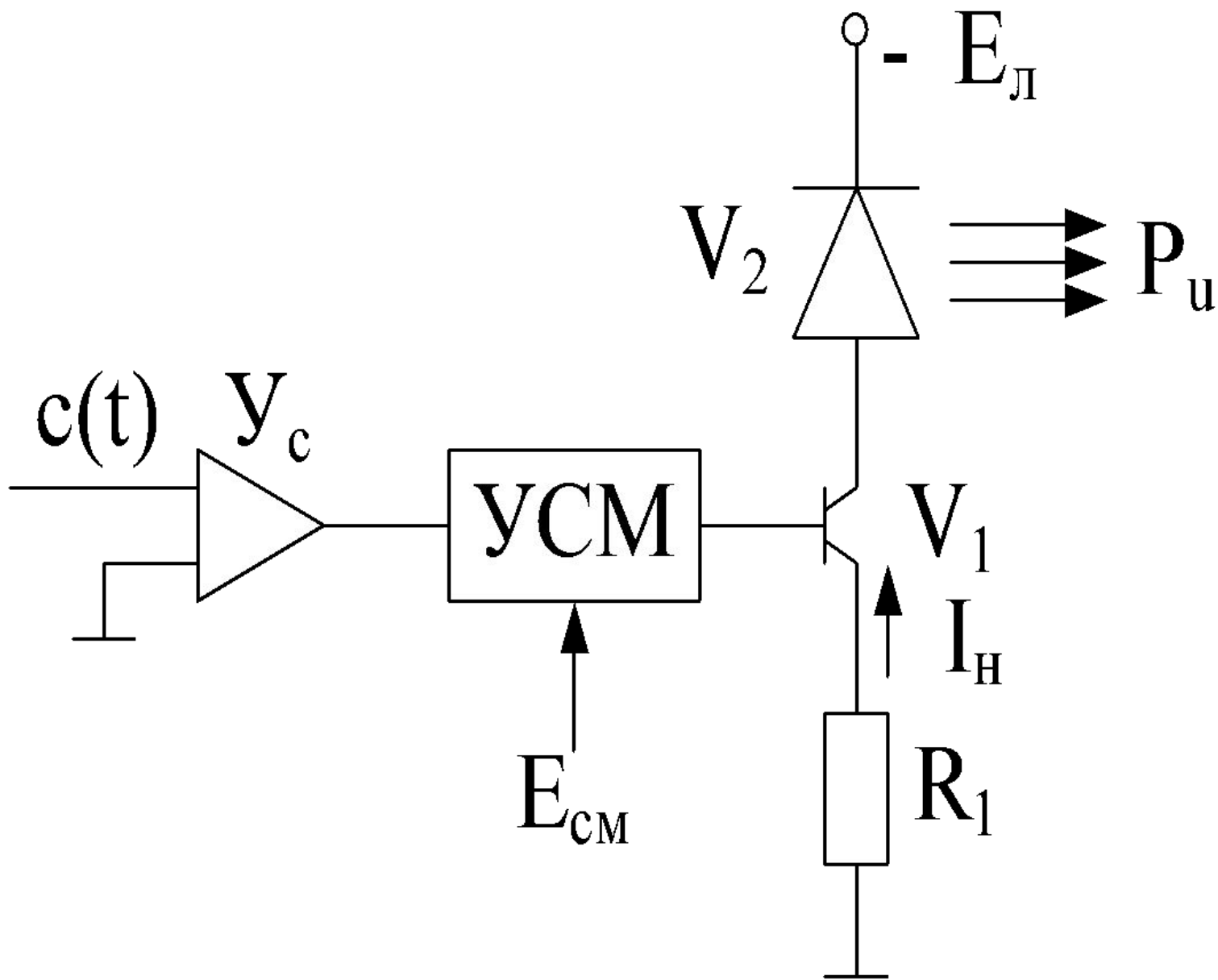


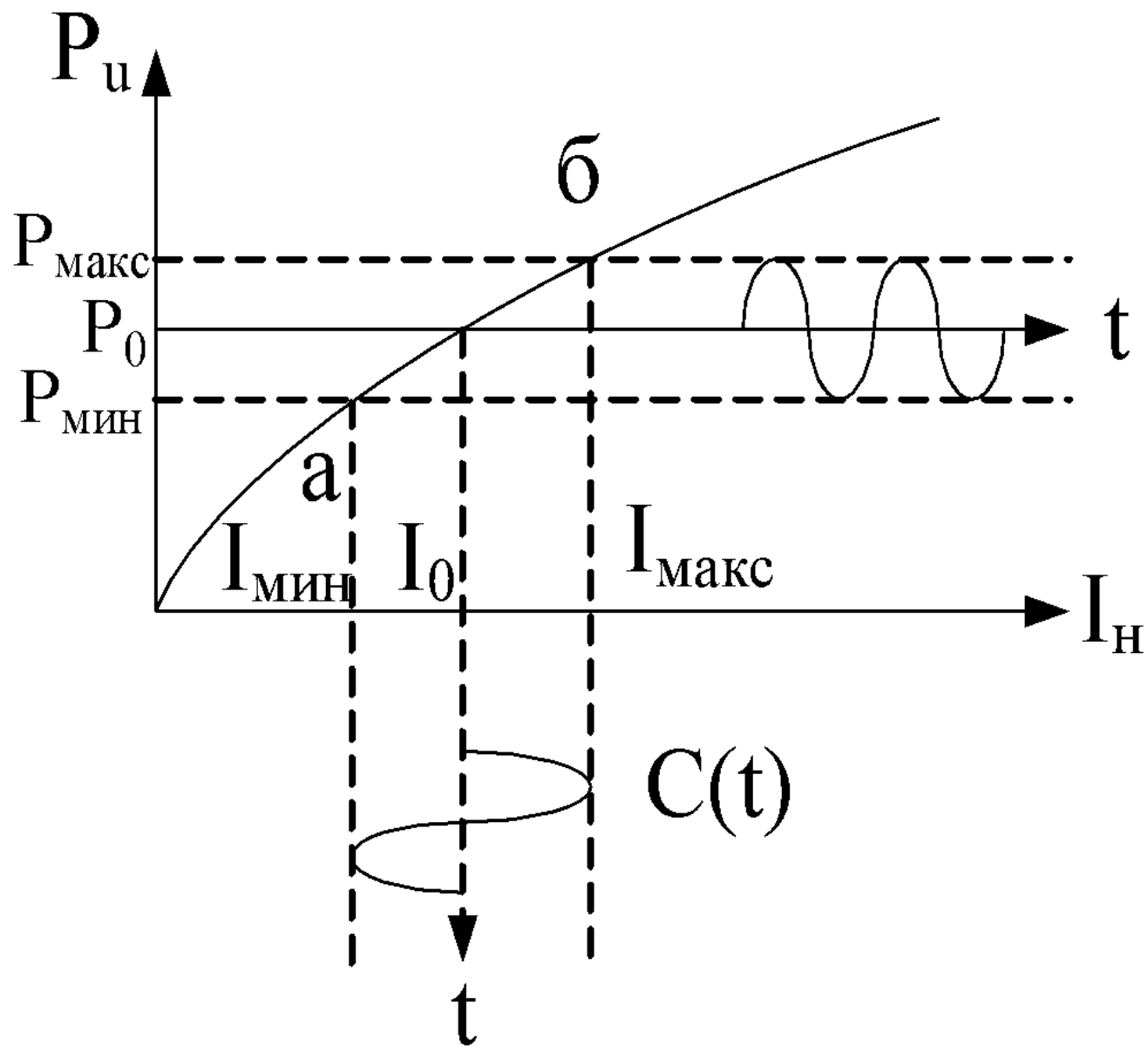
а

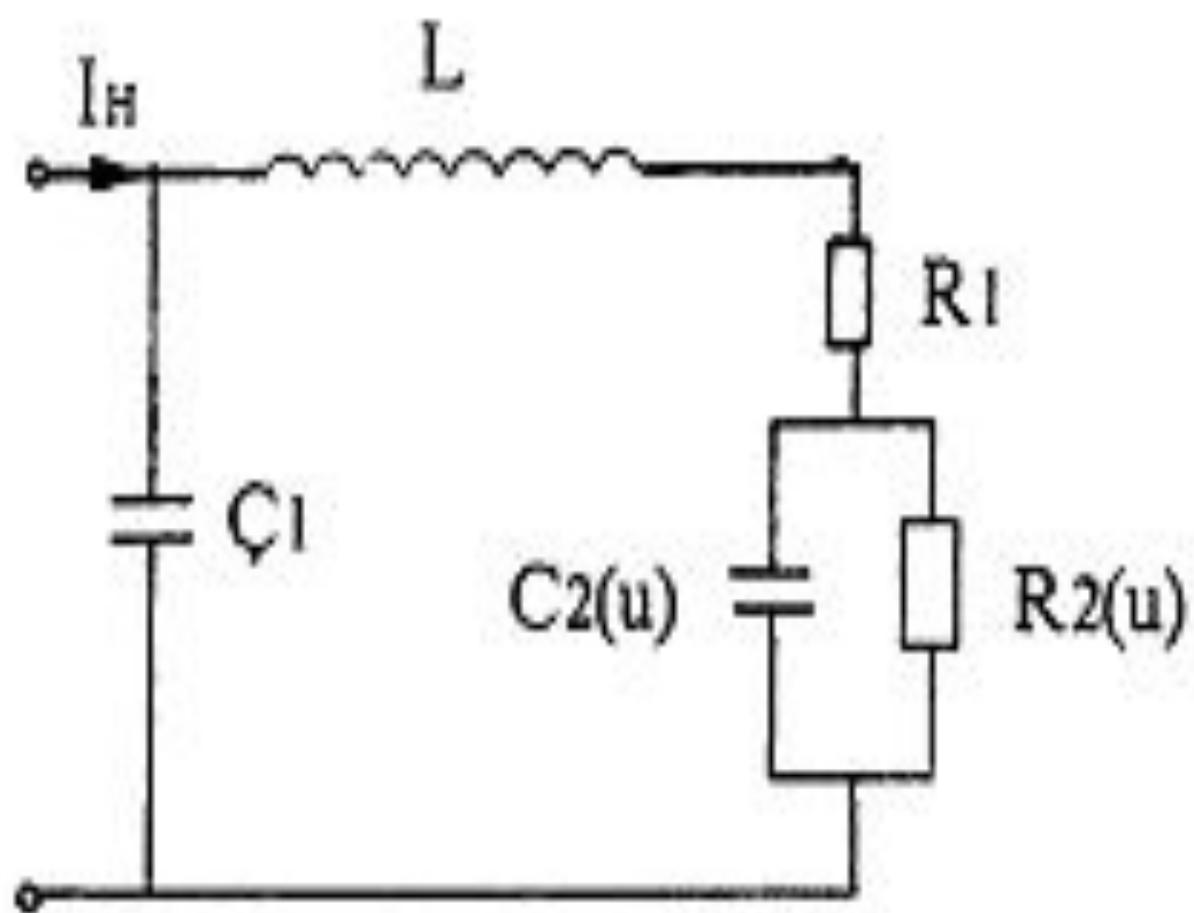


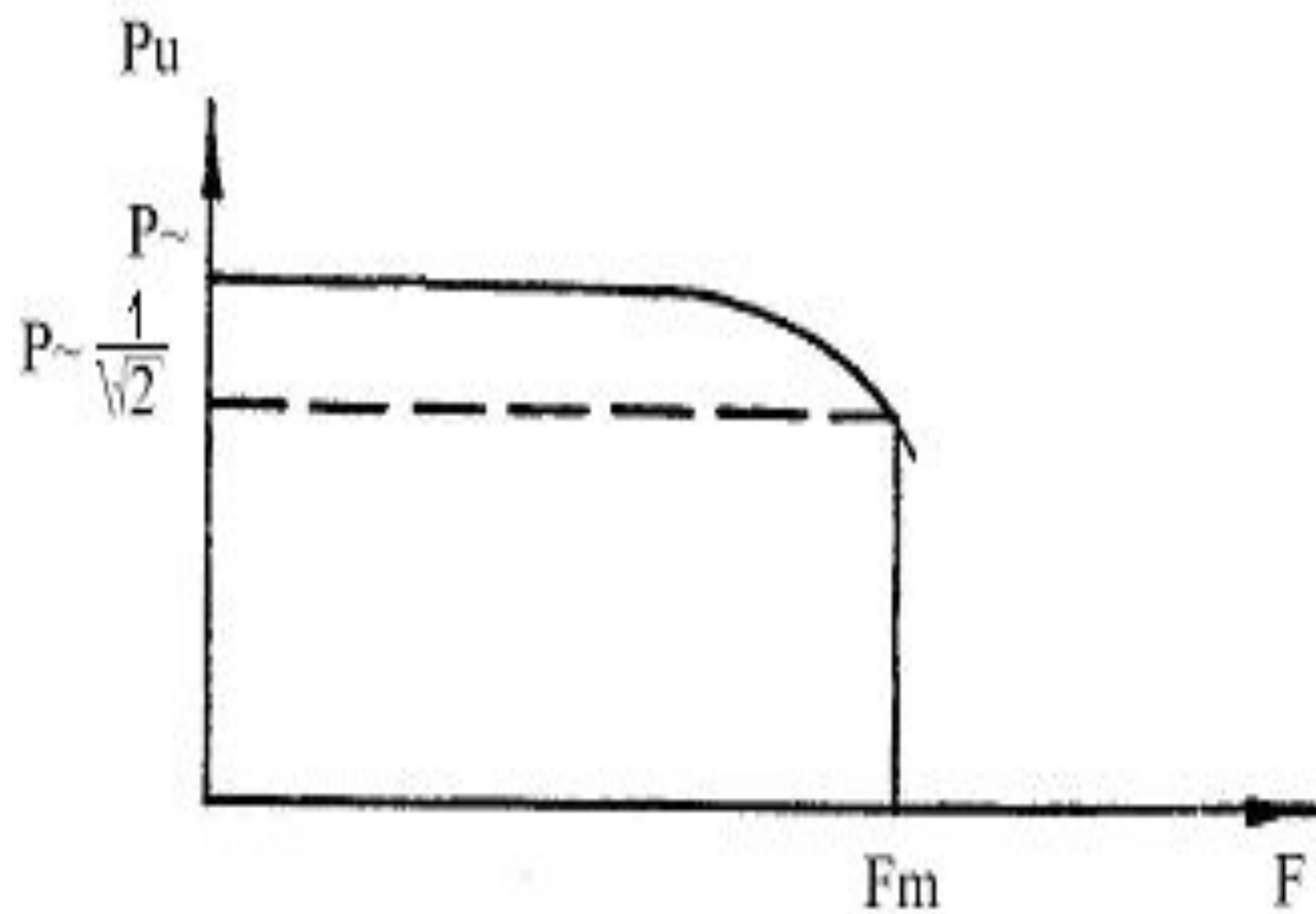
источник света

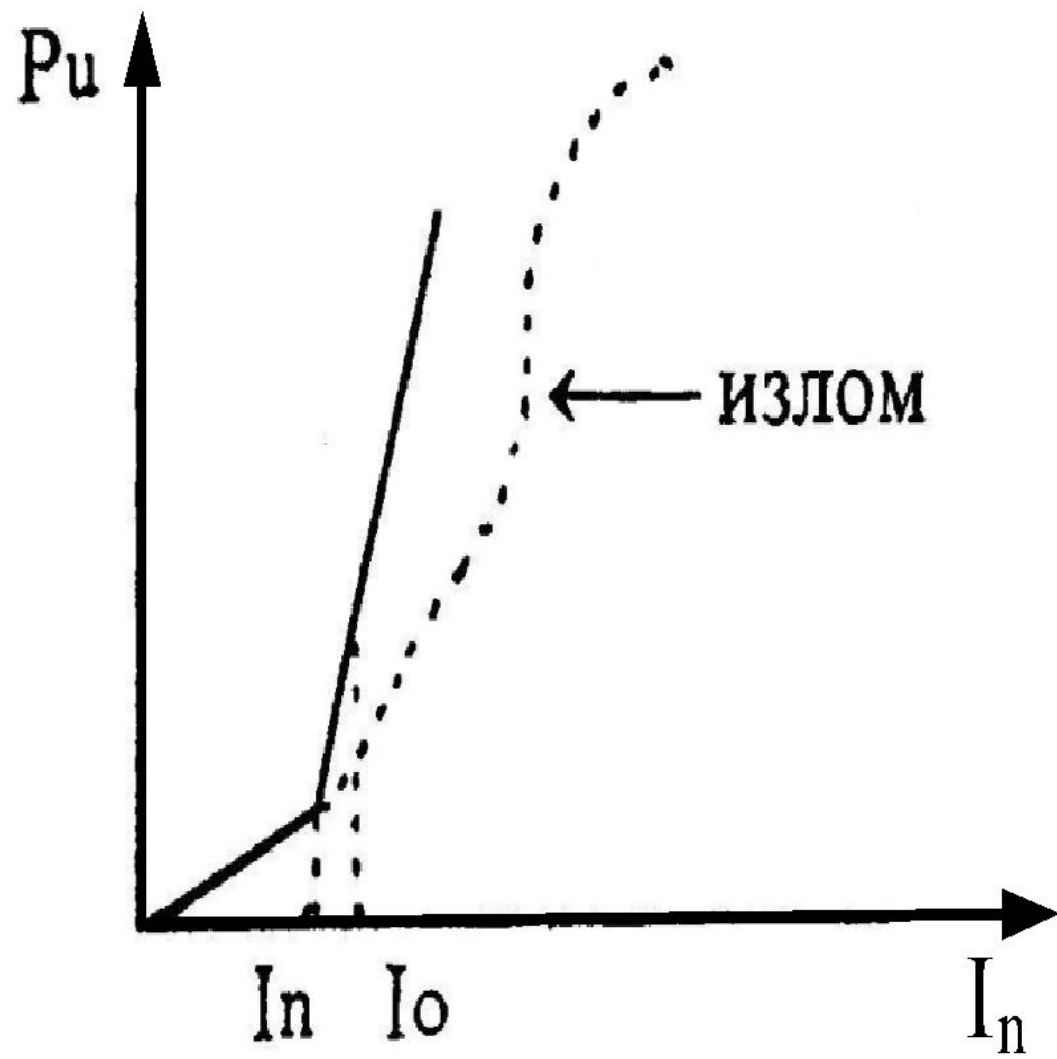
б

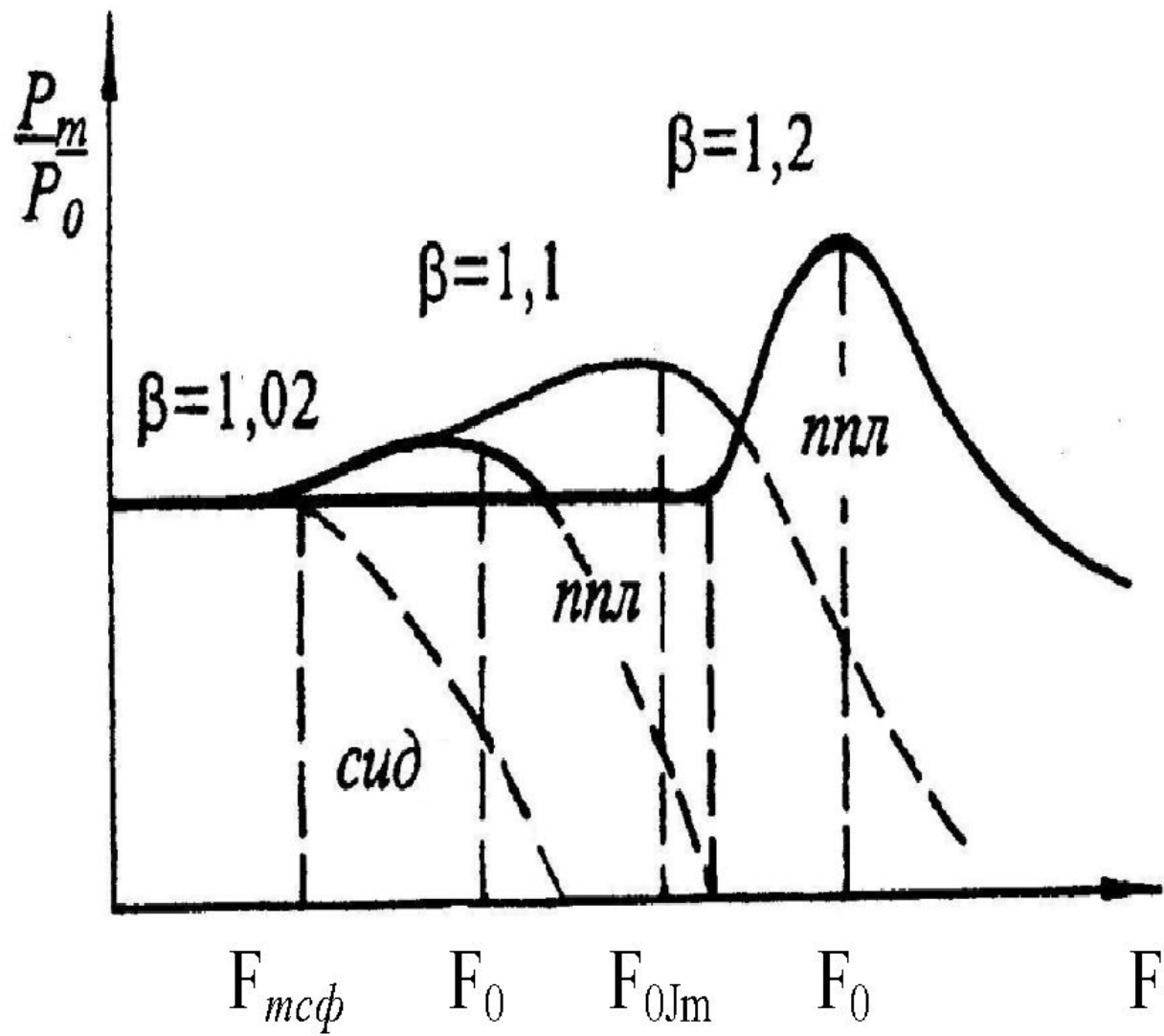


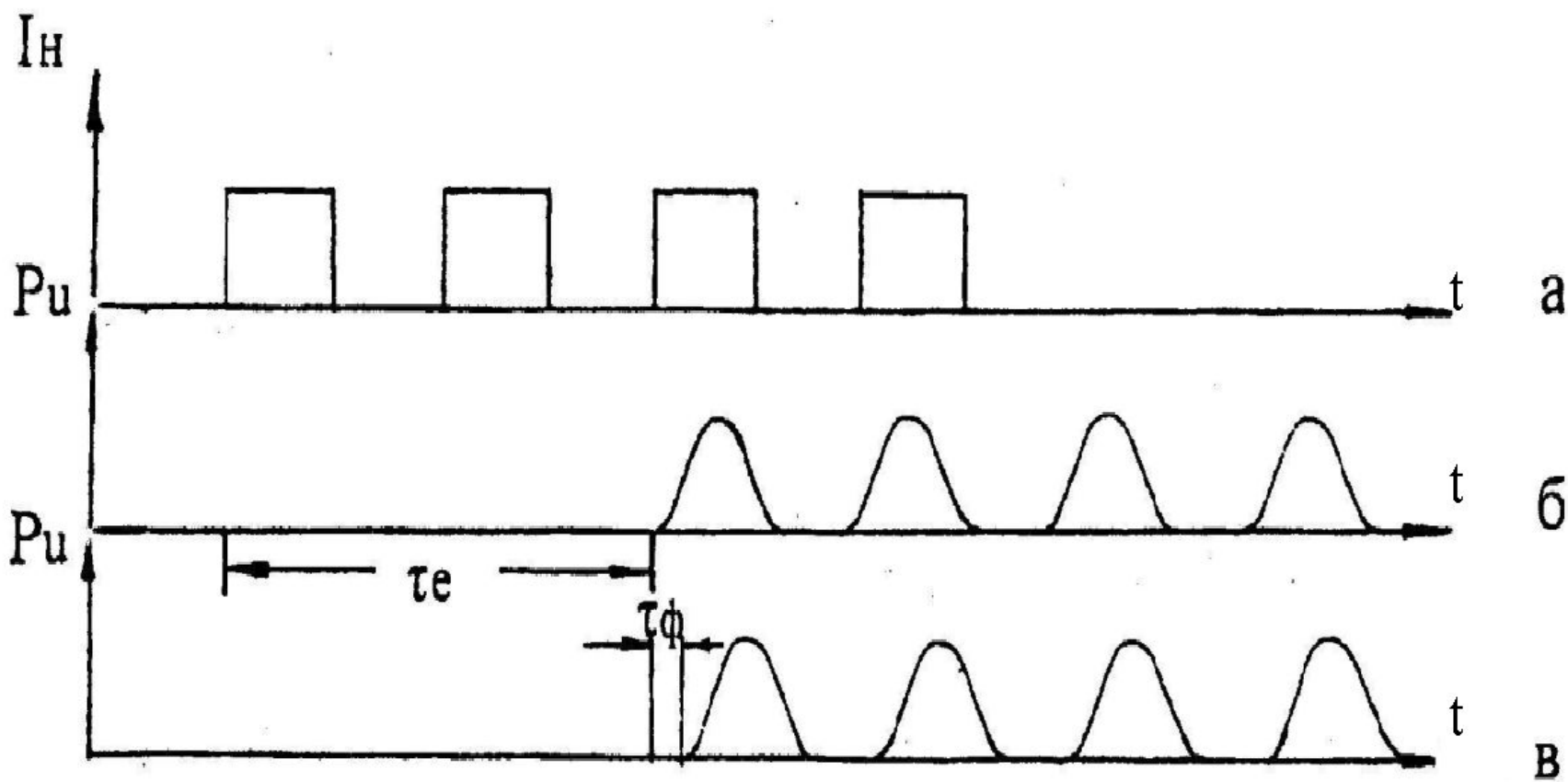


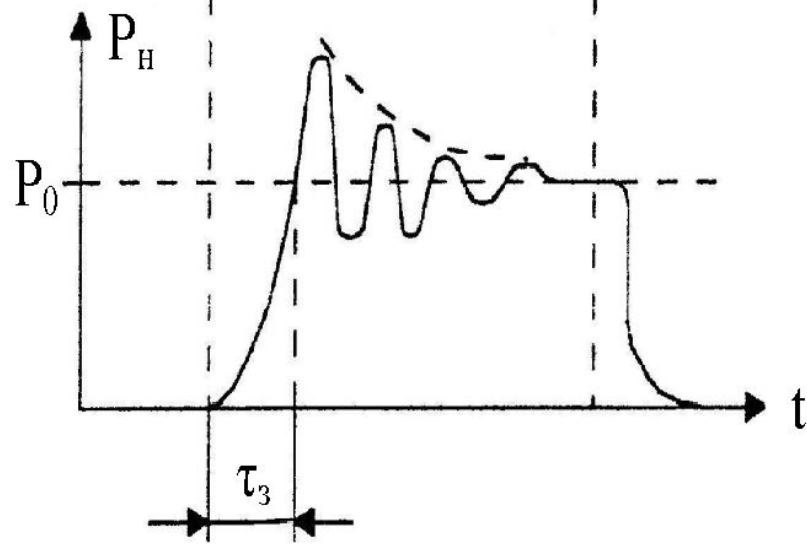
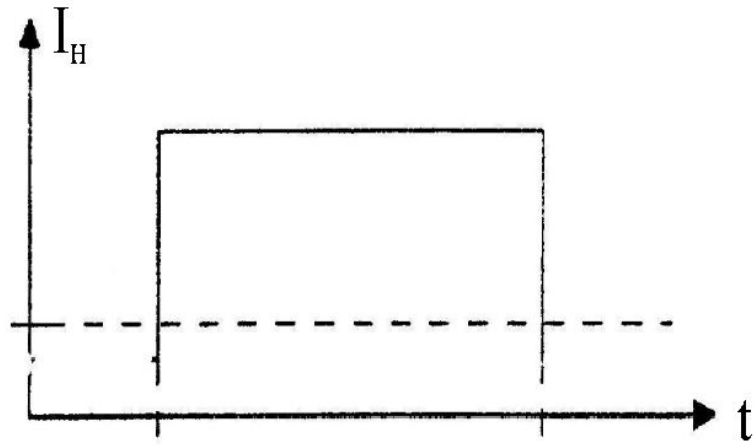




