

Основные характеристики сигналов электросвязи

$$s(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} (a_k \cos(2\pi kft) + b_k \sin(2\pi kft))$$

$$a_0 = \frac{2}{T} \int_{-T/2}^{T/2} s(t) dt \quad a_k = \frac{2}{T} \int_{-T/2}^{T/2} s(t) \cos(2\pi kft) dt \quad b_k = \frac{2}{T} \int_{-T/2}^{T/2} s(t) \sin(2\pi kft) dt$$

$$S(j\omega) = \int_{-\infty}^{\infty} s(t) \exp(-j\omega t) dt \quad s(t) \Leftrightarrow S(j\omega) \quad s(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S(j\omega) \exp(j\omega t) d\omega$$

$$s(t) = \frac{1}{T} \int_{-\infty}^{\infty} s^2(t) dt < \infty$$

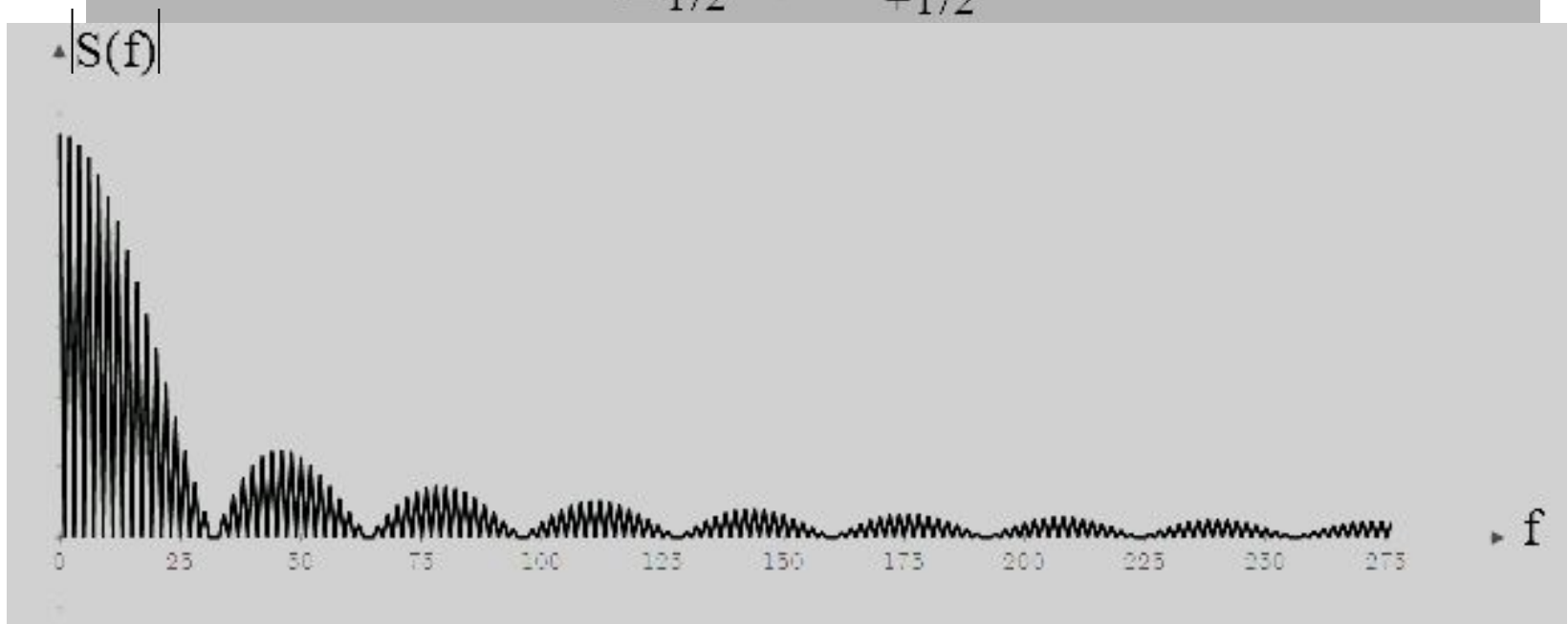
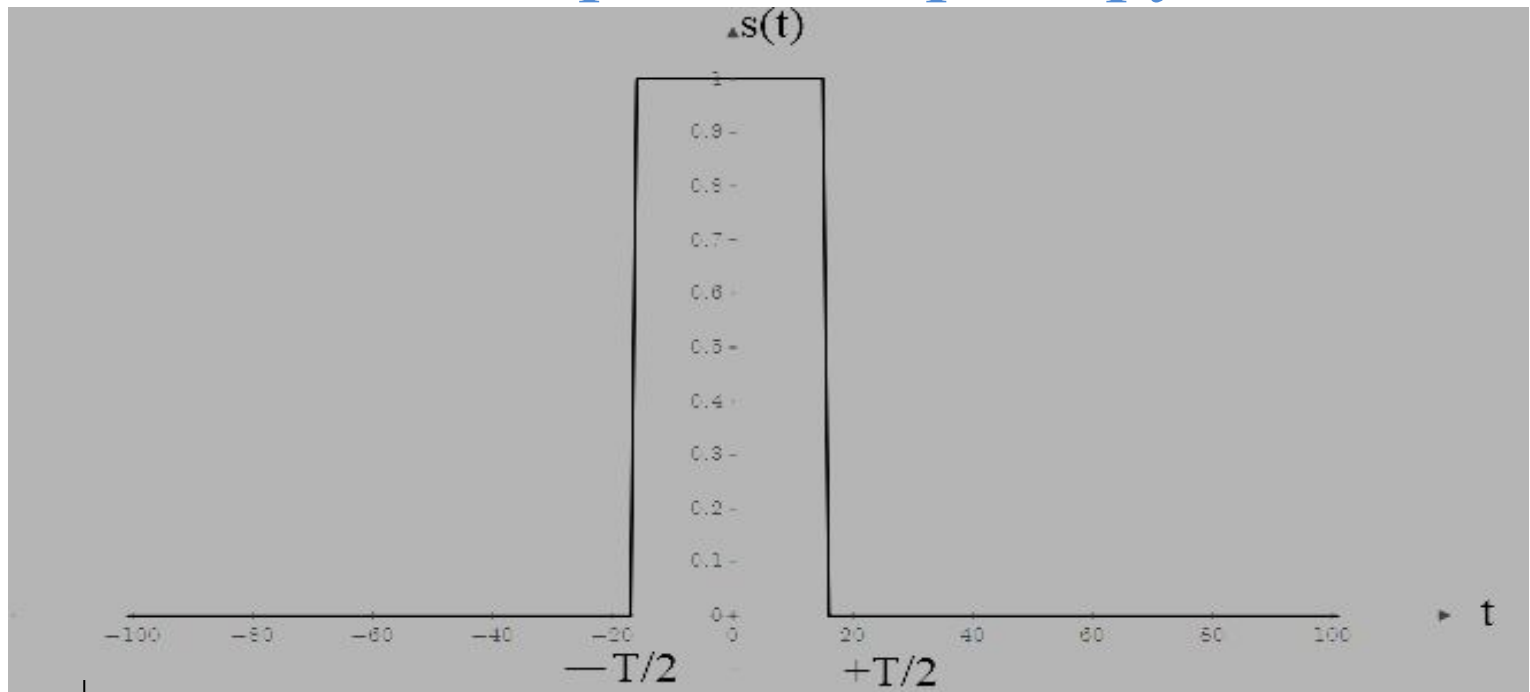
Пример: $s(t) = \begin{cases} U, & t \in [-T/2, T/2] \\ 0, & t \notin [-T/2, T/2] \end{cases}$