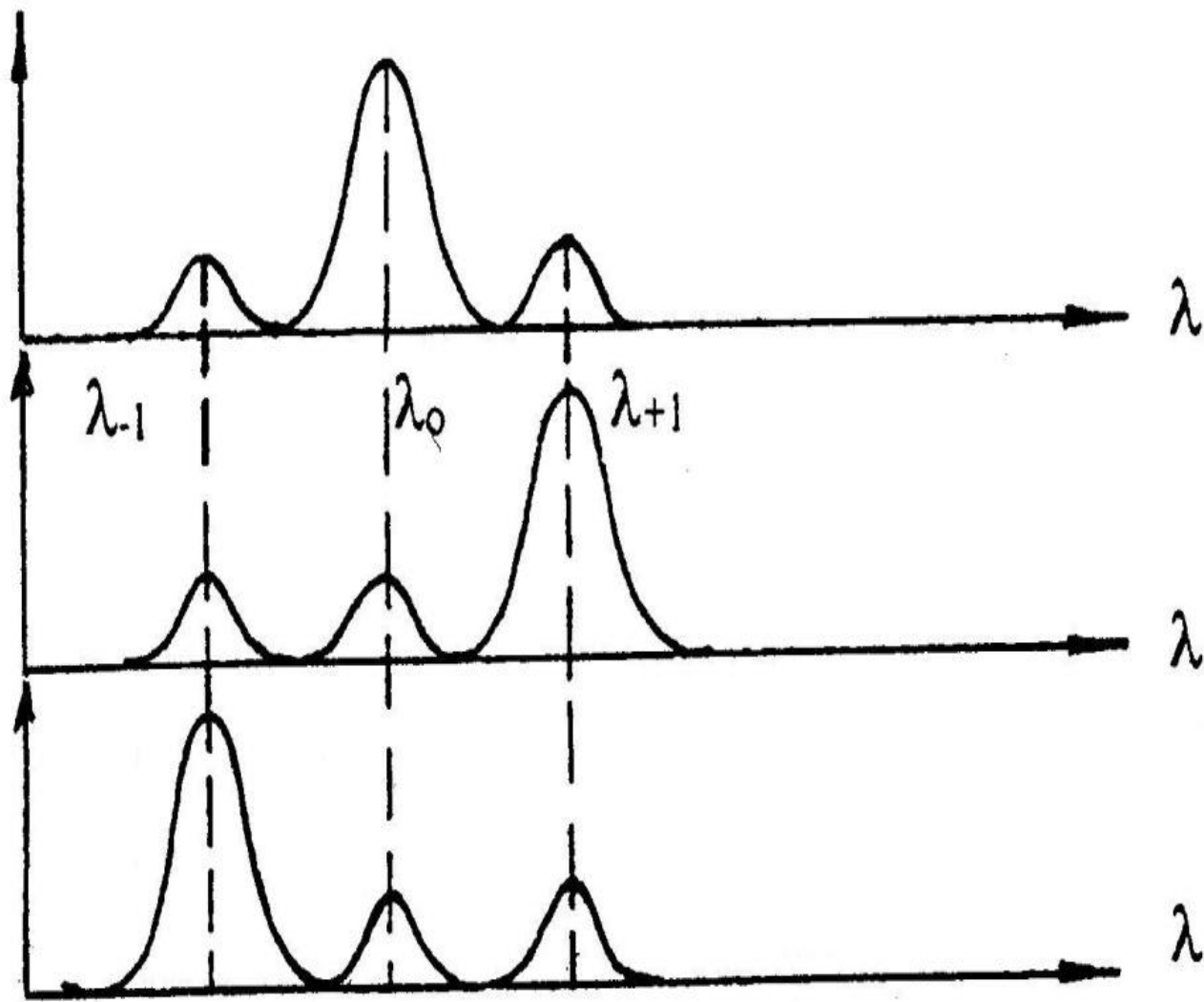


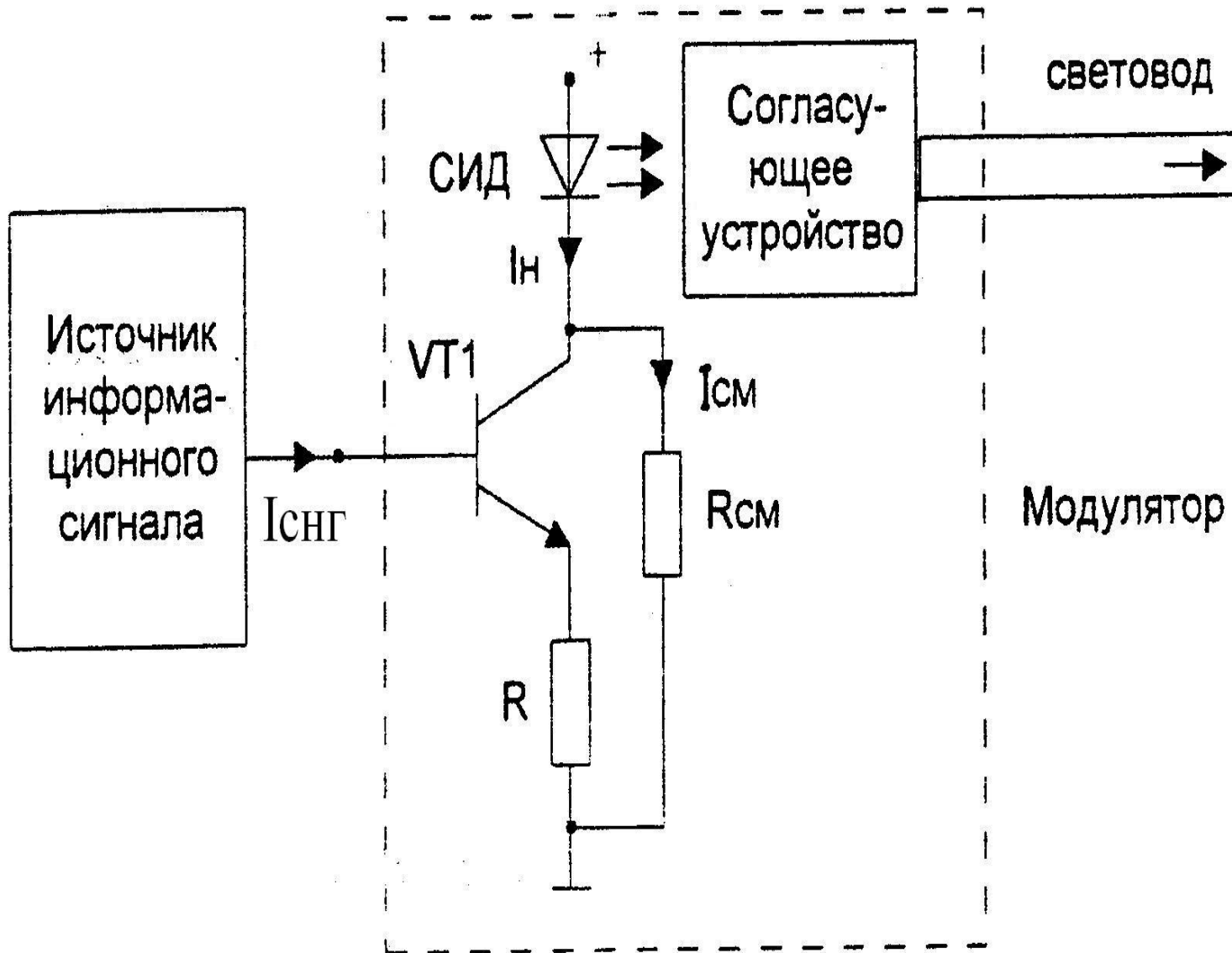


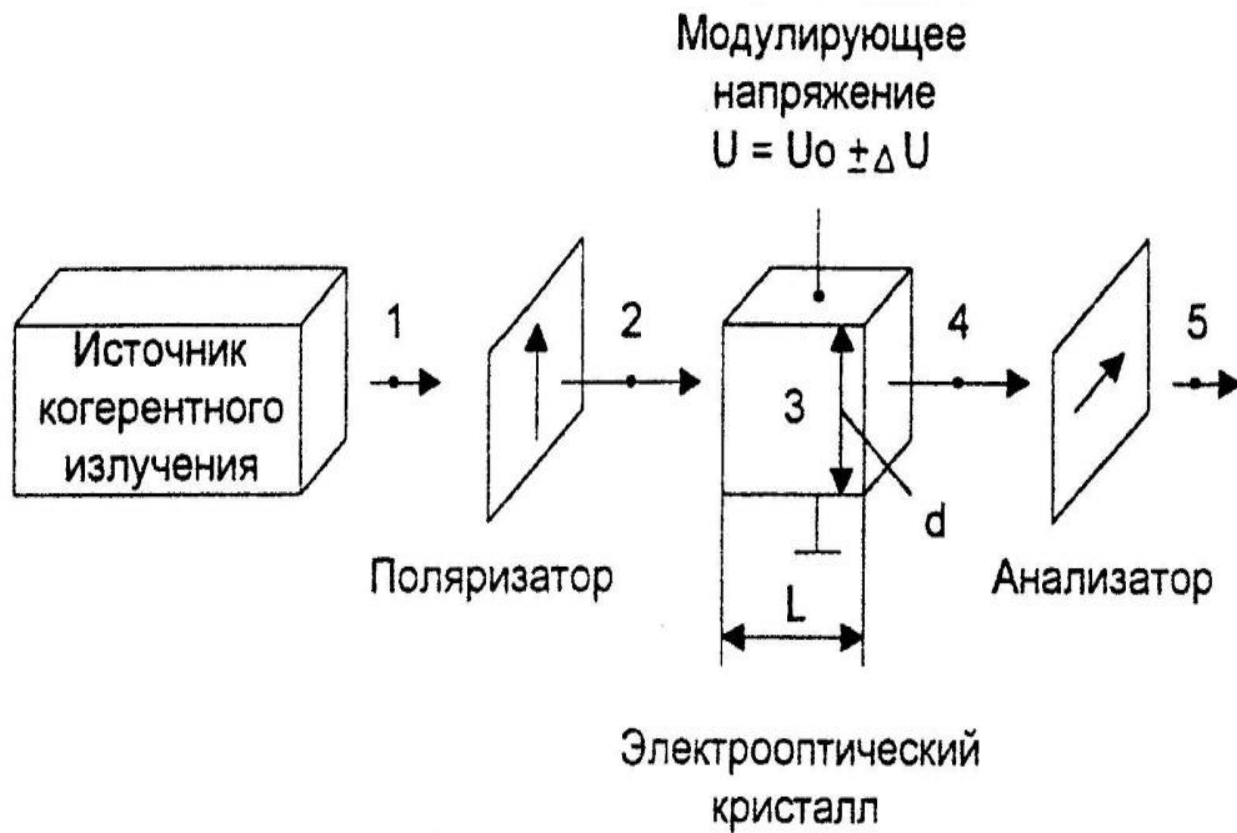


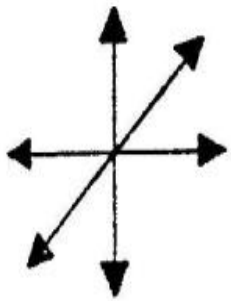


P_u









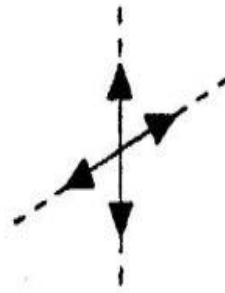
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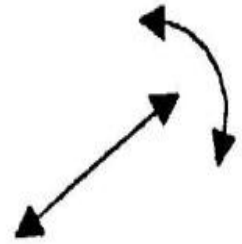
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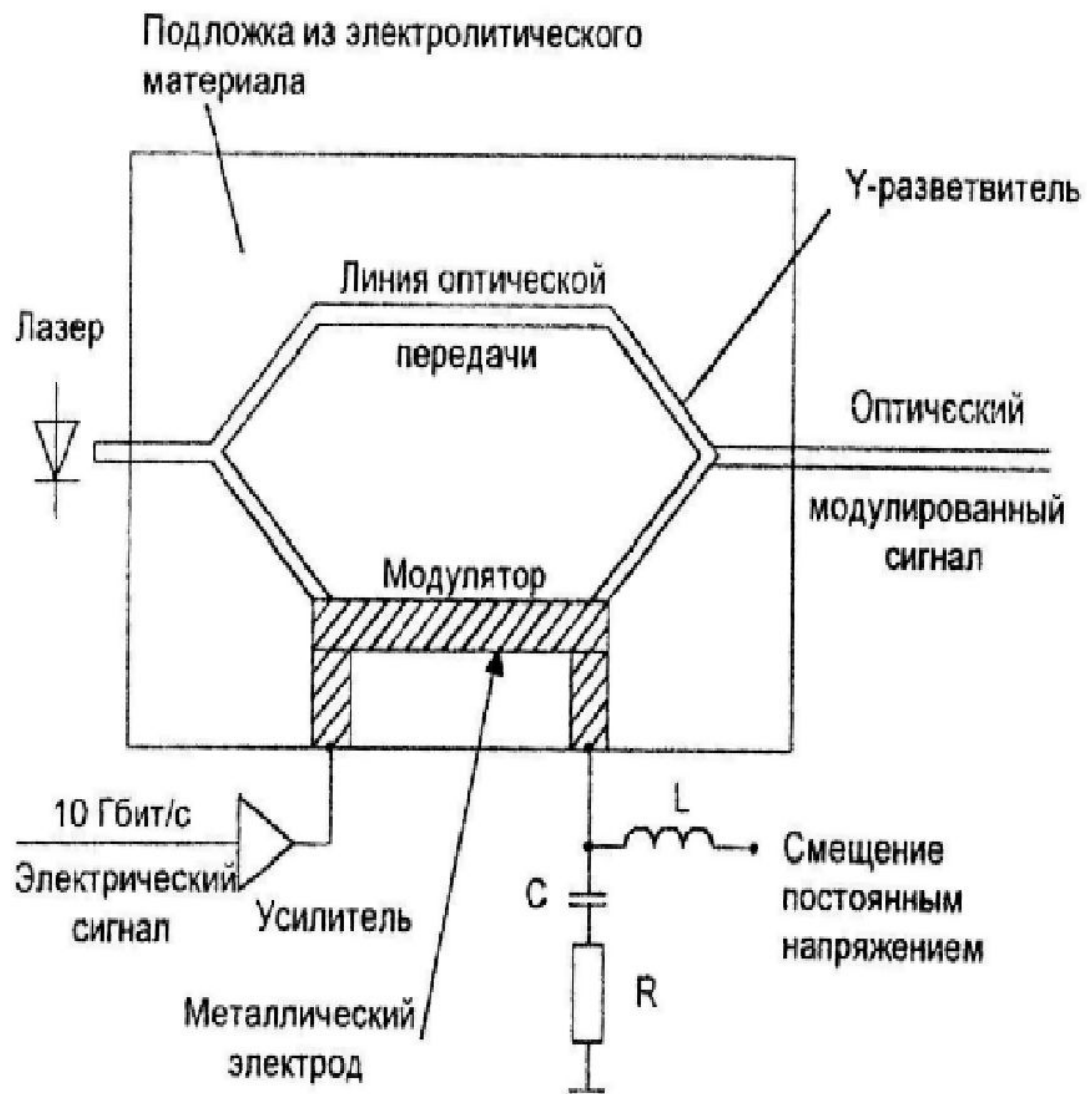
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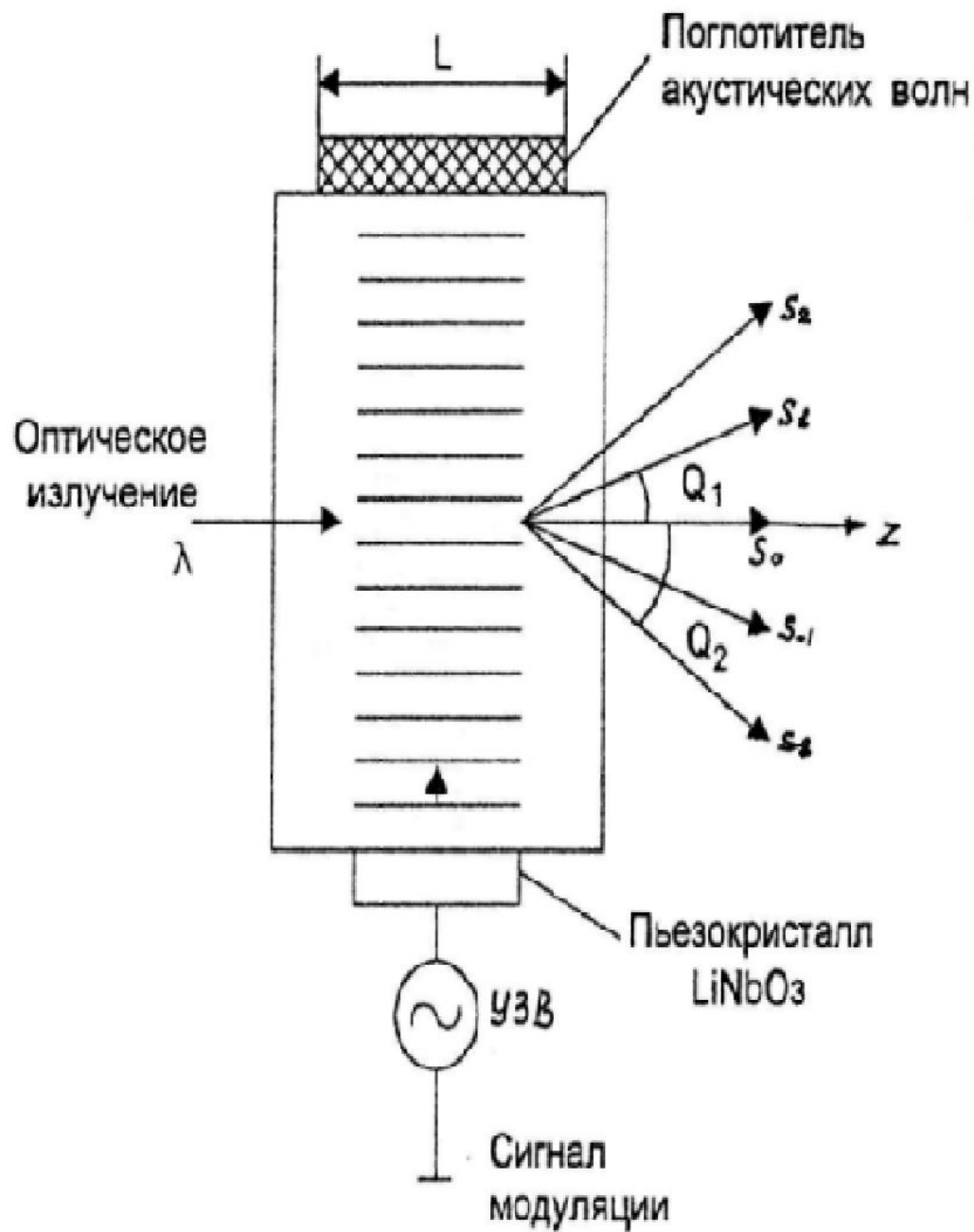


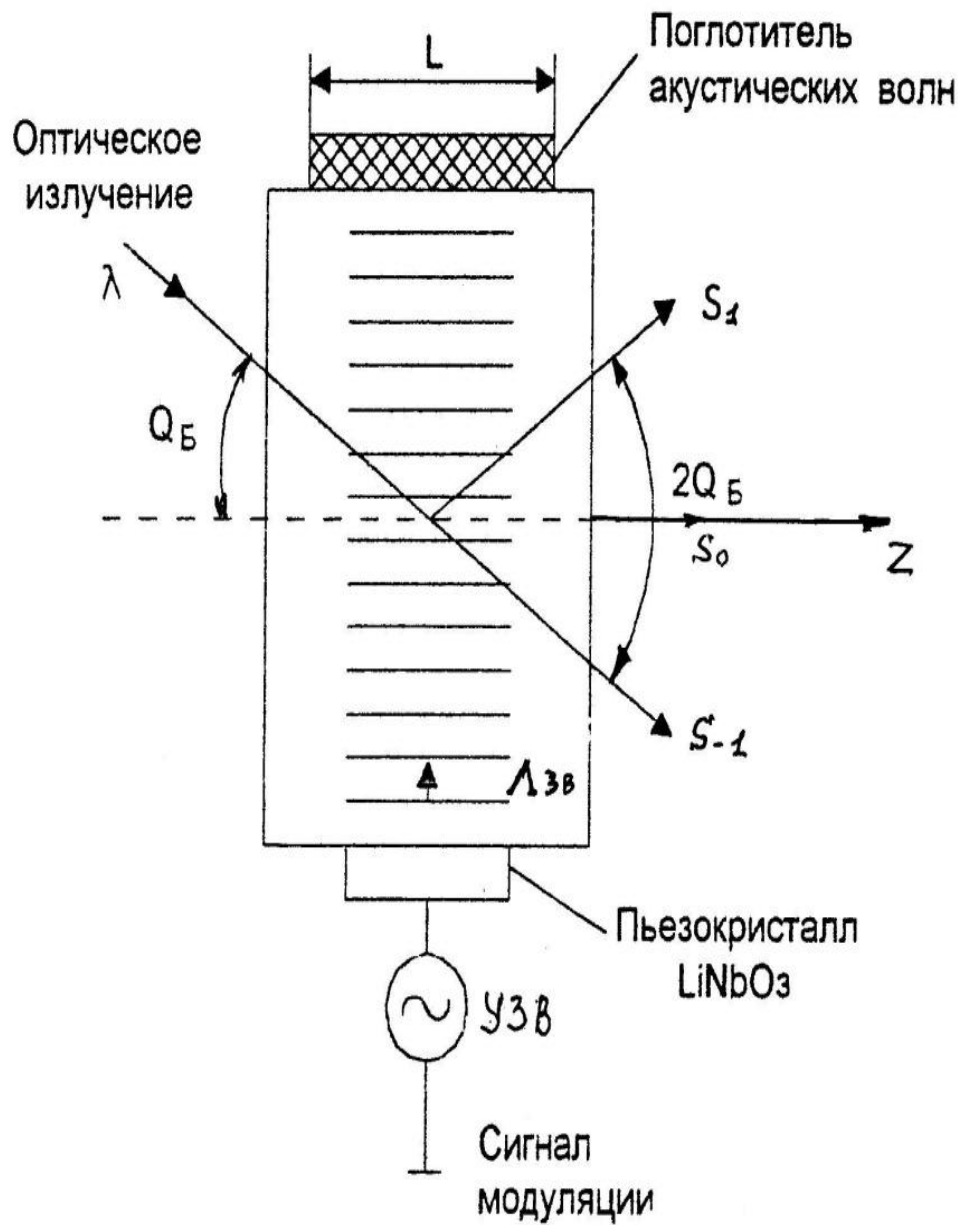
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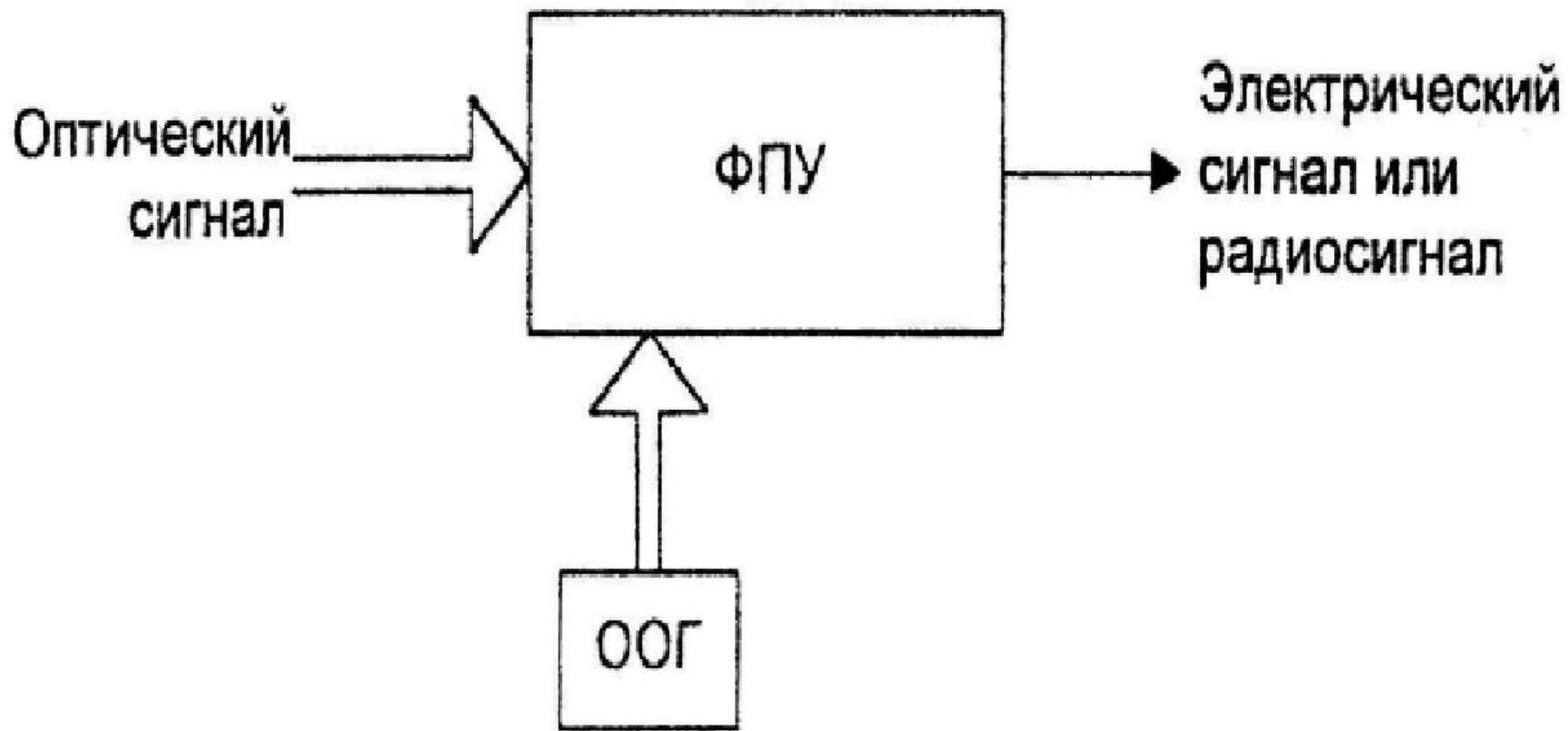
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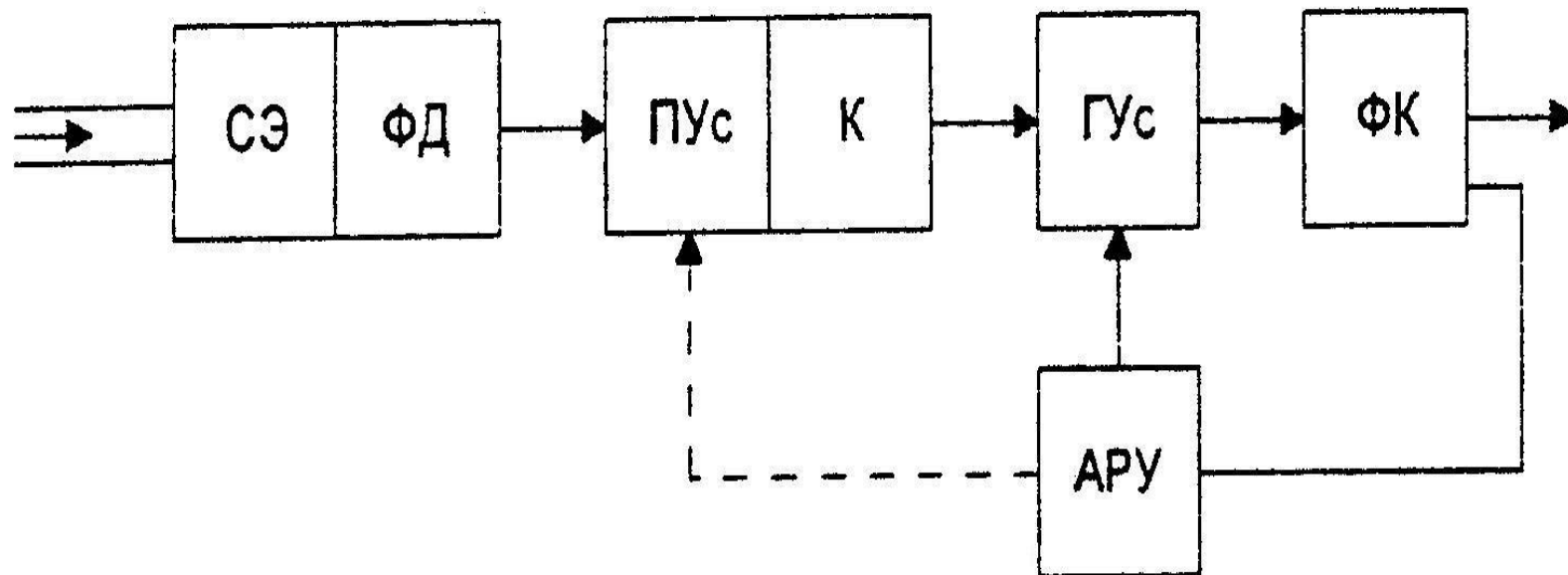




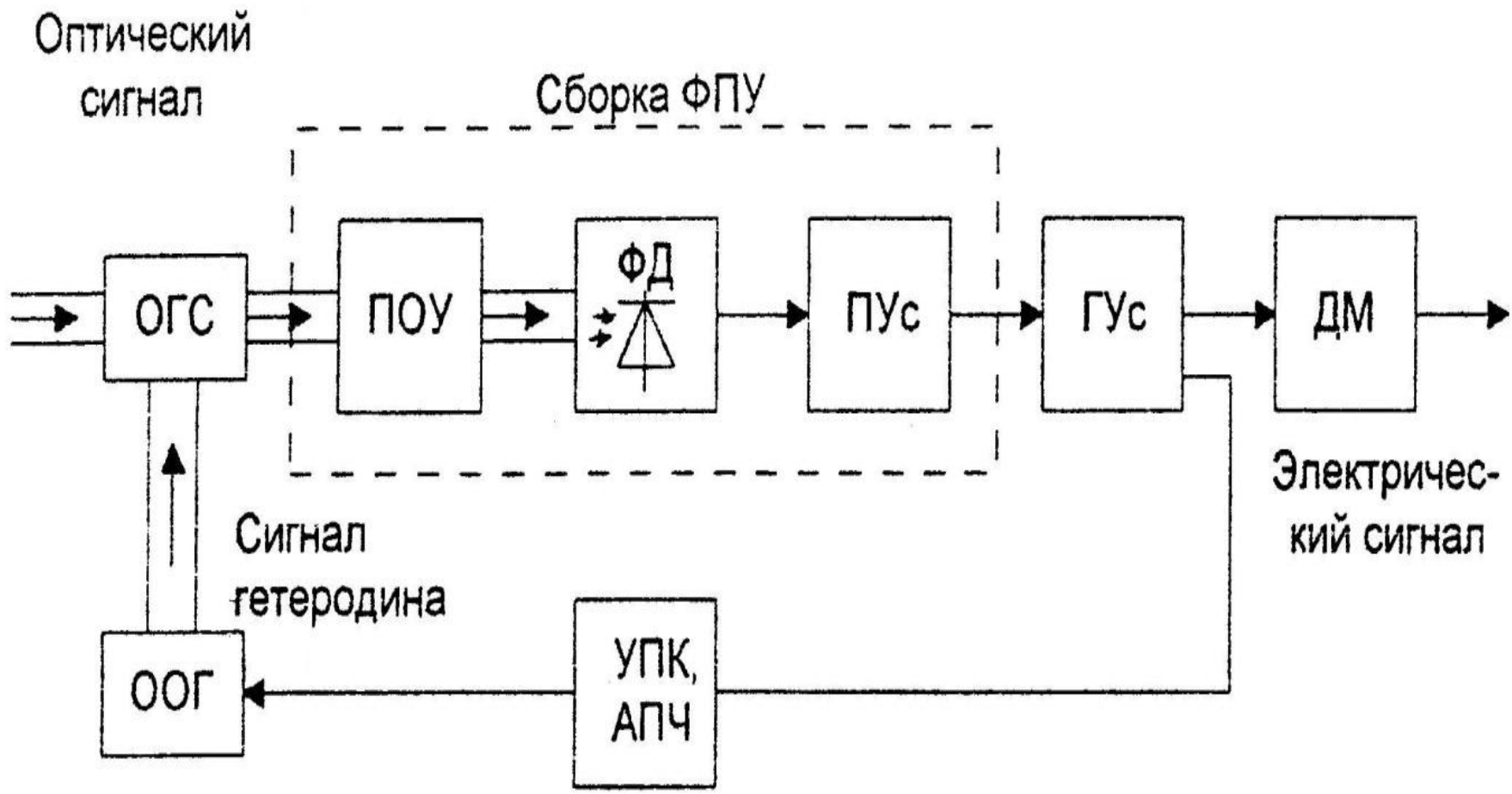


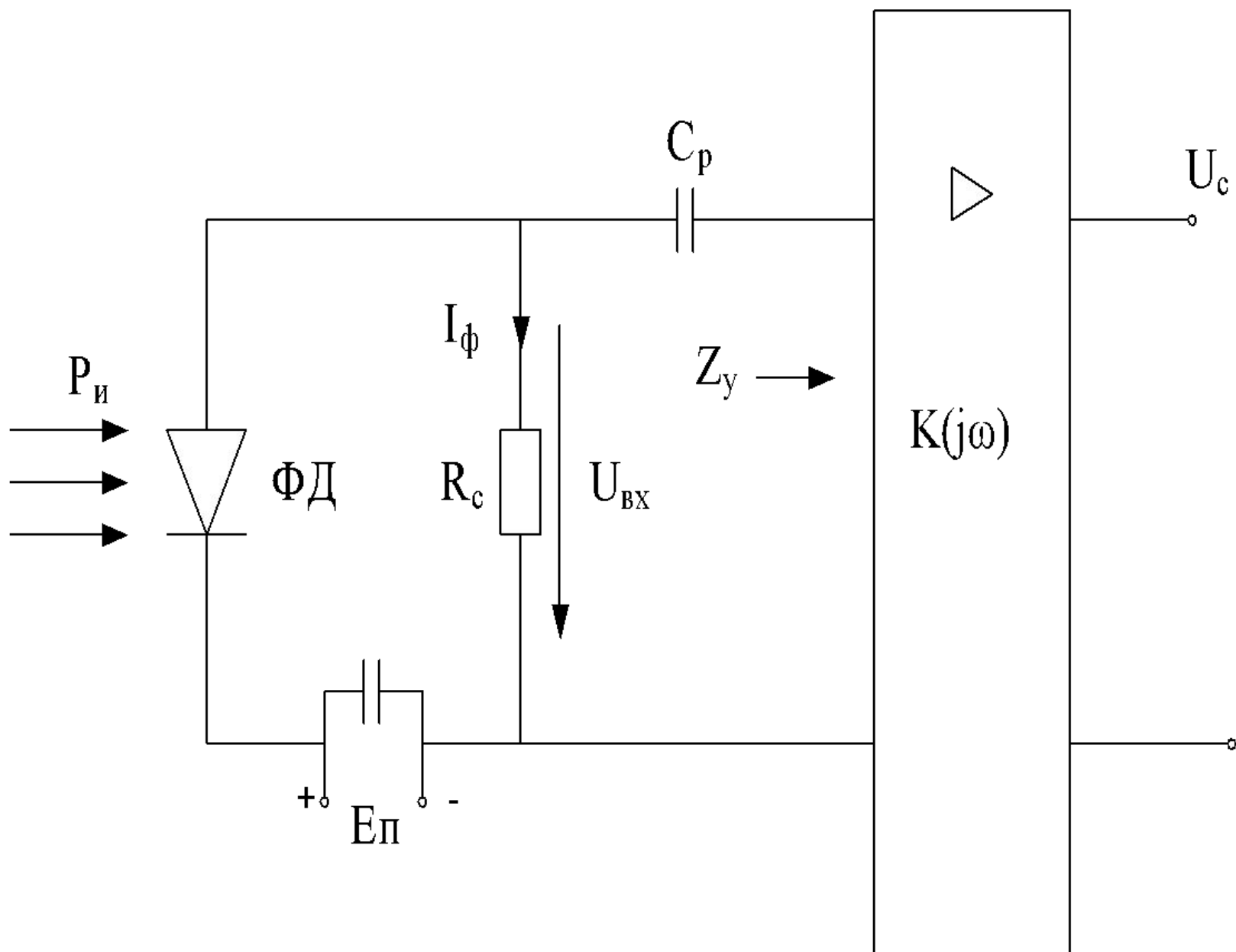


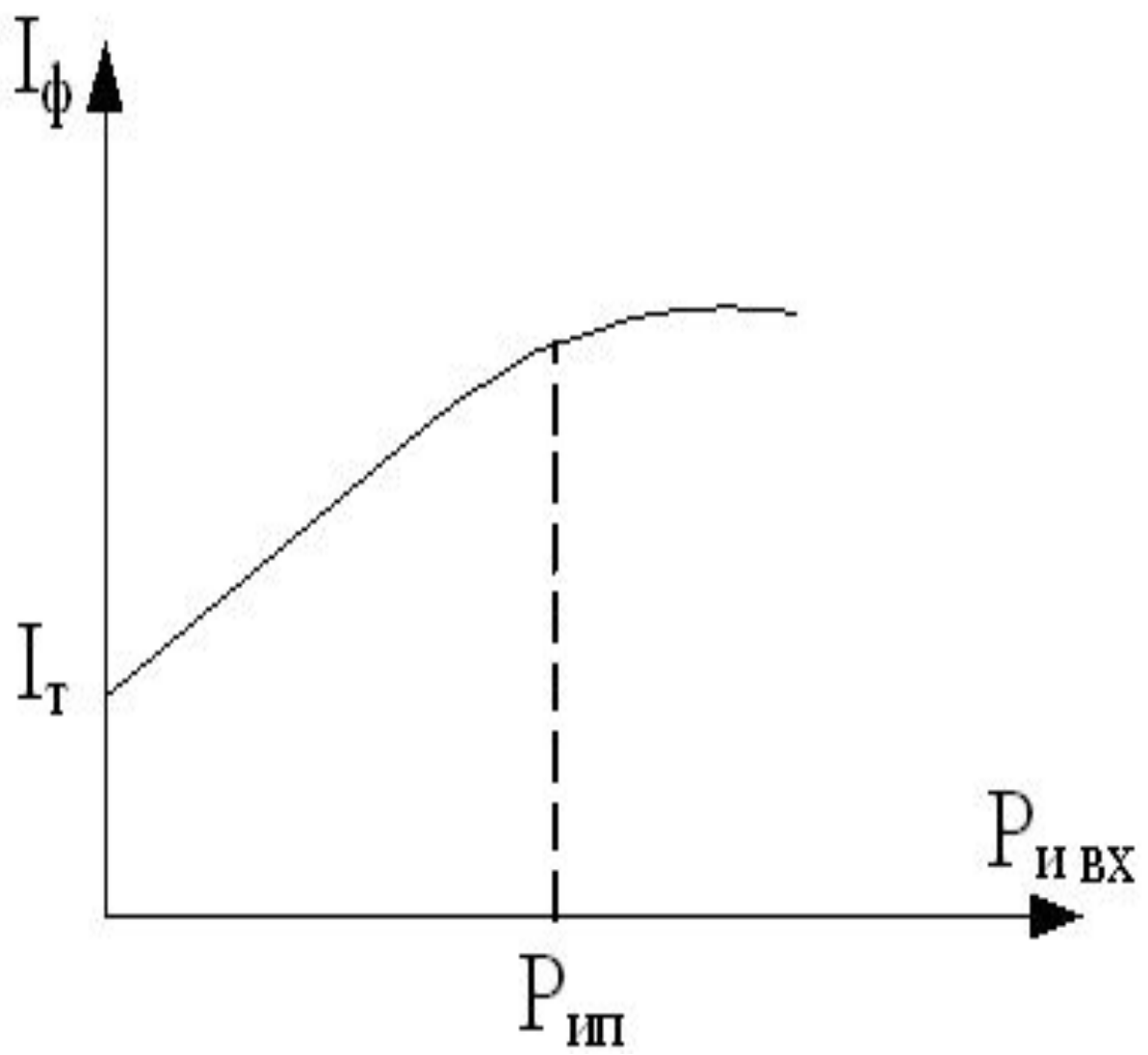
Оптический
сигнал

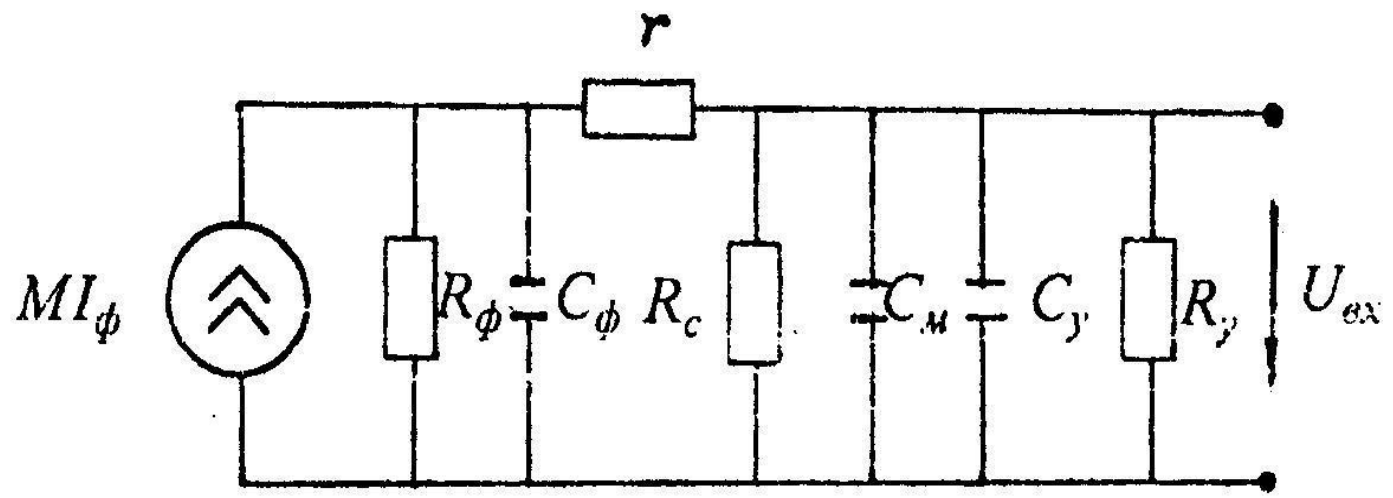


Сигнал для
последующей
обработки

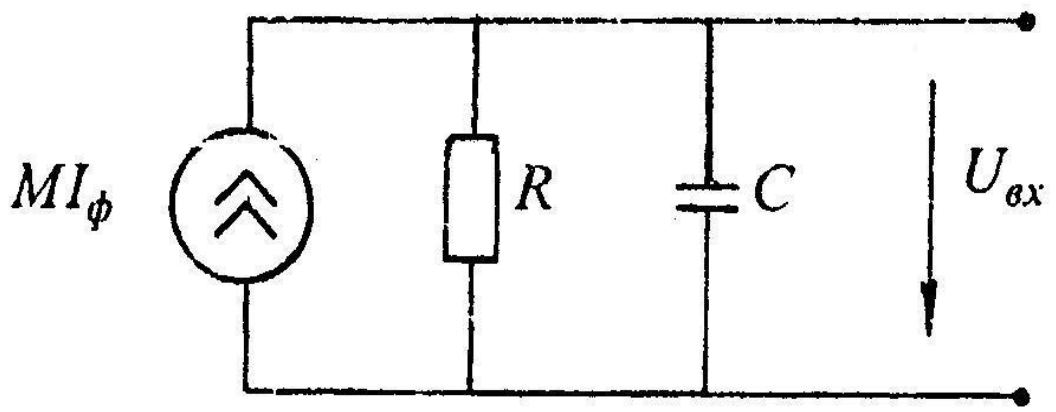




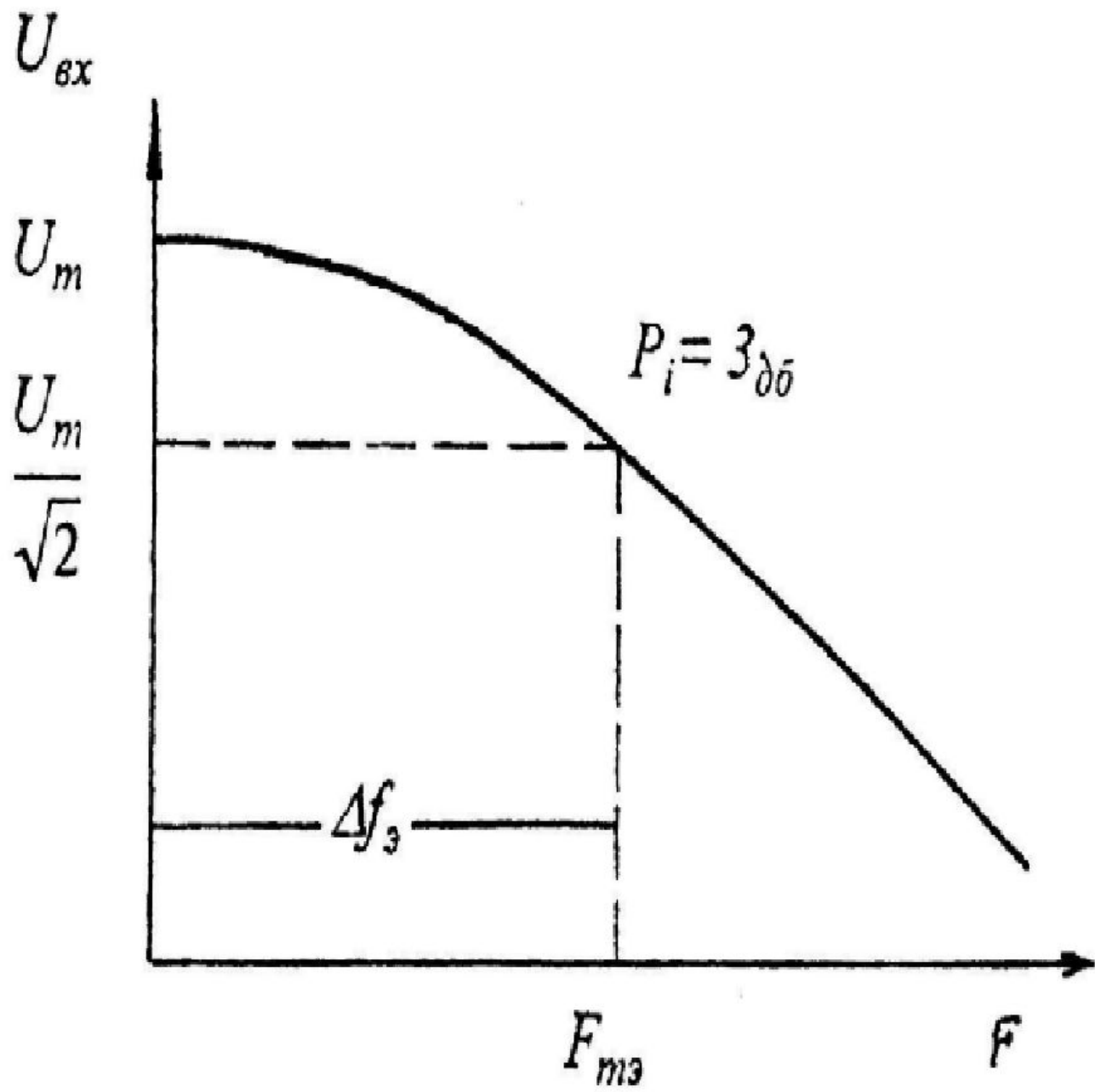


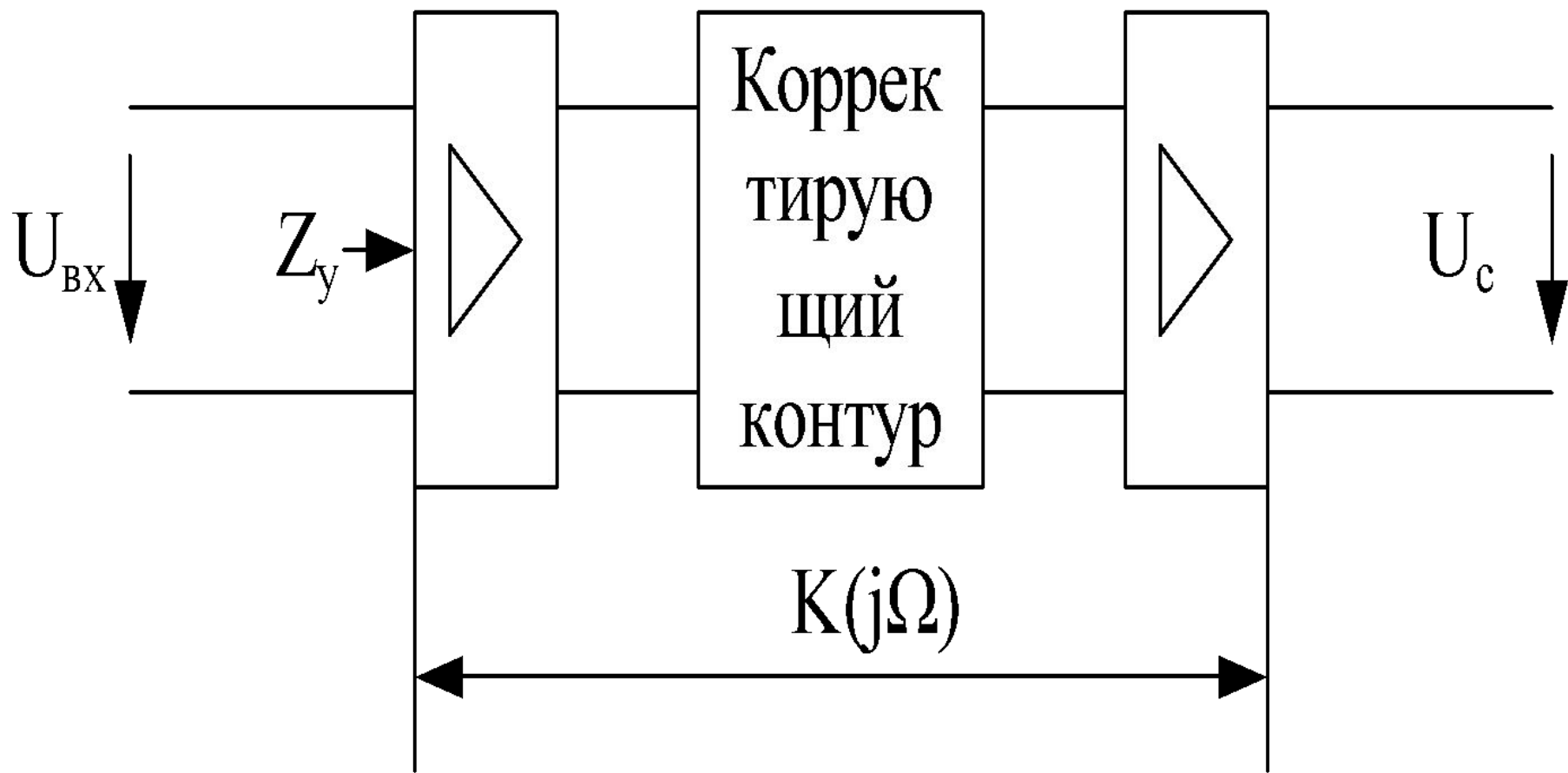


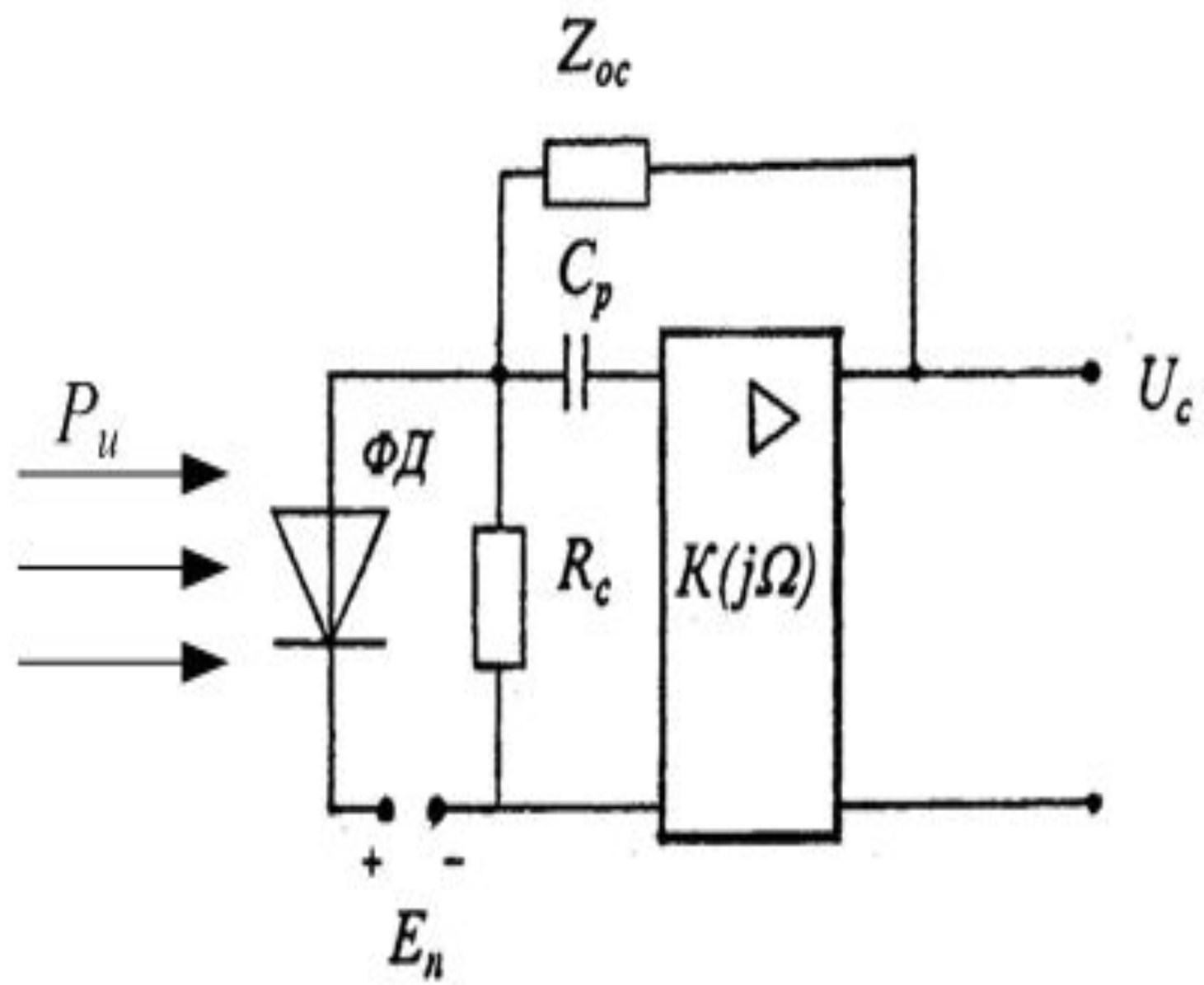
a

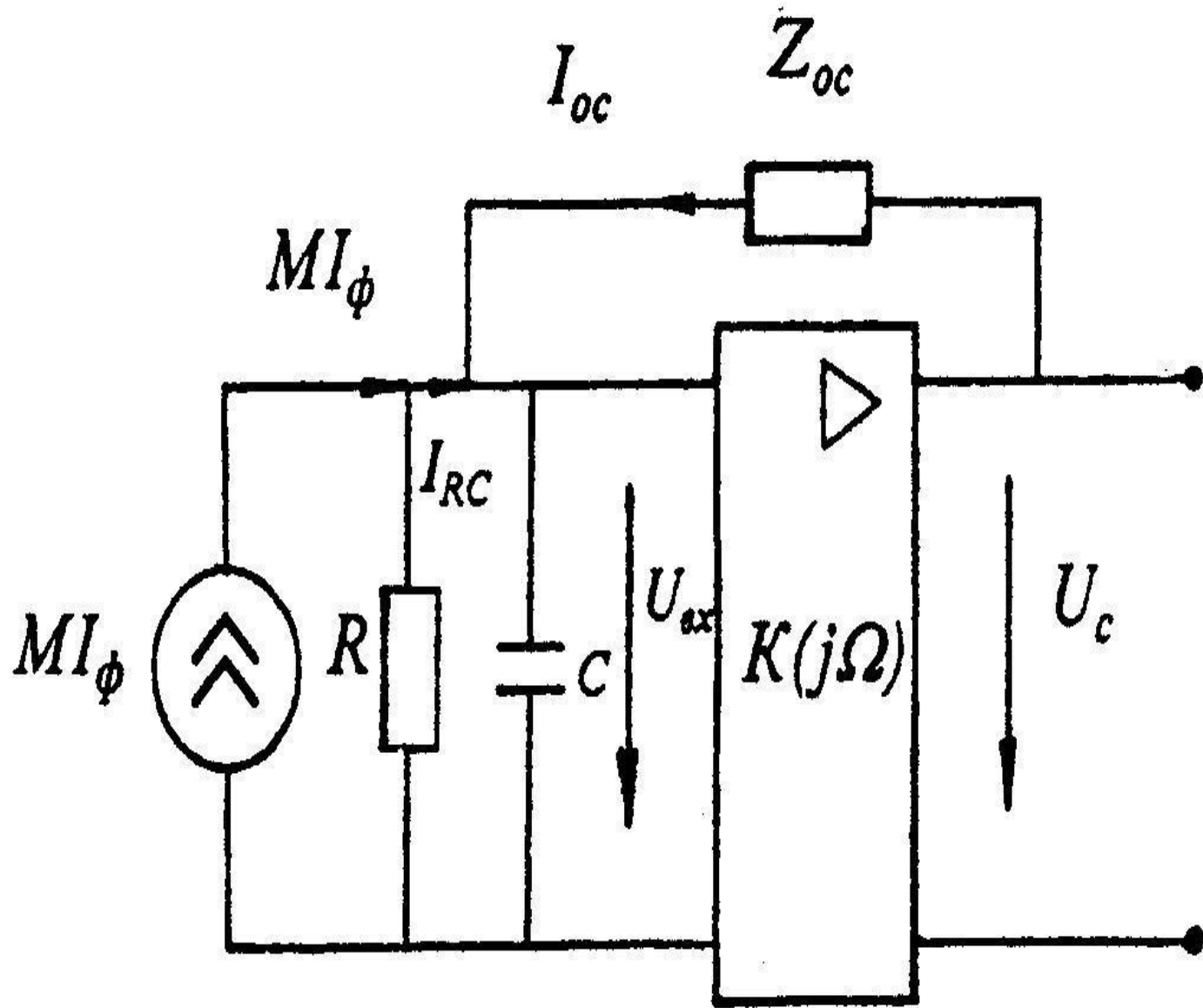


б





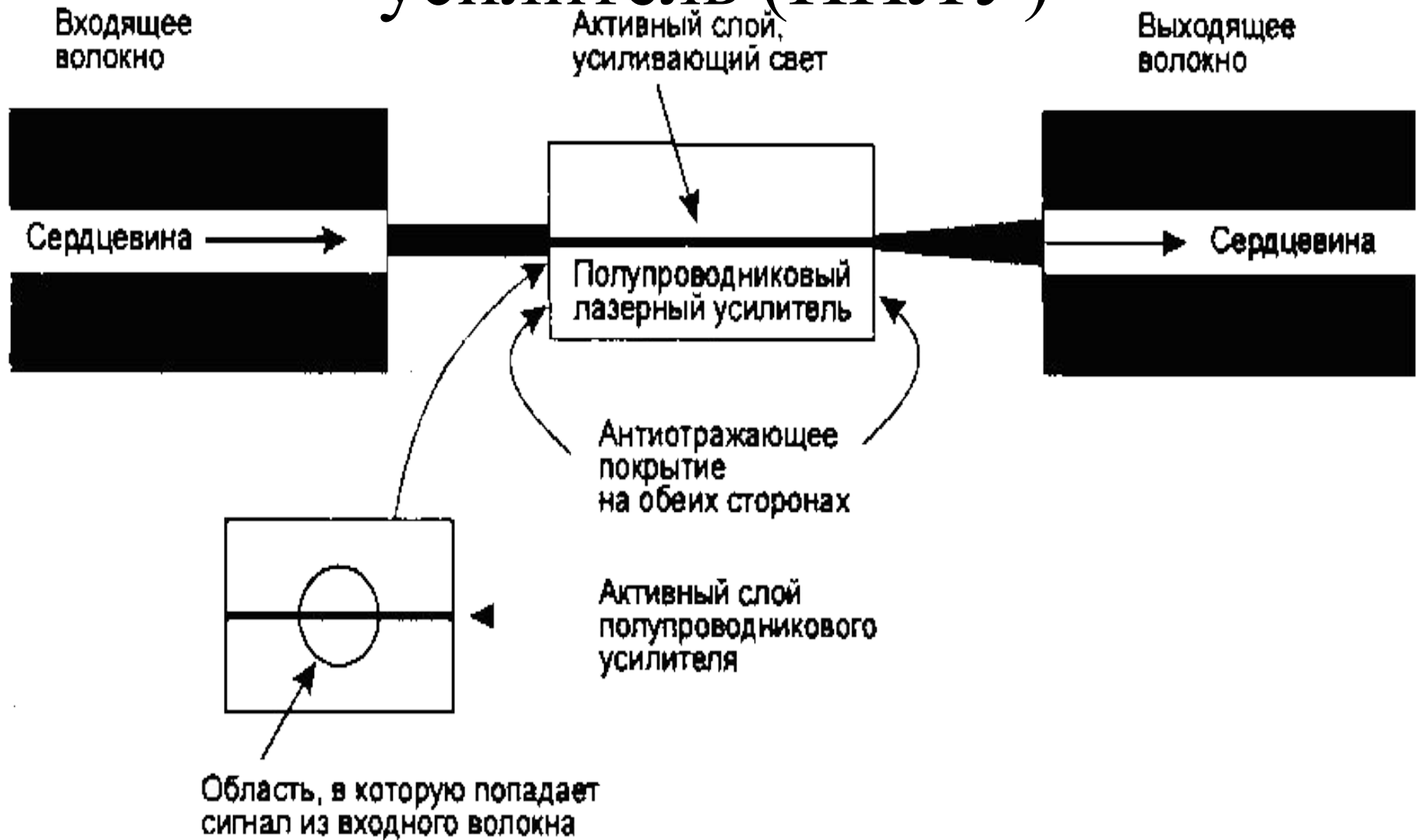




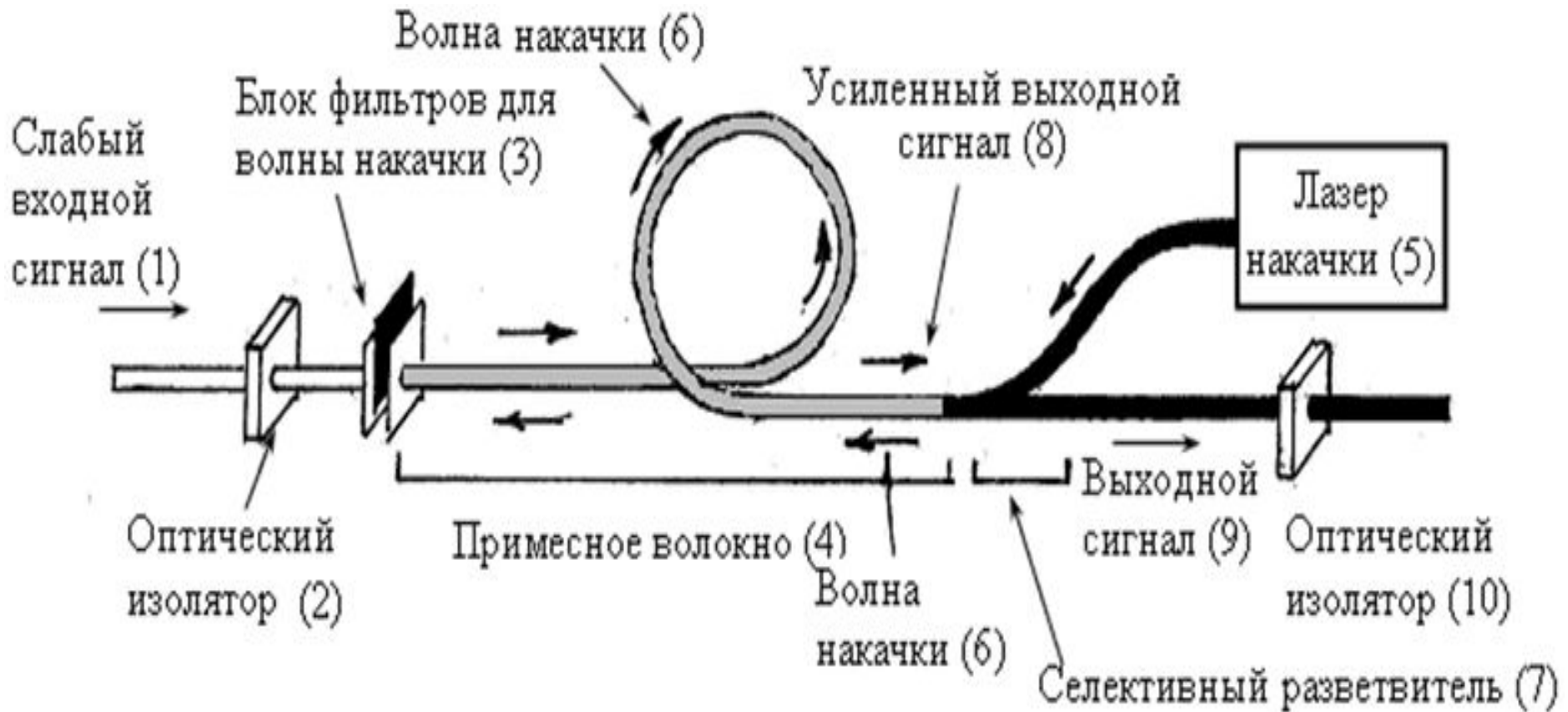
| | | | | | | | | |
|---------------|---------------------|---------------------|---------------------|---------------------|---------------------|----------------------|----------------------|-----------------------|