$$S(j\omega) = \operatorname{Re} \left\{ \int_{-\infty}^{\infty} s(t) \exp(-j\omega t) dt \right\} = \operatorname{Re} \left\{ \int_{-T/2}^{T/2} U \exp(-j\omega t) dt \right\} =$$

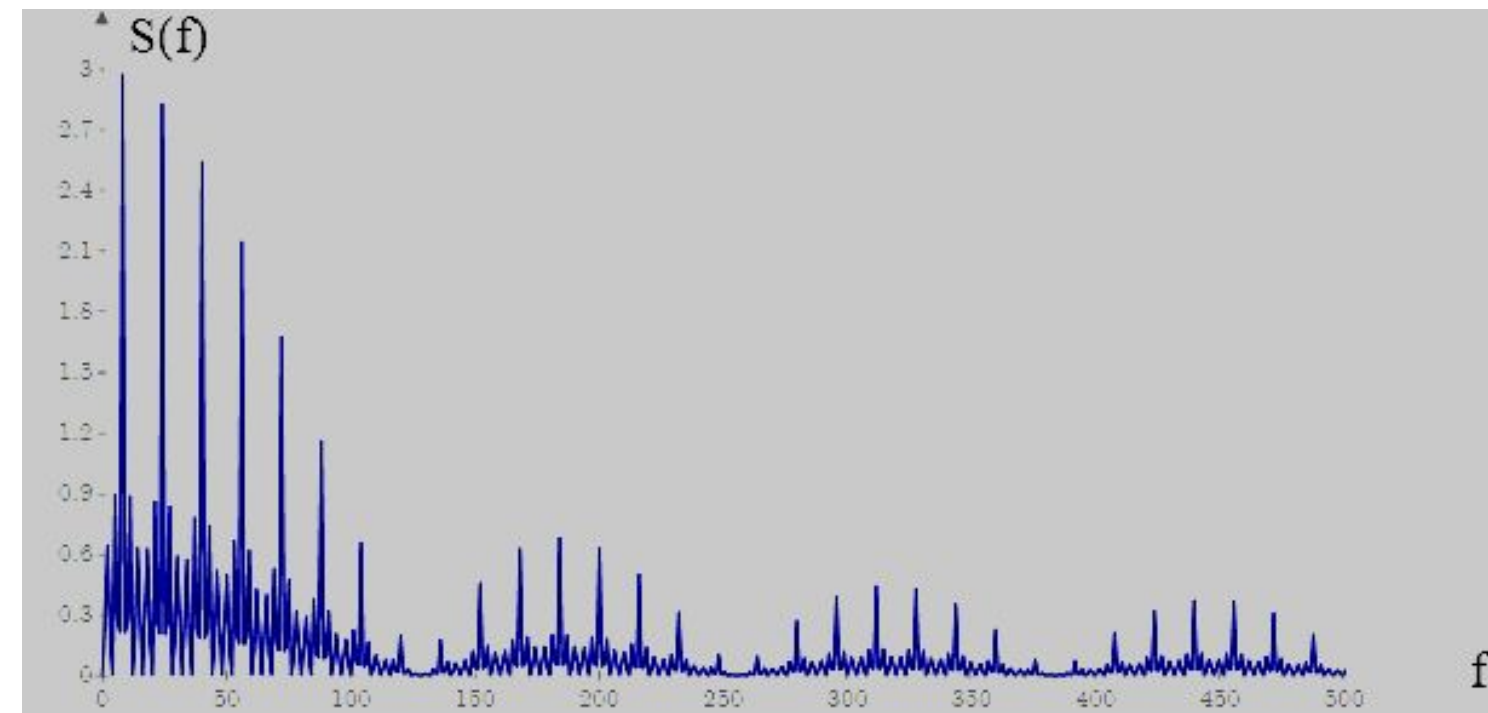
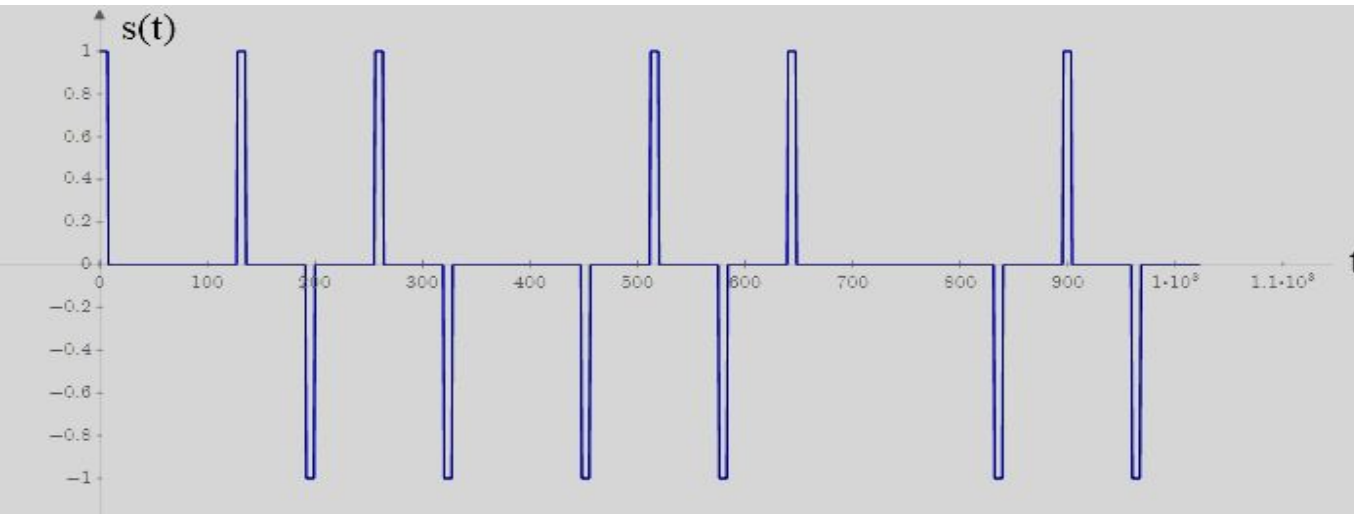
$$= \operatorname{Re} \left\{ \frac{U}{-j\omega} \exp(-j\omega t) \right\} \Big|_{-T/2}^{T/2} = \operatorname{Re} \left\{ \frac{U}{-j\omega} \cos(\omega t) - j \frac{U}{-j\omega} \sin(\omega t) \right\} \Big|_{-T/2}^{T/2} =$$

$$= \operatorname{Re} \left\{ \frac{jU}{\omega} \cos(\omega t) + \frac{U}{\omega} \sin(\omega t) \right\} \Big|_{-T/2}^{T/2} = \frac{U}{\omega} \sin(\omega T) = UT \frac{\sin(\omega T)}{\omega T}$$