| ε | 6 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| BER | $1,5 \cdot 10^{-3}$ | $3,6 \cdot 10^{-6}$ | $3,0 \cdot 10^{-7}$ | $2,0 \cdot 10^{-9}$ | $1,0 \cdot 10^{-9}$ | $4,0 \cdot 10^{-11}$ | $1,3 \cdot 10^{-12}$ | $3,25 \cdot 10^{-14}$ |
| A,дБ | 15,3 | 19,1 | 20 | 20,8 | 21,6 | 22,2 | 22,9 | 23,5 |

Оптические усилители

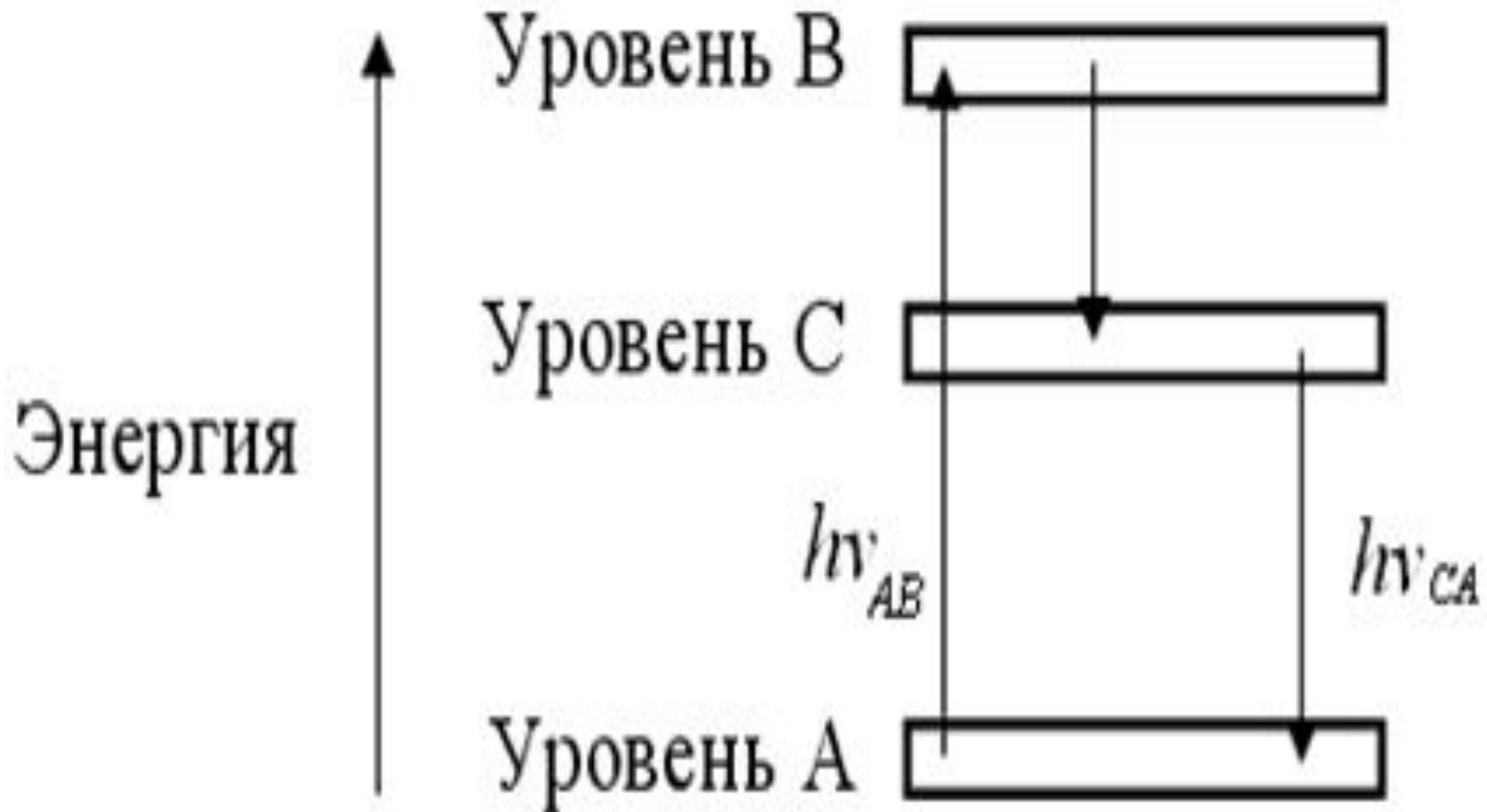
Полупроводниковый лазерный усилитель (ПЛУ)



Оптический усилитель на примесном волокне



Энергетическая диаграмма уровней атомной системы усилителя на примесном волокне



Усилитель на кремниевом
волокне, легированном
эрбием

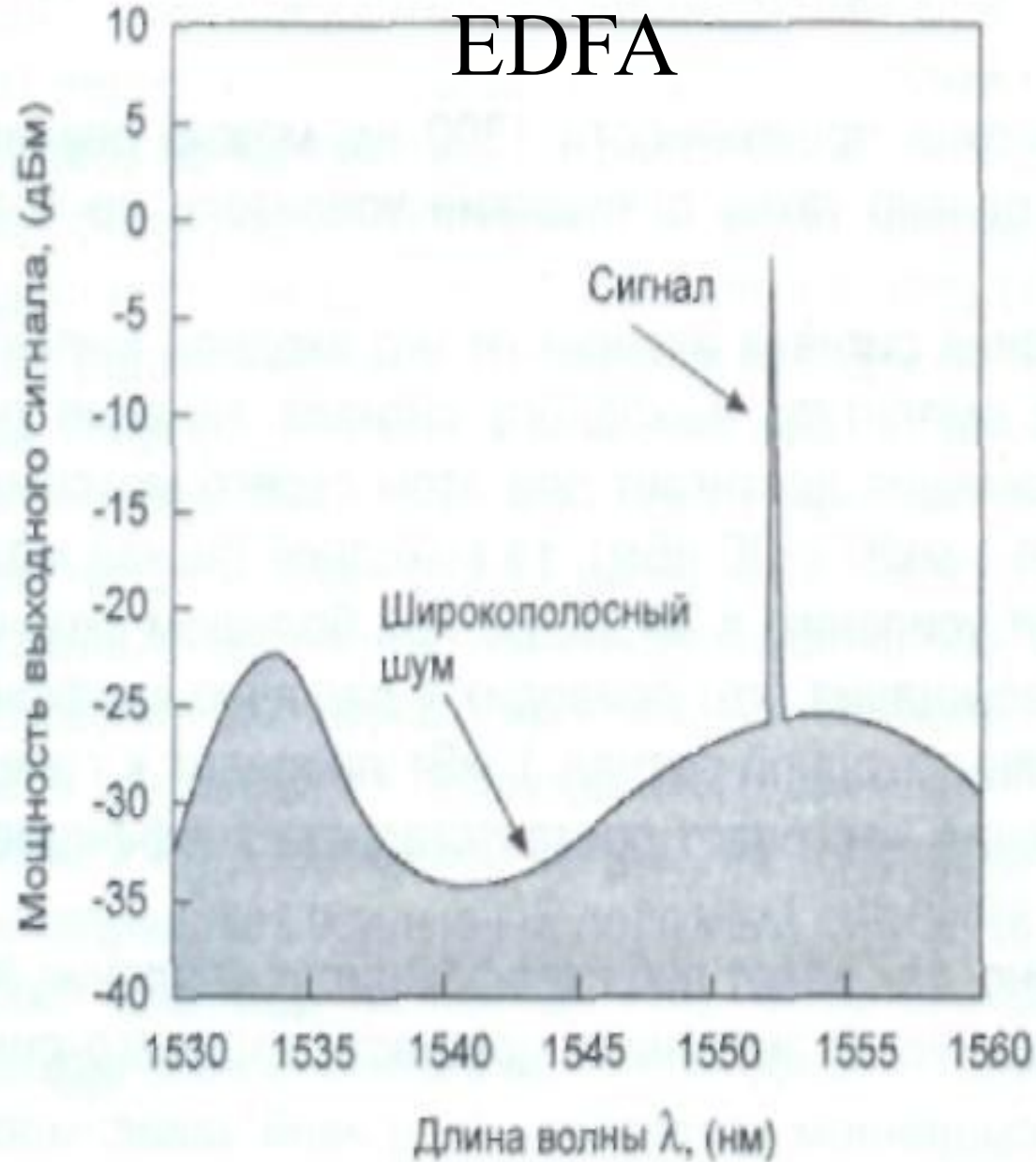
или

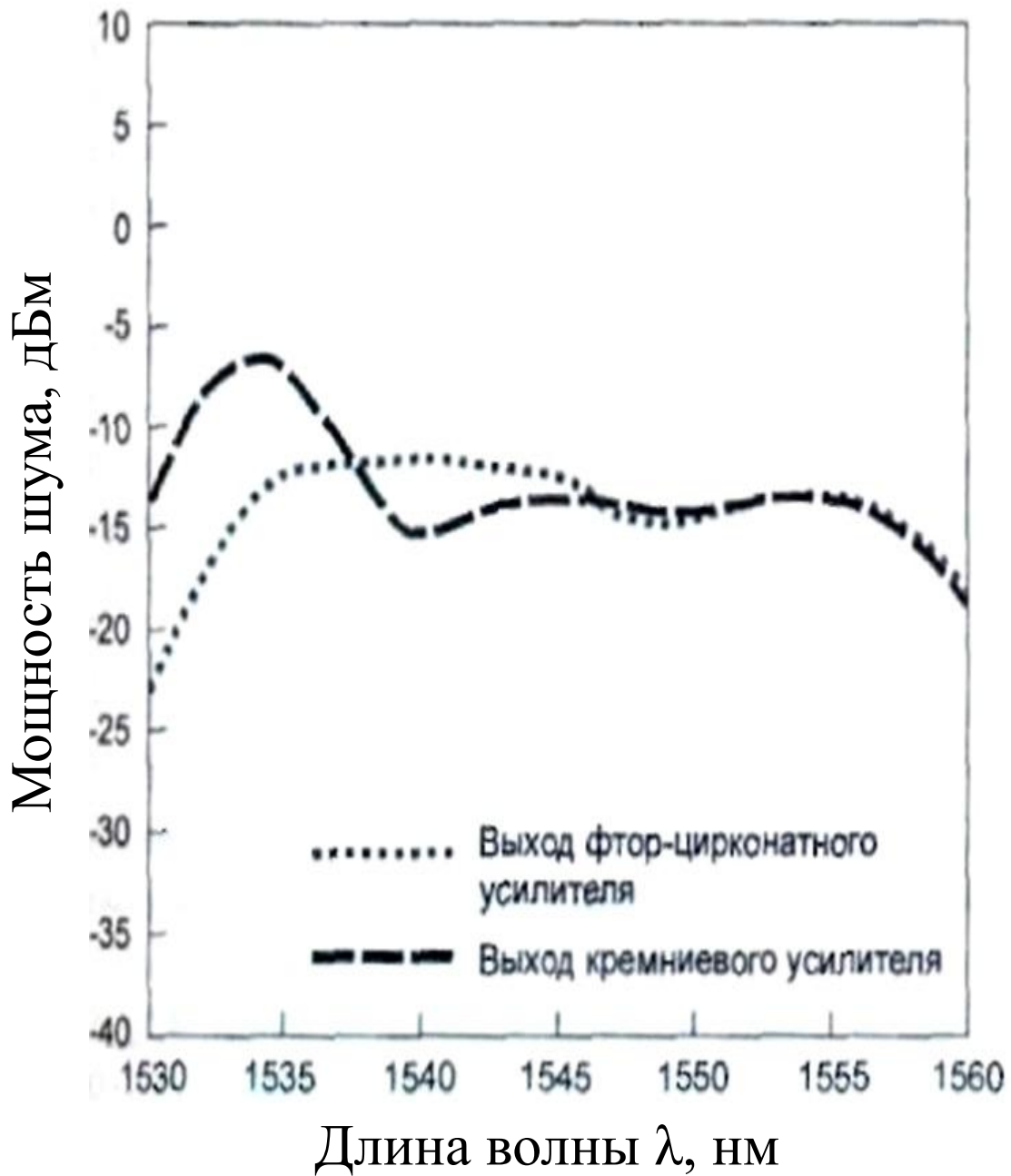
усилитель EDFA
(Erbium Doped Fiber
Amplifier)

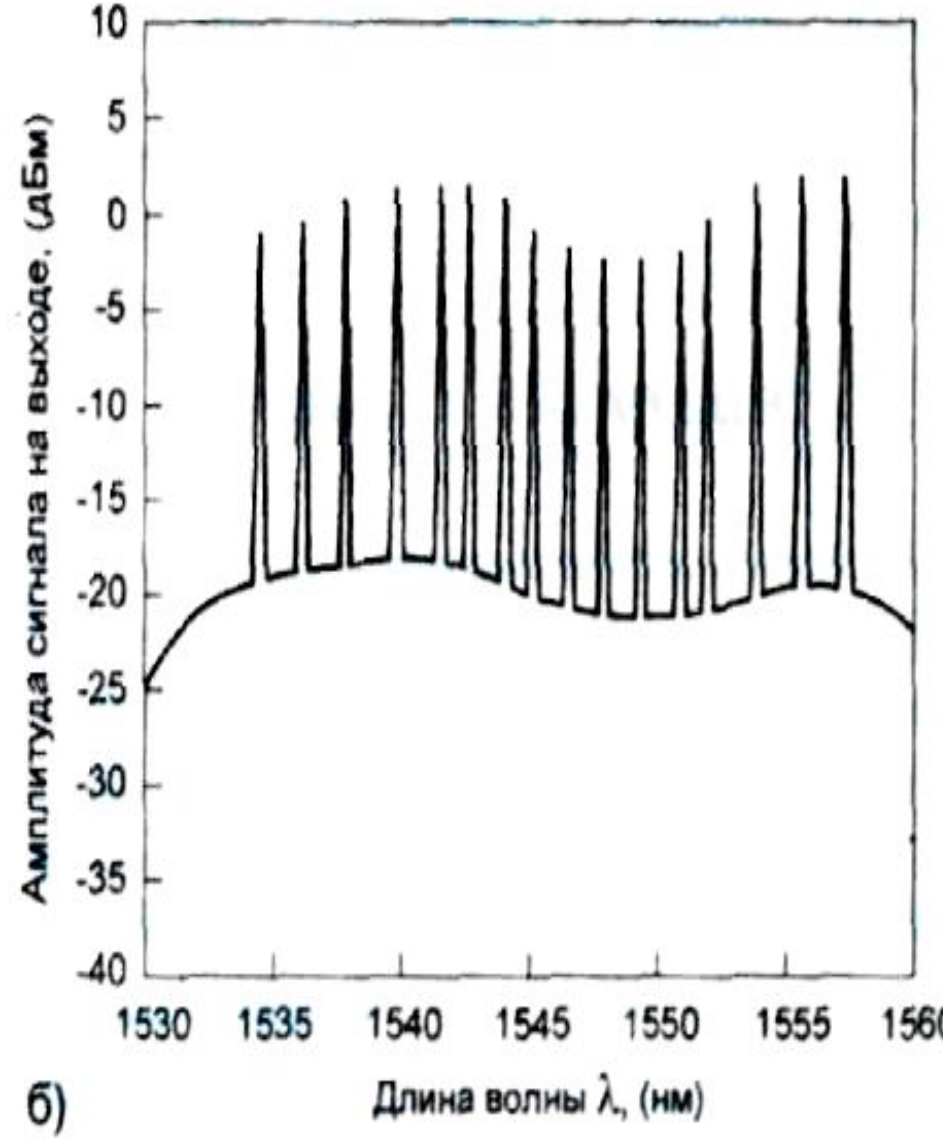
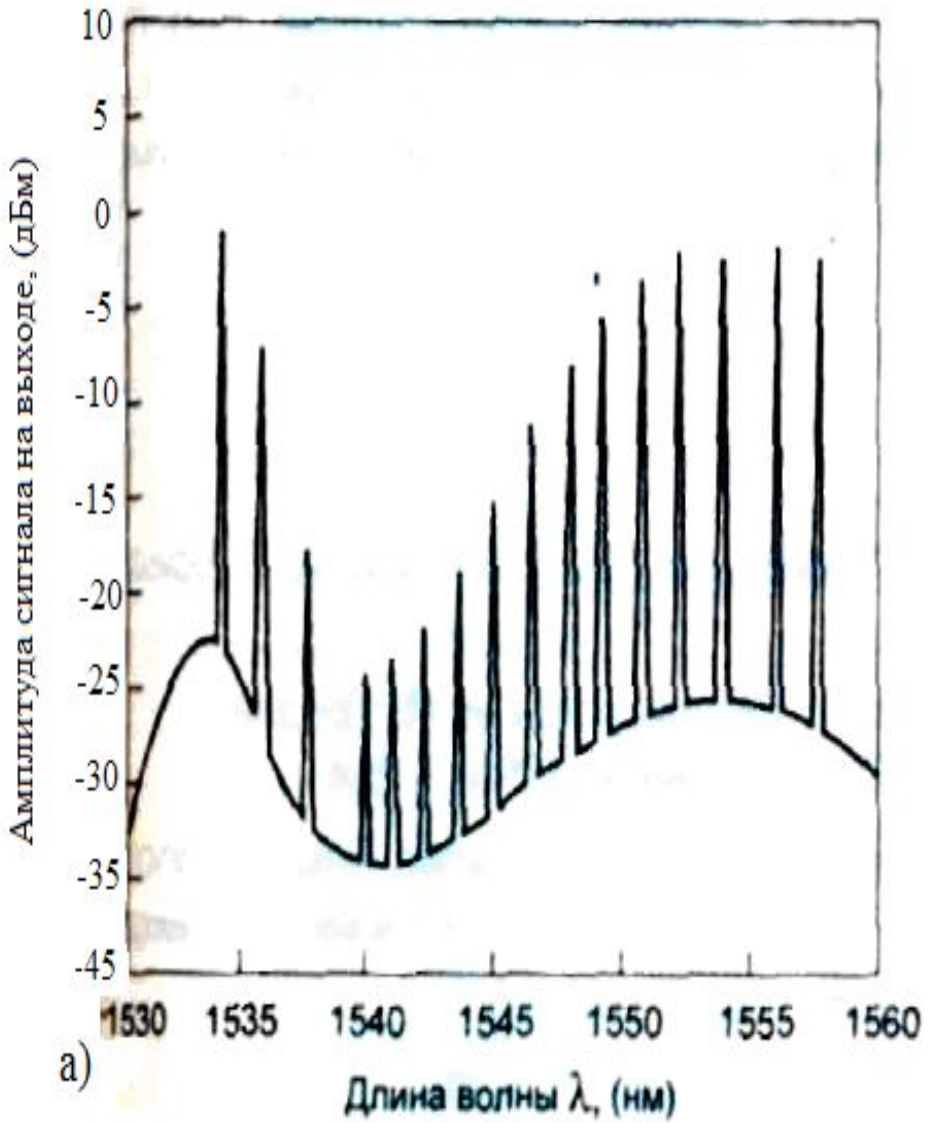
Коэффициент усиления кремниевого EDFA при различных значениях мощности входного оптического сигнала



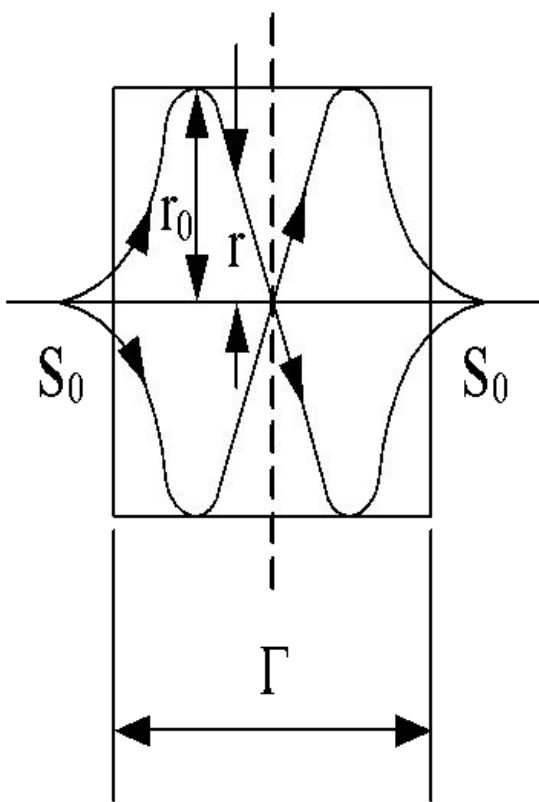
Мощность выходного сигнала и шума в EDFA





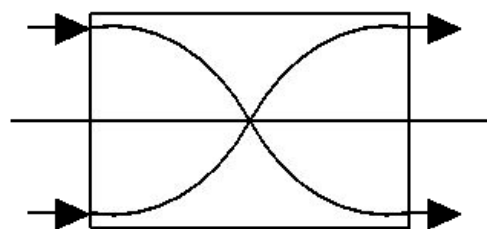
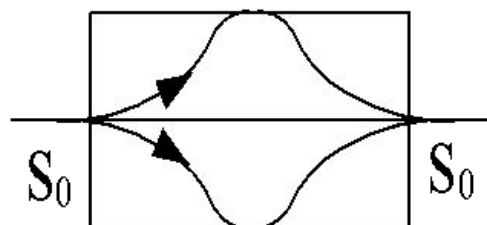


ПАССИВНЫЕ
ОПТИЧЕСКИЕ
КОМПОНЕНТЫ
ДЛЯ ВОСП



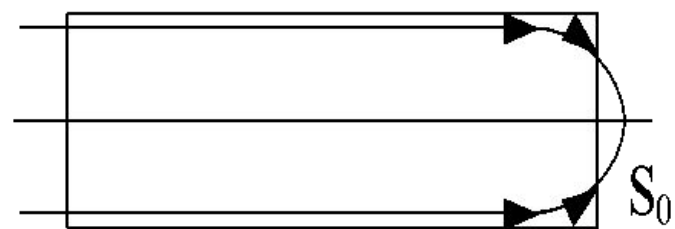
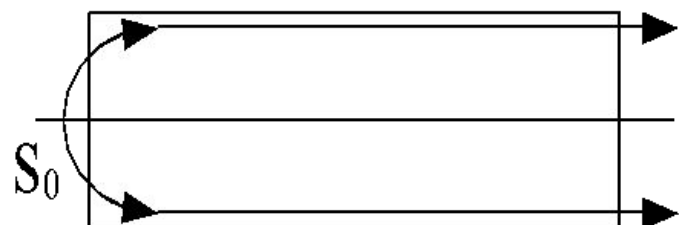
$$\Gamma = \frac{2\pi}{g}$$

a)



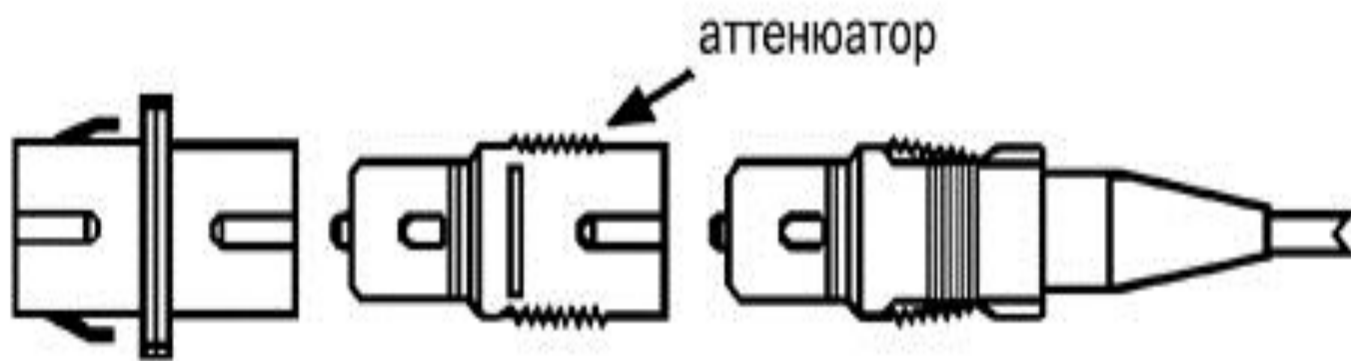
$$\Gamma = \frac{\pi}{g}$$

б)