Иллюстрации к примеру

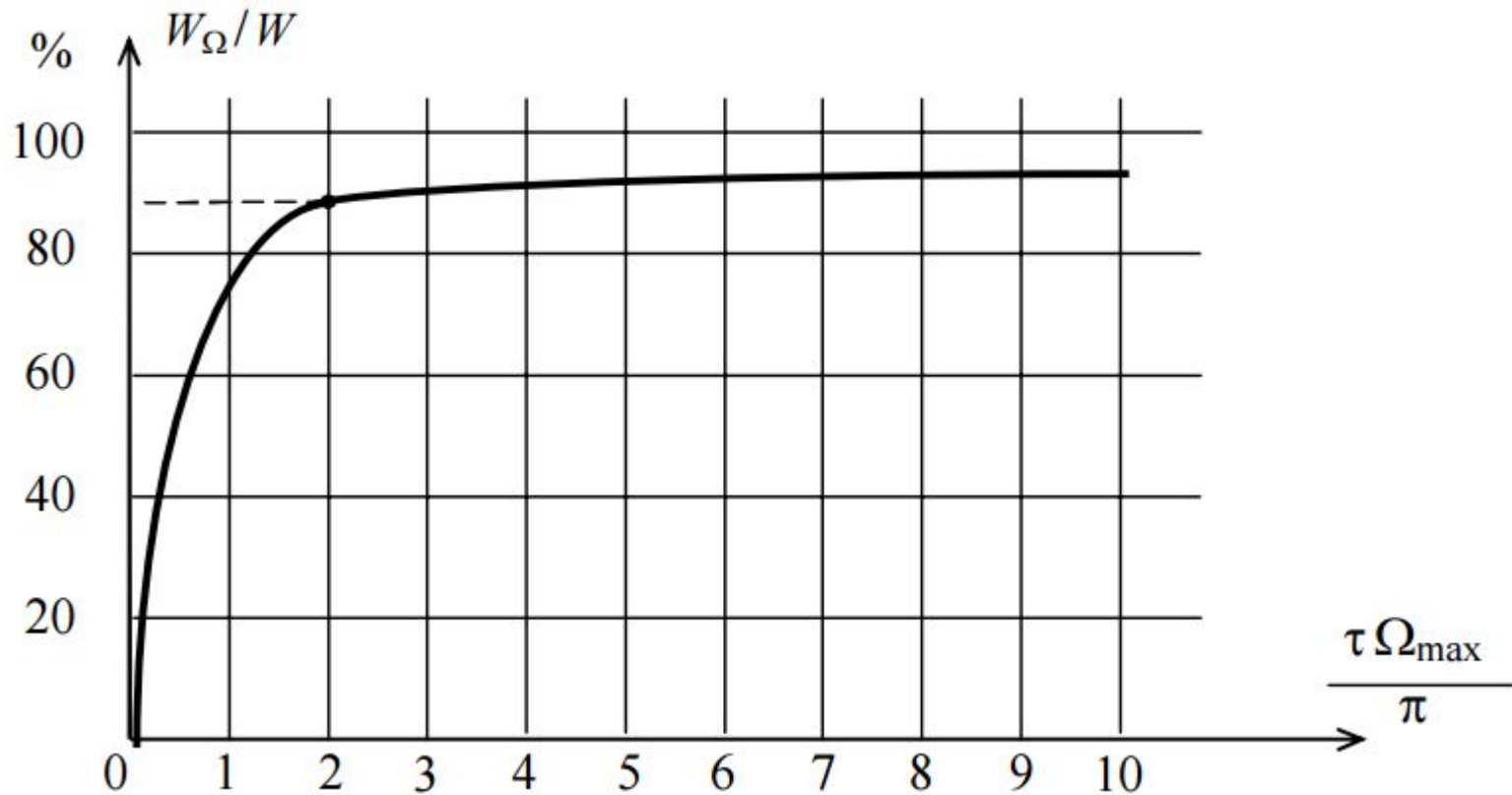


Иллюстрации к примеру

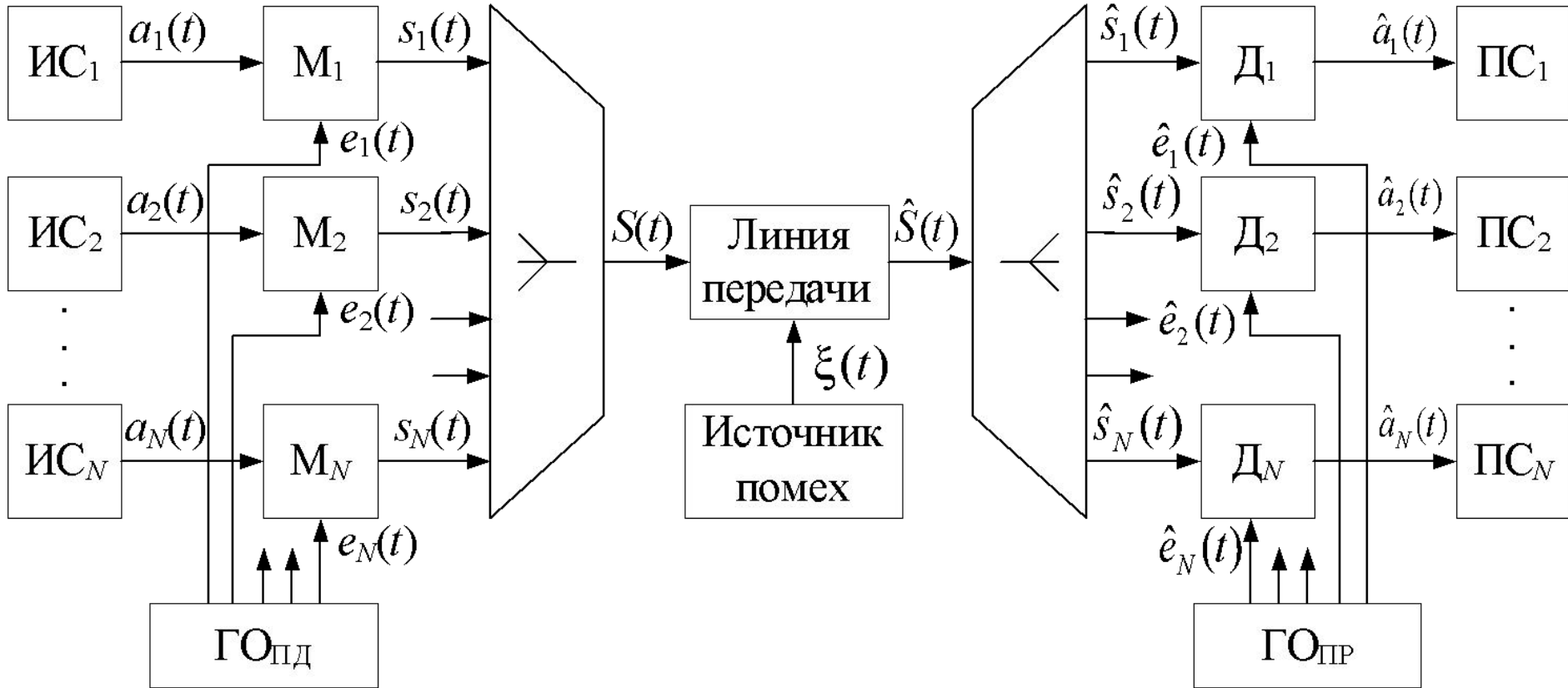


Зависимость энергии импульса от ширины сохраняемой части спектра

$$s(t) = \frac{1}{\pi} \int_0^{\omega_{\max}} |s(\omega)|^2 d\omega$$



Структурная схема многоканальной системы передачи



- ИС- источник сигнала
- М- модулятор
- Д- демодулятор
- ПС- приемник сигнала
- $ГО_{пд}$, $ГО_{пр}$ - генераторное оборудование передачи / приема

Пояснения к структурной схеме МСП

$$s_n(t) = M_n[a_n(t)]$$

линейное преобразование : $M_n \left[\sum_{n=1}^N \beta_n a_n(t) \right] = \sum_{n=1}^N \beta_n M_n \{a_n(t)\}$

$$S(t) = U[s_n(t)] = U[M_n[a_n(t)]] = \sum_{n=1}^N s_n(t) = \sum_{n=1}^N M_n[a_n(t)]$$

$$\hat{S}(t) = L[S(t), \xi(t)]$$

$$\hat{s}_n(t) = U^{-1}[\hat{S}(t)]$$

$$\hat{a}_n(t) = M_n^{-1}[\hat{s}_n(t)] = \left\{ M_n^{-1} \left[U^{-1} \left[L \left[U \left[M_n \left[a_n(t) \right] \right] \right] \right] \right] \right\}$$

Линейное разделение сигналов

$$S(i\Delta t) = e_1 a_1(i\Delta t) + e_2 a_2(i\Delta t) + \dots + e_n a_n(i\Delta t)$$

$$S_1 = e_{11} a_1 + e_{12} a_2 + \dots + e_{1N} a_N$$

$$S_2 = e_{21} a_1 + e_{22} a_2 + \dots + e_{2N} a_N$$

... ..

$$S_N = e_{N1} a_1 + e_{N2} a_2 + \dots + e_{NN} a_N$$

$$a_1 = \frac{\Delta_1}{\Delta} \quad a_2 = \frac{\Delta_2}{\Delta} \quad \dots \quad a_N = \frac{\Delta_N}{\Delta}$$