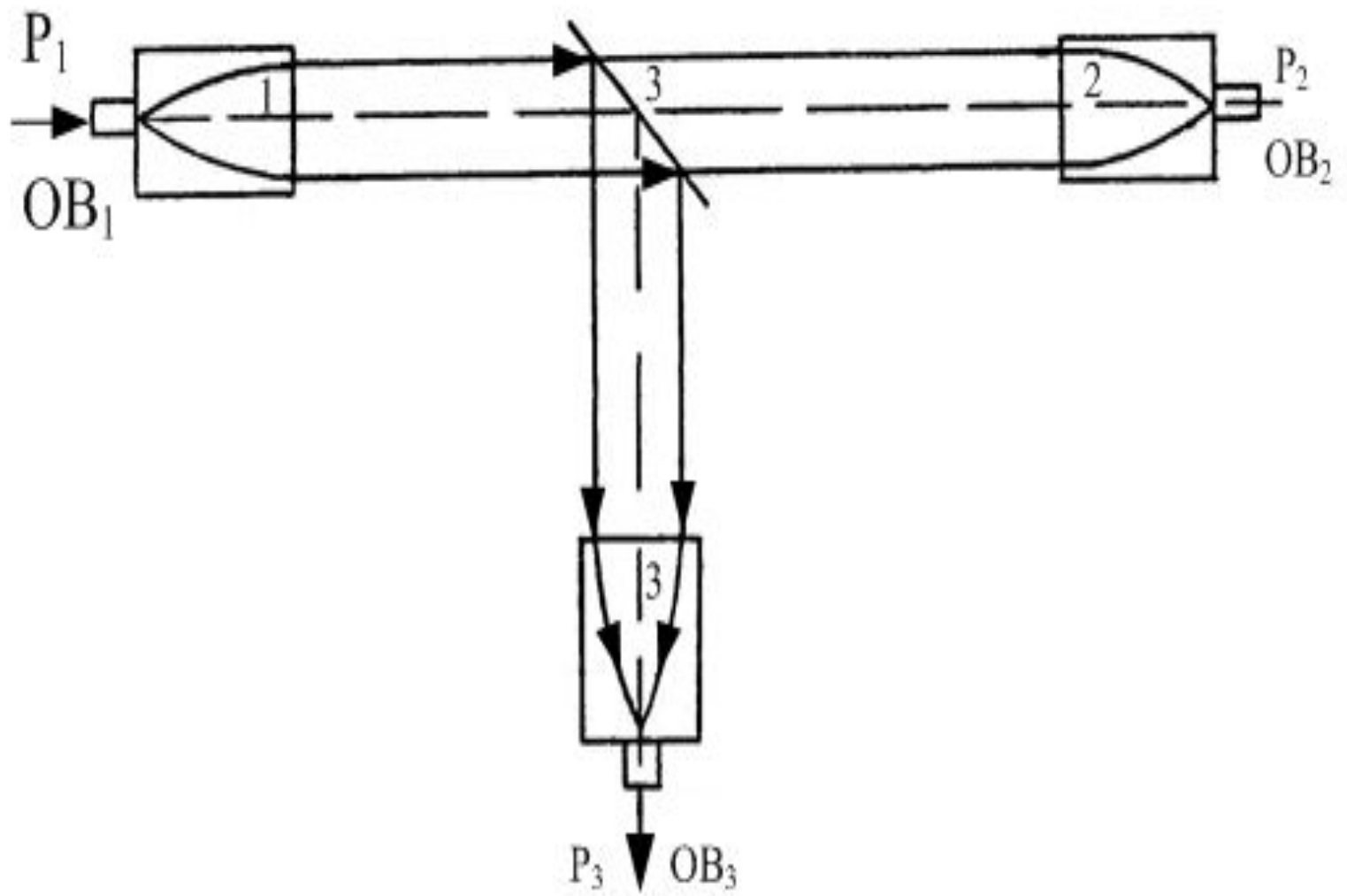


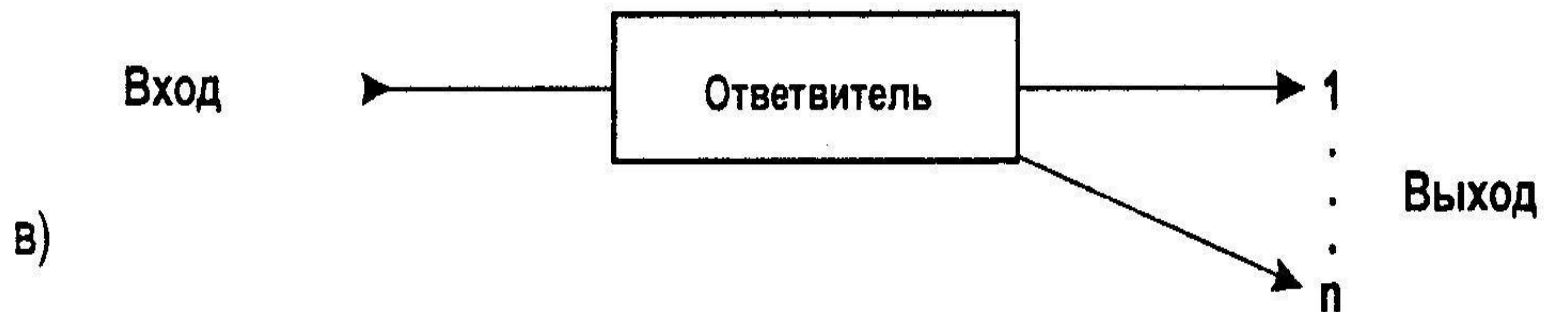
$$\Gamma = \frac{\pi}{2g}$$

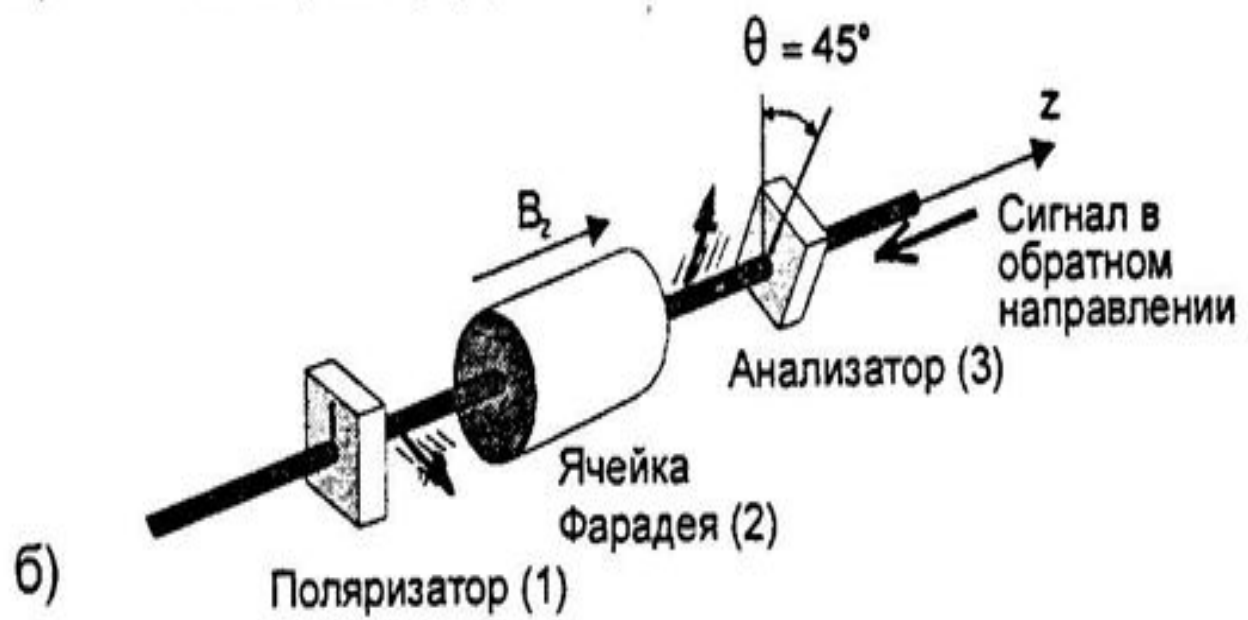
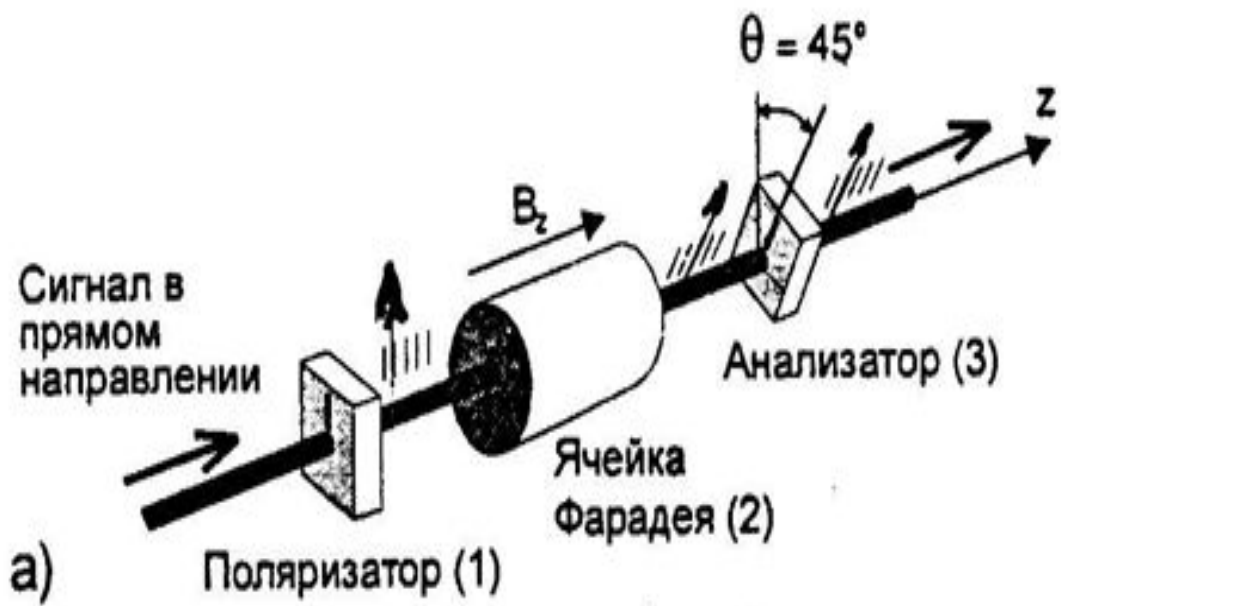
в)