$$\Delta = \begin{bmatrix} e_{11} & \square & e_{1N} \\ e_{21} & \square & e_{2N} \\ \square & \square & \square \\ e_{N1} & \square & e_{NN} \end{bmatrix} \quad \Delta_1 = \begin{bmatrix} S_1 & \square & e_{1N} \\ S_2 & \square & e_{2N} \\ \square & \square & \square \\ S_N & \square & e_{NN} \end{bmatrix} \quad \dots \quad \Delta_N = \begin{bmatrix} e_{11} & \square & S_1 \\ e_{21} & \square & S_2 \\ \square & \square & \square \\ e_{N1} & \square & S_N \end{bmatrix}$$

Пример

$$5 = 1a_1 + 3a_2 - 4a_N$$

$$3 = 2a_1 - a_2 + 2a_N$$

$$-2 = a_1 - 3a_2 + 2a_N$$

$$\Delta = \begin{bmatrix} 1 & 3 & -4 \\ 2 & -1 & 2 \\ 1 & -3 & 2 \end{bmatrix} = 18 \quad \Delta_1 = \begin{bmatrix} 5 & 3 & -4 \\ 3 & -1 & 2 \\ -2 & -3 & 2 \end{bmatrix} = 34$$

$$\Delta_2 = \begin{bmatrix} 1 & 5 & -4 \\ 2 & 3 & 2 \\ 1 & -2 & 2 \end{bmatrix} = -12 \quad \Delta_3 = \begin{bmatrix} 1 & 3 & 5 \\ 2 & -1 & 3 \\ 1 & -3 & -2 \end{bmatrix} = 7$$

$$a_1 = \frac{34}{18} = 1.89 \quad a_2 = \frac{-12}{18} = -0.67 \quad a_3 = \frac{7}{18} = 0.39$$

Условие линейного разделения сигналов

$$a_1 \begin{bmatrix} e_{11} \\ e_{21} \\ \square \\ e_{N1} \end{bmatrix} + a_2 \begin{bmatrix} e_{12} \\ e_{22} \\ \square \\ e_{N2} \end{bmatrix} + \square + a_N \begin{bmatrix} e_{1N} \\ e_{2N} \\ \square \\ e_{NN} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \square \\ 0 \end{bmatrix} \Leftrightarrow a_1 \equiv a_2 \equiv \square \equiv a_N \equiv 0$$

$$a_1 \mathbf{e}_1 + a_2 \mathbf{e}_2 + \square + a_N \mathbf{e}_N = \mathbf{0}$$

$$\Gamma = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \square & \gamma_{1N} \\ \gamma_{21} & \gamma_{22} & \square & \gamma_{2N} \\ \square & \square & \square & \square \\ \gamma_{N1} & \gamma_{N2} & \square & \gamma_{NN} \end{bmatrix} \quad \gamma_{ij} = \mathbf{e}_i^T \mathbf{e}_j = \sum_{n=1}^N e_{in} e_{jn}$$

$\Gamma > 0 \Rightarrow \mathbf{e}_1, \mathbf{e}_2, \square, \mathbf{e}_N$ Линейно независимы

$\Gamma = 0 \Rightarrow \mathbf{e}_1, \mathbf{e}_2, \square, \mathbf{e}_N$ Линейно зависимы

Пример

$$\left. \begin{aligned} 0 &= 1a_1 + 3a_2 - 4a_N \\ 0 &= 2a_1 - a_2 + 2a_N \\ 0 &= 1a_1 - 3a_2 + 2a_N \end{aligned} \right\} \mathbf{e}_1 = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \quad \mathbf{e}_2 = \begin{bmatrix} 3 \\ -1 \\ -3 \end{bmatrix} \quad \mathbf{e}_3 = \begin{bmatrix} -4 \\ 2 \\ 2 \end{bmatrix}$$

$$\gamma_{11} = \mathbf{e}_1^T \mathbf{e}_1 = 1 \cdot 1 + 2 \cdot 2 + 1 \cdot 1 = 6 \quad \gamma_{12} = \mathbf{e}_1^T \mathbf{e}_2 = 1 \cdot 3 + 2 \cdot (-1) + 1 \cdot (-3) = -2$$

$$\gamma_{13} = \mathbf{e}_1^T \mathbf{e}_3 = 2 \quad \gamma_{21} = \mathbf{e}_2^T \mathbf{e}_1 = -2 \quad \gamma_{22} = \mathbf{e}_2^T \mathbf{e}_2 = 19 \quad \gamma_{23} = \mathbf{e}_2^T \mathbf{e}_3 = -20$$

$$\gamma_{31} = \mathbf{e}_3^T \mathbf{e}_1 = 2 \quad \gamma_{32} = \mathbf{e}_3^T \mathbf{e}_2 = -20 \quad \gamma_{33} = \mathbf{e}_3^T \mathbf{e}_3 = 24$$

$$\Gamma = \begin{bmatrix} 6 & -2 & 2 \\ -2 & 19 & -20 \\ 2 & -20 & 24 \end{bmatrix} = 324 \Rightarrow \text{Сигналы линейно независимы}$$

$$\left. \begin{array}{l} 0 = 1a_1 + 3a_2 - 2a_N \\ 0 = 2a_1 - a_2 - 4a_N \\ 0 = 1a_1 - 3a_2 - 2a_N \end{array} \right\} \mathbf{e}_1 = \begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \quad \mathbf{e}_2 = \begin{bmatrix} 3 \\ -1 \\ -3 \end{bmatrix} \quad \mathbf{e}_3 = \begin{bmatrix} -2 \\ -4 \\ -2 \end{bmatrix}$$

$$\Gamma = \begin{bmatrix} 6 & -2 & -12 \\ -2 & 19 & 4 \\ -12 & 4 & 24 \end{bmatrix} = 0 \Rightarrow \text{Сигналы линейно зависимы}$$

$$\mathbf{e}_3 = -2\mathbf{e}_1$$

Максимальное количество линейно разделимых сигналов в N-мерном линейном пространстве

$$a_1 \mathbf{e}_1 + a_2 \mathbf{e}_2 + \square + a_N \mathbf{e}_N = \mathbf{0}$$

$$a_1 \mathbf{e}_1 + a_2 \mathbf{e}_2 + \square + a_N \mathbf{e}_N + \mathbf{e}_{N+1} = \mathbf{0}$$

$$\mathbf{E}\mathbf{A} + \mathbf{e}_{N+1} = \mathbf{0} \quad \mathbf{e}_{N+1} = -\mathbf{E}\mathbf{A}$$

$$\mathbf{A} = -\mathbf{E}^{-1} \mathbf{e}_{N+1}$$

$$\mathbf{E} = \begin{bmatrix} e_{11} & e_{12} & \square & e_{1N} \\ e_{21} & e_{22} & \square & e_{2N} \\ \square & \square & \square & \square \\ e_{N1} & e_{N2} & \square & e_{NN} \end{bmatrix} \quad \mathbf{A} = \begin{bmatrix} a_1 \\ a_2 \\ \square \\ a_N \end{bmatrix}$$

Формирование группового сигнала

$$\mathbf{S} = a_1 \mathbf{e}_1 + a_2 \mathbf{e}_2 + \square + a_N \mathbf{e}_N = \mathbf{s}_1 + \mathbf{s}_2 + \dots + \mathbf{s}_N = \sum_{n=1}^N \mathbf{s}_n$$

$$\mathbf{S} = \mathbf{E}\mathbf{A}$$

$$\mathbf{A} = \mathbf{E}^{-1}\mathbf{S} = \mathbf{E}^{-1}\mathbf{E}\mathbf{A}$$

$$\mathbf{E}^{-1}\mathbf{E} = \mathbf{E}^T\mathbf{E} = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \square & \gamma_{1N} \\ \gamma_{21} & \gamma_{22} & \square & \gamma_{2N} \\ \square & \square & \square & \square \\ \gamma_{N1} & \gamma_{N2} & \square & \gamma_{NN} \end{bmatrix} = \begin{bmatrix} 1 & 0 & \square & 0 \\ 0 & 1 & \square & 0 \\ \square & \square & \square & \square \\ 0 & 0 & \square & 1 \end{bmatrix} = \mathbf{I}$$

$$\gamma_{ij} = \mathbf{e}_i^T \mathbf{e}_j = \begin{cases} 1, \forall i = j \\ 0, \forall i \neq j \end{cases}$$

$$\mathbf{e}_2^T \mathbf{S} = a_1 \mathbf{e}_2^T \mathbf{e}_1 + a_2 \mathbf{e}_2^T \mathbf{e}_2 + \square + a_N \mathbf{e}_2^T \mathbf{e}_N = a_2$$