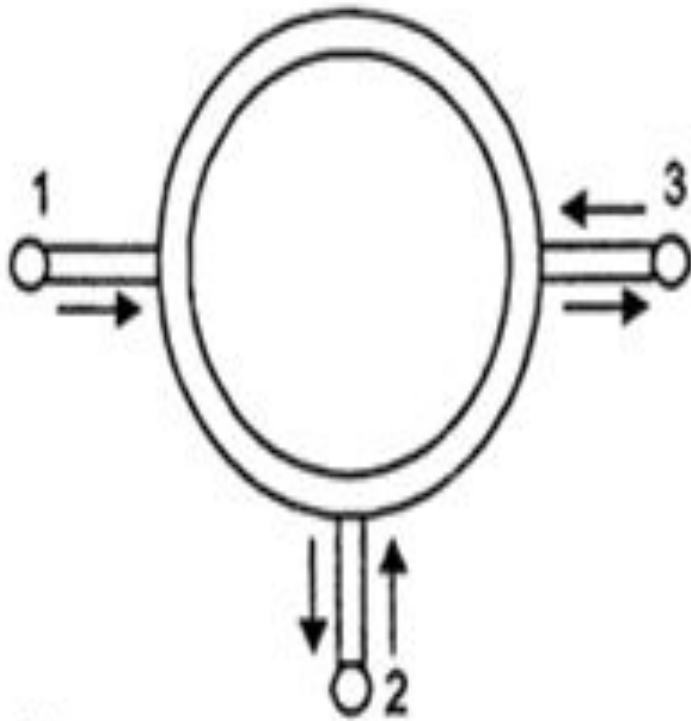




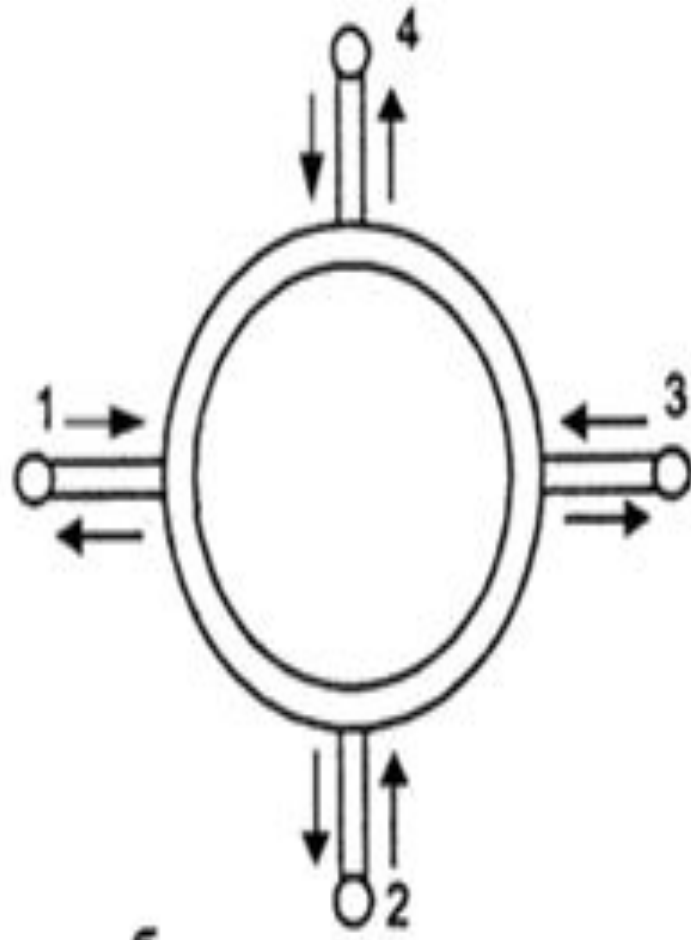




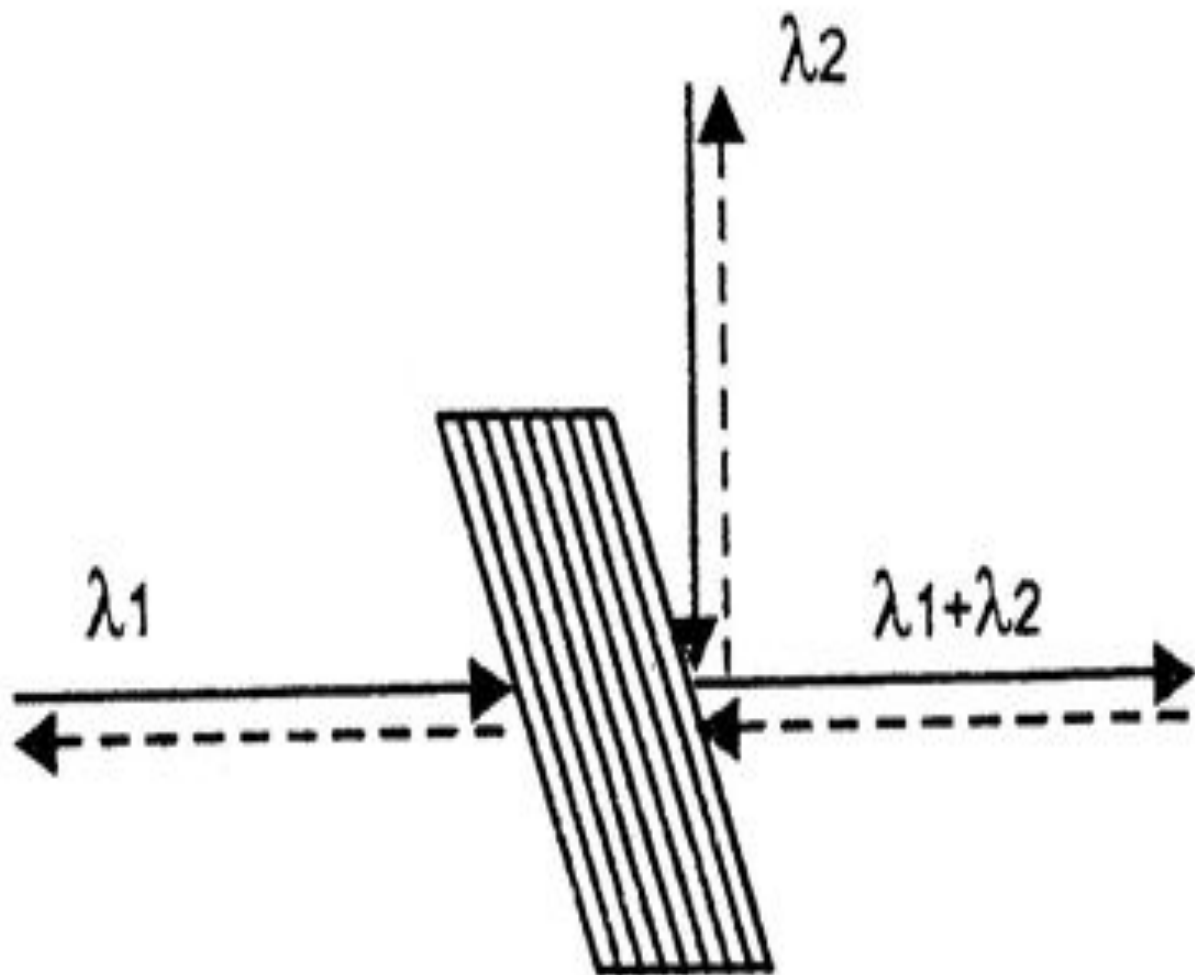


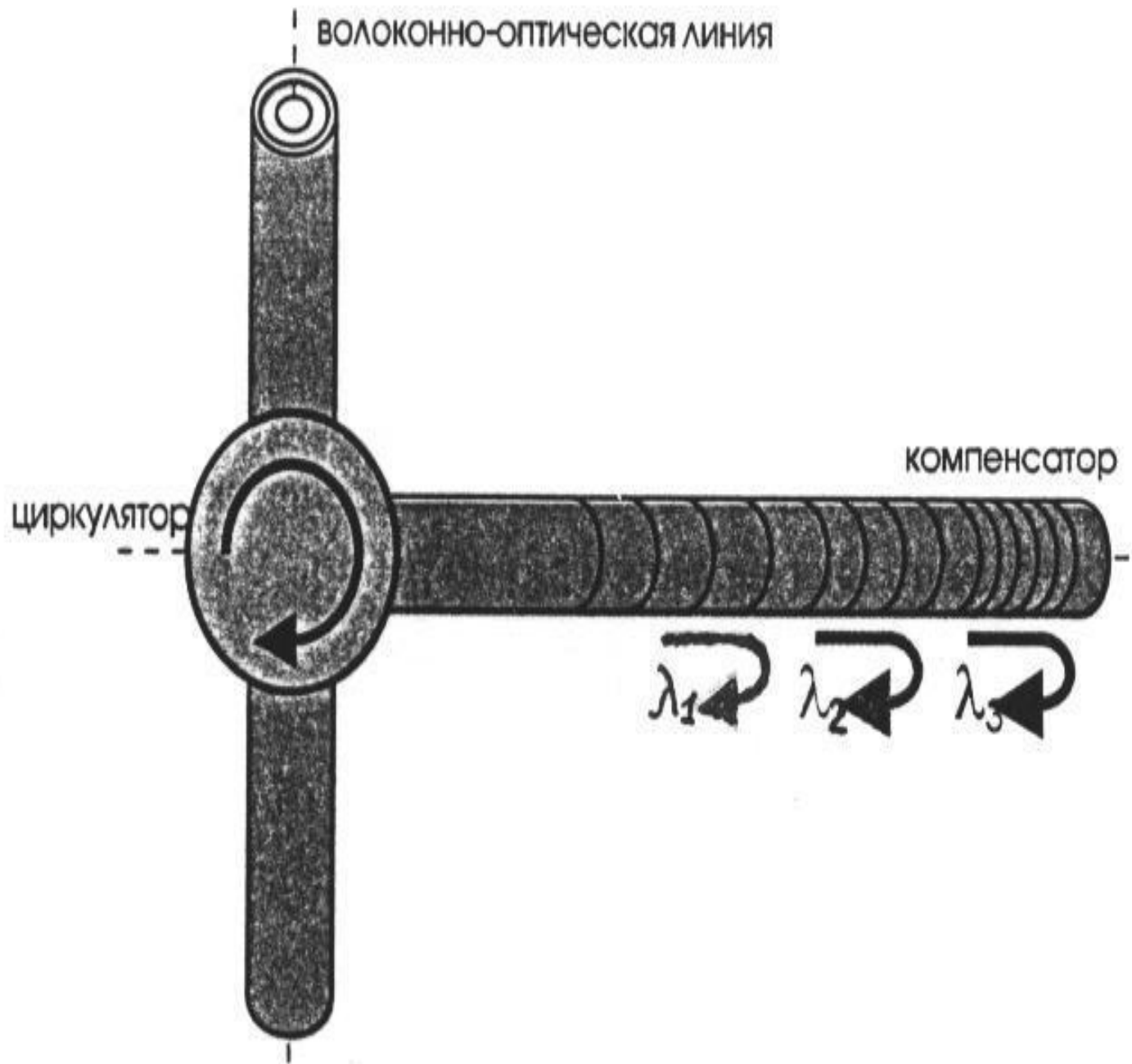


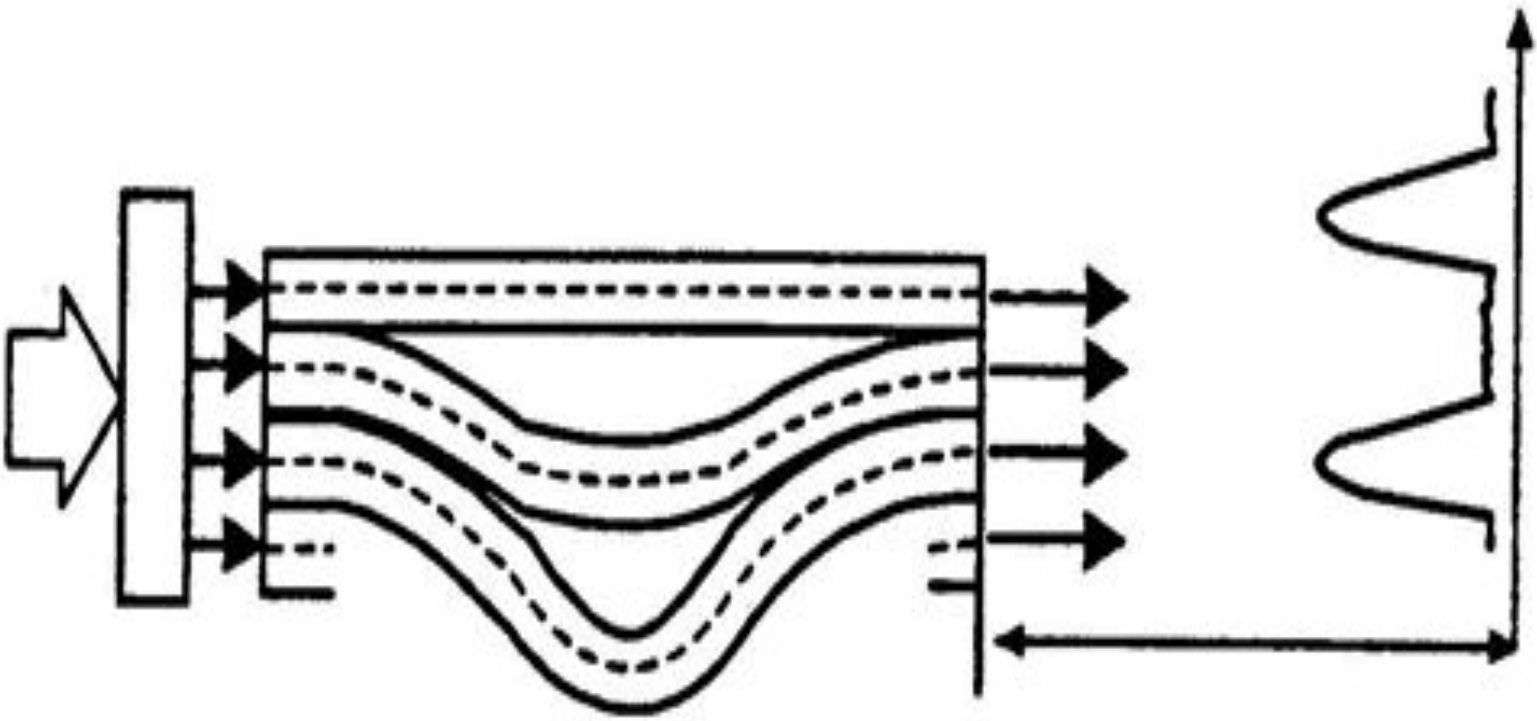
a

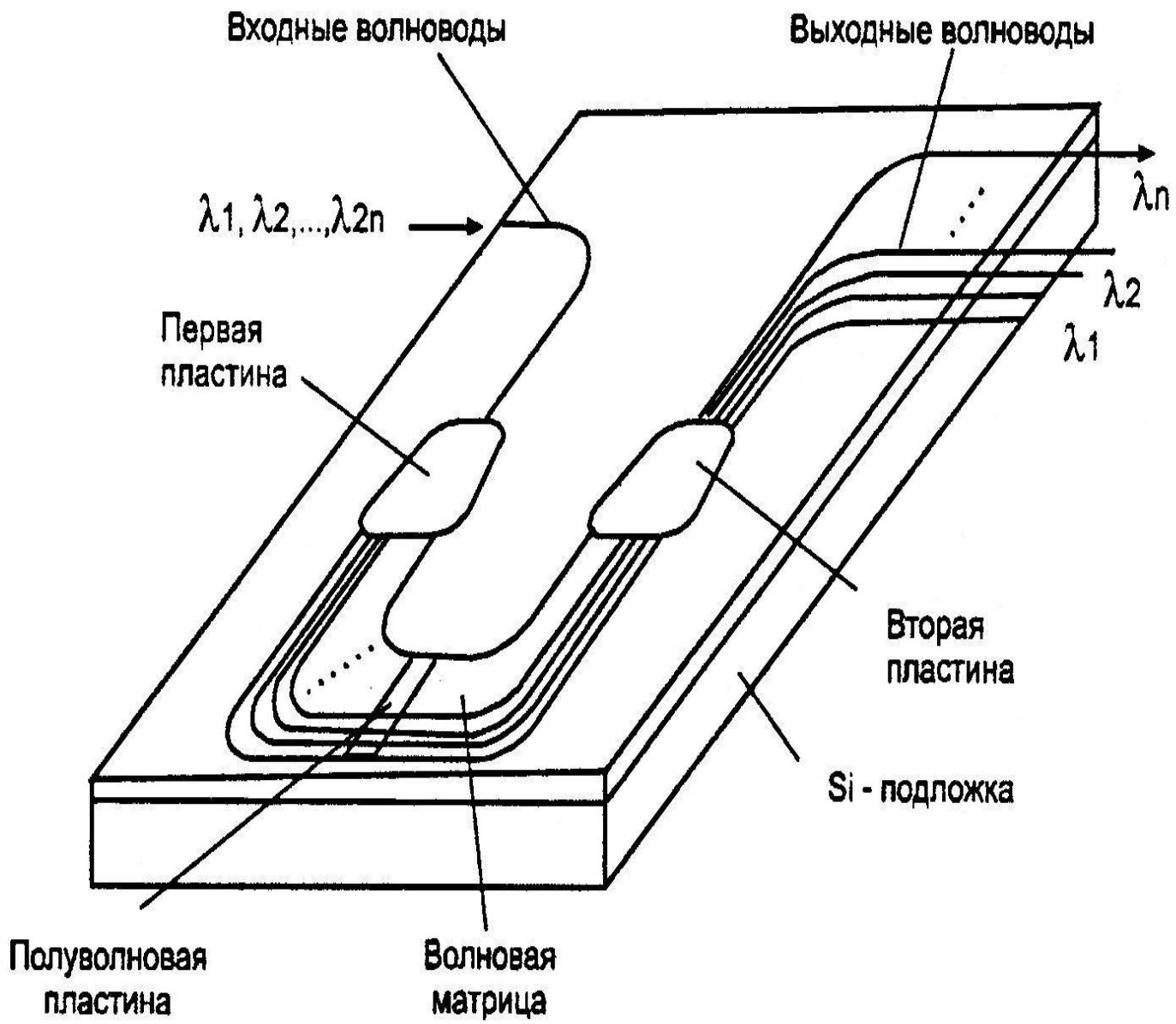


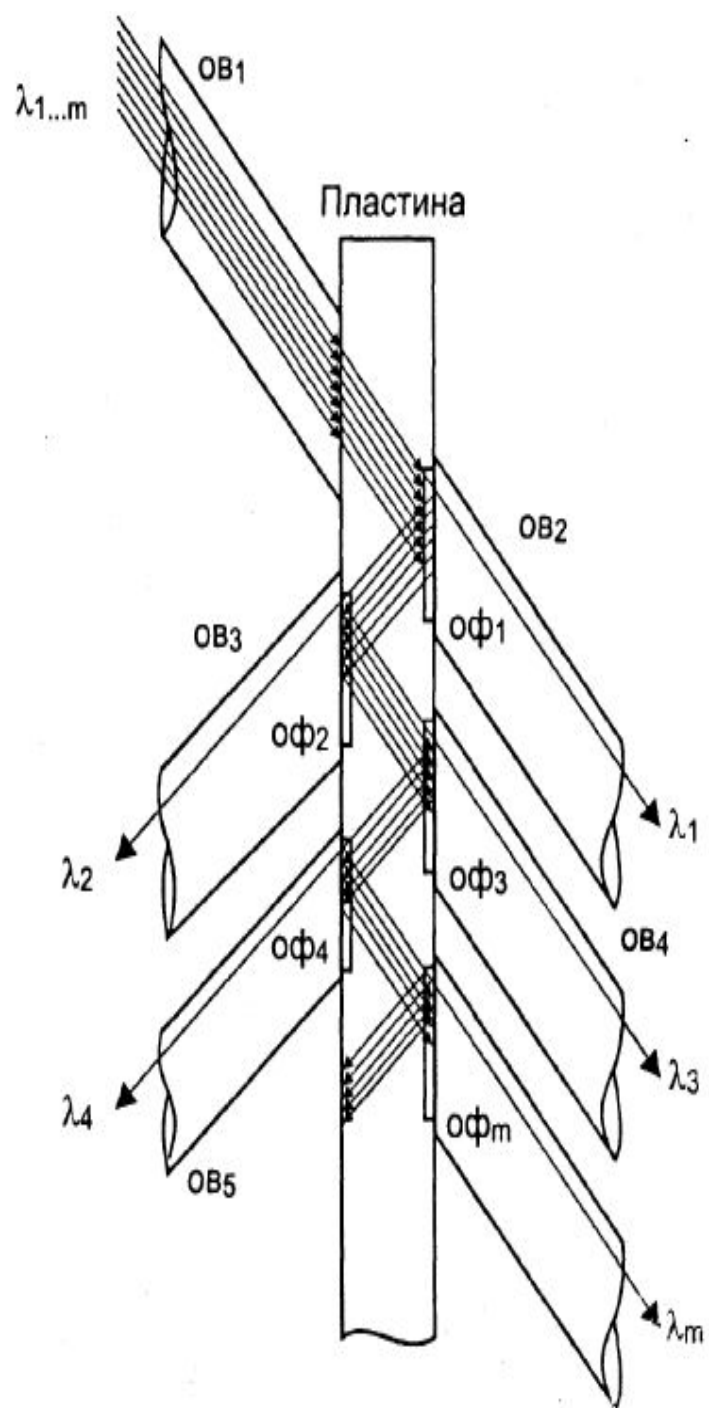
b

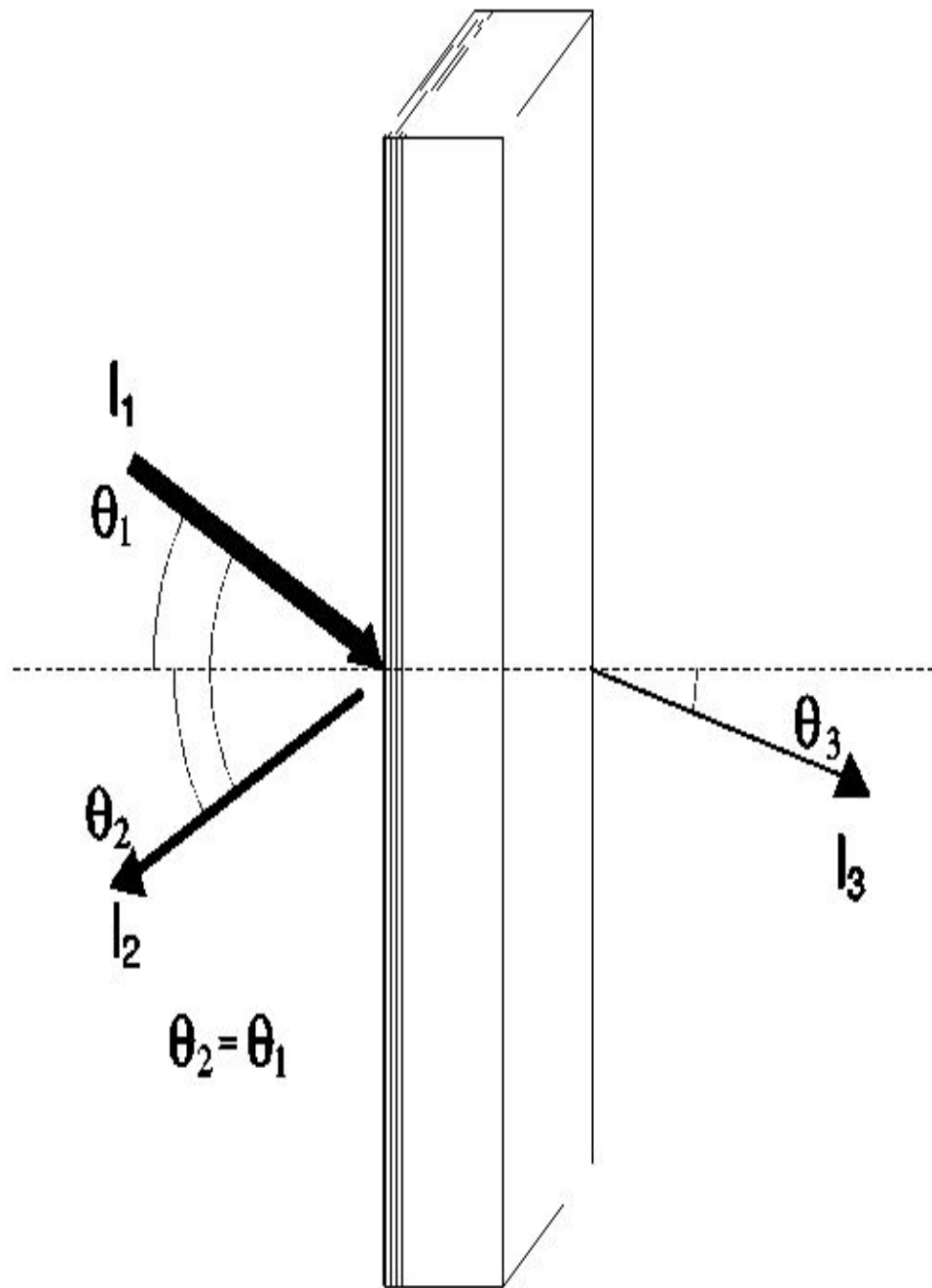


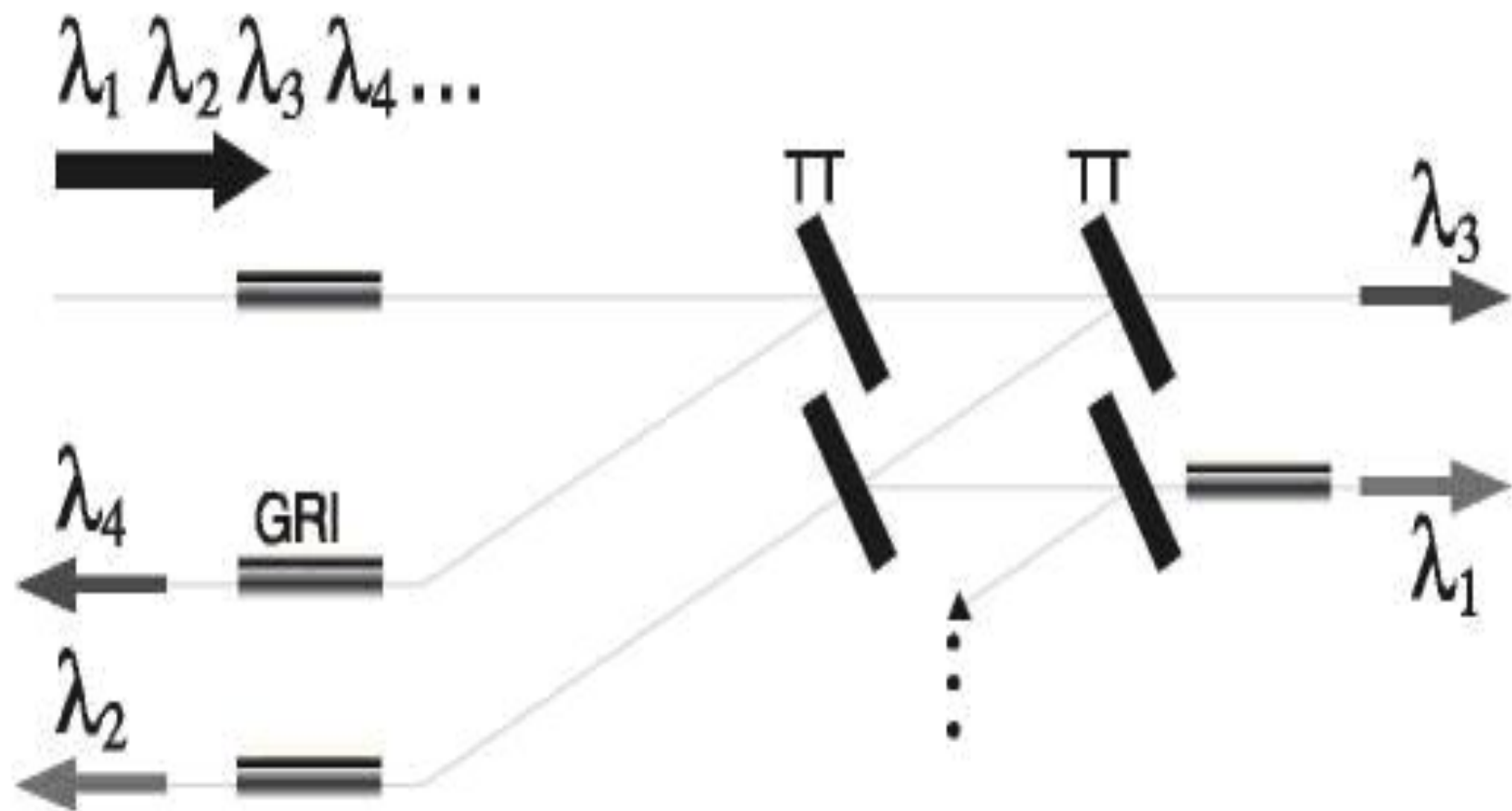


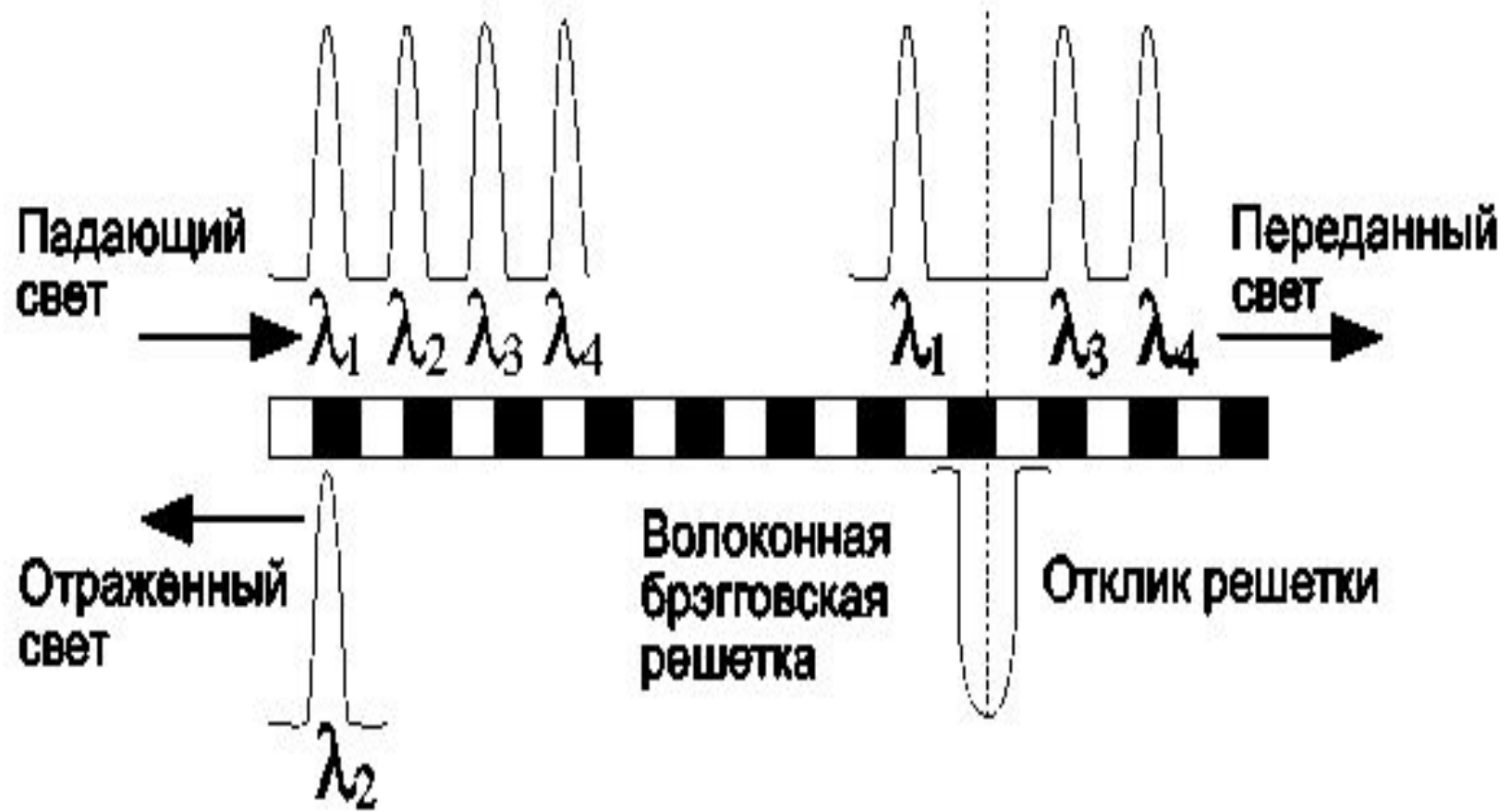












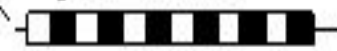
$\lambda_1, \lambda_2 \dots \lambda_N$



Вывод λ_1



Волоконная
брэгговская
решетка



Ввод λ_1



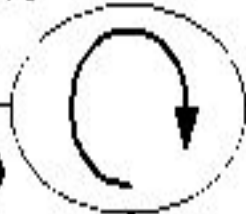
$\lambda_1, \lambda_2 \dots \lambda_N$

$\lambda_1, \lambda_2 \dots \lambda_N$



Циркулятор

Вывод λ_1



$\lambda_1, \lambda_2 \dots \lambda_{N-1}$



Волоконная
брэгговская
решетка

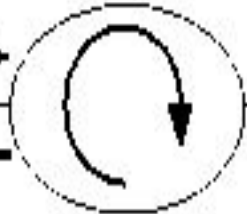


$\lambda_1, \lambda_2 \dots \lambda_N$



Циркулятор

Ввод λ_1



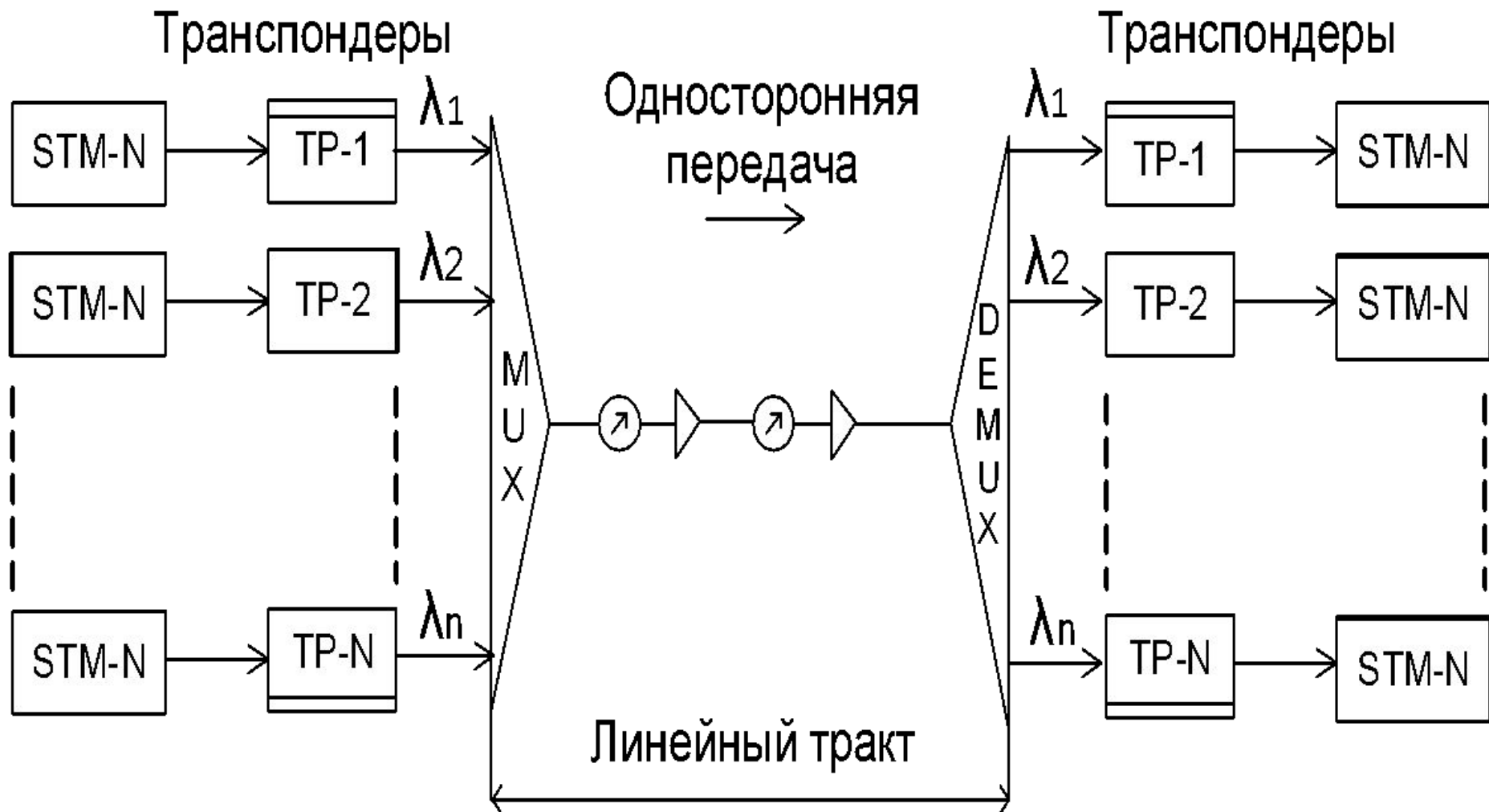


Рисунок 11.1 - Схема многоволновой системы передачи