Разделение линейно-независимых сигналов

$$\mathbf{b}_1 = c_{11}\mathbf{e}_1 + c_{12}\mathbf{e}_2 + \square + c_{1N}\mathbf{e}_N$$

$$\mathbf{b}_2 = c_{21}\mathbf{e}_1 + c_{22}\mathbf{e}_2 + \square + c_{2N}\mathbf{e}_N$$

\square

$$\mathbf{b}_N = c_{N1}\mathbf{e}_1 + c_{N2}\mathbf{e}_2 + \square + c_{NN}\mathbf{e}_N$$

$$\mathbf{b}_i^T \mathbf{e}_j = \begin{cases} 1, \forall i = j \\ 0, \forall i \neq j \end{cases} \quad i, j = 1 \dots N$$

$$\mathbf{b}_1 = c_{11}\mathbf{e}_1 + c_{12}\mathbf{e}_2 + \square + c_{1N}\mathbf{e}_N$$

$$\mathbf{b}_2 = c_{21}\mathbf{e}_1 + c_{22}\mathbf{e}_2 + \square + c_{2N}\mathbf{e}_N$$

\square

$$\mathbf{b}_N = c_{N1}\mathbf{e}_1 + c_{N2}\mathbf{e}_2 + \square + c_{NN}\mathbf{e}_N$$

Пример

$$\mathbf{e}_1 = \begin{bmatrix} 2 \\ 1 \end{bmatrix} \quad \mathbf{e}_2 = \begin{bmatrix} 2 \\ 2 \end{bmatrix}$$

$$\mathbf{b}_1 = c_{11}\mathbf{e}_1 + c_{12}\mathbf{e}_2$$

$$\mathbf{b}_2 = c_{21}\mathbf{e}_1 + c_{22}\mathbf{e}_2$$

$$\Rightarrow \mathbf{b}_1^T \mathbf{e}_1 = 1 \quad \mathbf{b}_1^T \mathbf{e}_2 = 0 \quad \mathbf{b}_2^T \mathbf{e}_1 = 0 \quad \mathbf{b}_2^T \mathbf{e}_2 = 1$$

$$\left\{ \begin{array}{l} \mathbf{b}_1^T \mathbf{e}_1 = c_{11}\mathbf{e}_1^T \mathbf{e}_1 + c_{12}\mathbf{e}_2^T \mathbf{e}_1 = c_{11}5 + c_{12}6 = 1 \\ \mathbf{b}_1^T \mathbf{e}_2 = c_{11}\mathbf{e}_1^T \mathbf{e}_2 + c_{12}\mathbf{e}_2^T \mathbf{e}_2 = c_{11}6 + c_{12}8 = 0 \end{array} \right.$$

$$\left\{ \begin{array}{l} \mathbf{b}_2^T \mathbf{e}_1 = c_{21}\mathbf{e}_1^T \mathbf{e}_1 + c_{22}\mathbf{e}_2^T \mathbf{e}_1 = c_{21}5 + c_{22}6 = 0 \\ \mathbf{b}_2^T \mathbf{e}_2 = c_{21}\mathbf{e}_1^T \mathbf{e}_2 + c_{22}\mathbf{e}_2^T \mathbf{e}_2 = c_{21}6 + c_{22}8 = 1 \end{array} \right.$$

$$c_{11} = -0.125 \quad c_{12} = 0.271$$

$$c_{21} = -1.5 \quad c_{22} = 1.25$$

Разделение сигналов с конечной мощностью

$$\int_{-\infty}^{\infty} g(t, \tau) e_i(\tau) e_j(\tau) d\tau = \begin{cases} \text{const}, \forall i = j \\ 0, \forall i \neq j \end{cases} \quad i, j = 1..N$$

$$g(\tau) = 2G_0 \Delta f \frac{\sin(\Delta\omega\tau)}{\Delta\omega\tau} \quad g(\tau) \Leftrightarrow G(\omega) = \begin{cases} G_0, 0 \leq |\omega| \leq \Delta\omega \\ 0, |\omega| > \Delta\omega \end{cases}$$

$$S(t) = \sum_{n=1}^N a_n(t) e_n(t) = \mathbf{A}^T(t) \mathbf{E}(t)$$

$$\mathbf{A}(t) = \int_{-\infty}^{\infty} \mathbf{E}(\tau) s(\tau) g(t - \tau) d\tau \quad a_n(t) = \int_{-\infty}^{\infty} e_n(\tau) s(\tau) g(t - \tau) d\tau$$

Разделение сигналов с конечной энергией

$$\int_{i\Delta t}^{(i+1)\Delta t} e_n^2(t) dt < \infty, \quad n = 1 \dots N$$

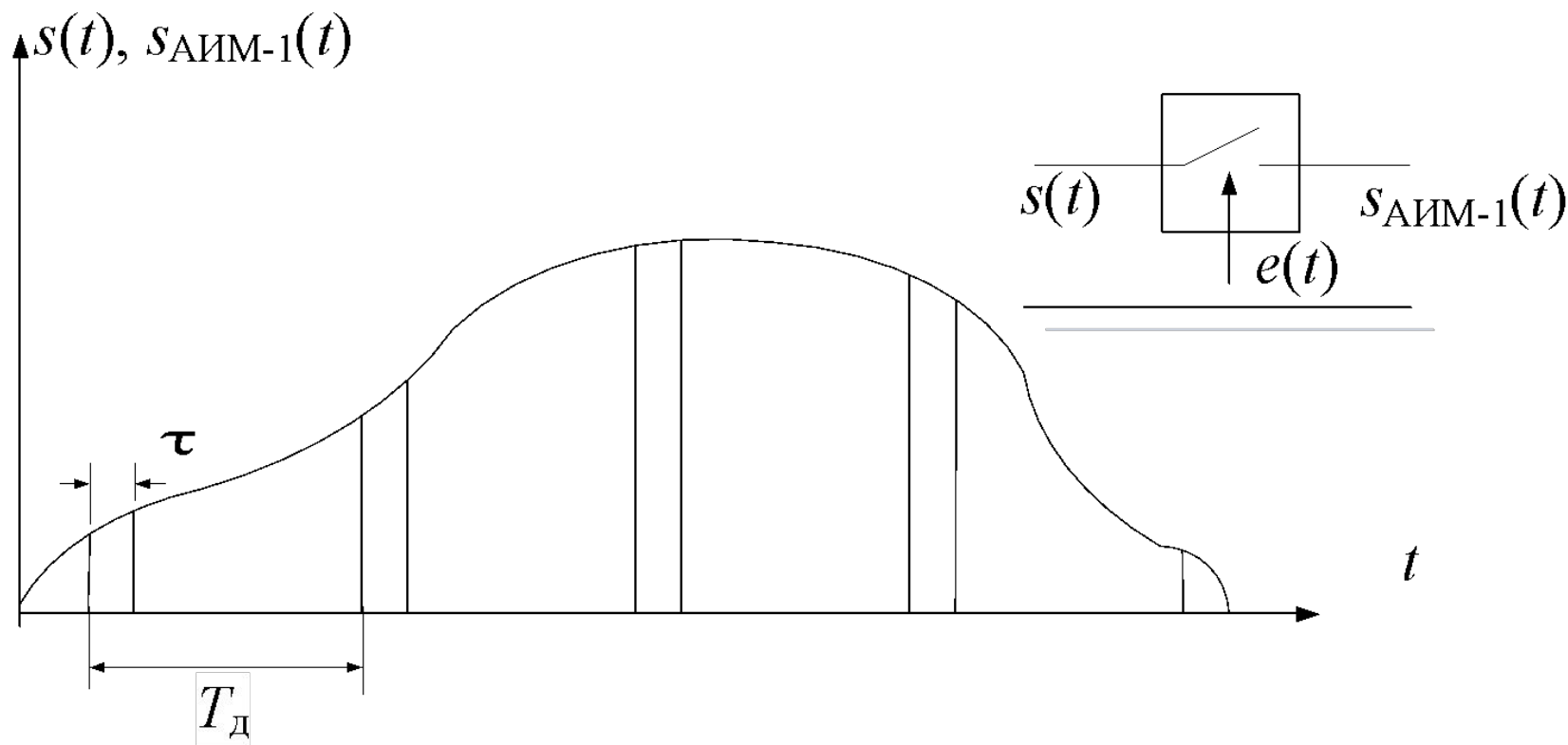
$$\int_{i\Delta t}^{(i+1)\Delta t} e_i(t)e_j(t) dt = \begin{cases} 1, & \forall i = j \\ 0, & \forall i \neq j \end{cases} \quad i, j = 1 \dots N$$

$$S(t) = a_1 e_1(t) + a_2 e_2(t) + \dots + a_N e_N(t) = \sum_{n=1}^N a_n e_n(t) = \mathbf{A}^T \mathbf{E}(t)$$

$$\mathbf{A} = \int_{i\Delta t}^{(i+1)\Delta t} s(t) \mathbf{E}(t) dt$$

$$a_n = \int_{i\Delta t}^{(i+1)\Delta t} s(t) e_n(t) dt, \quad n = 1 \dots N$$

Амплитудно-импульсная модуляция 1-го рода



$$a(t) = A_0 + A_1 \cos(2\pi f_c t) = A_0 + A_1 \cos(\Omega t)$$

$$s_{\text{АИМ-1}}(t) = a(t)e(t) = a(t) \sum_k e_0(t - kT_d)$$

$$s_{\text{АИМ-1}}(t) = (A_0 + A_1 \cos \Omega t) \sum_k e_0(t - kT_d)$$

$$\sum_k e_0(t - kT_d) = \frac{2}{T_d} \int_0^{\frac{T_d}{2}} e_0(t) dt + \sum_{n=1}^{\infty} \left[\frac{4}{T_d} \int_0^{\frac{T_d}{2}} e_0(t) \cos n\Omega_d t dt \right] \cos n\Omega_d t$$

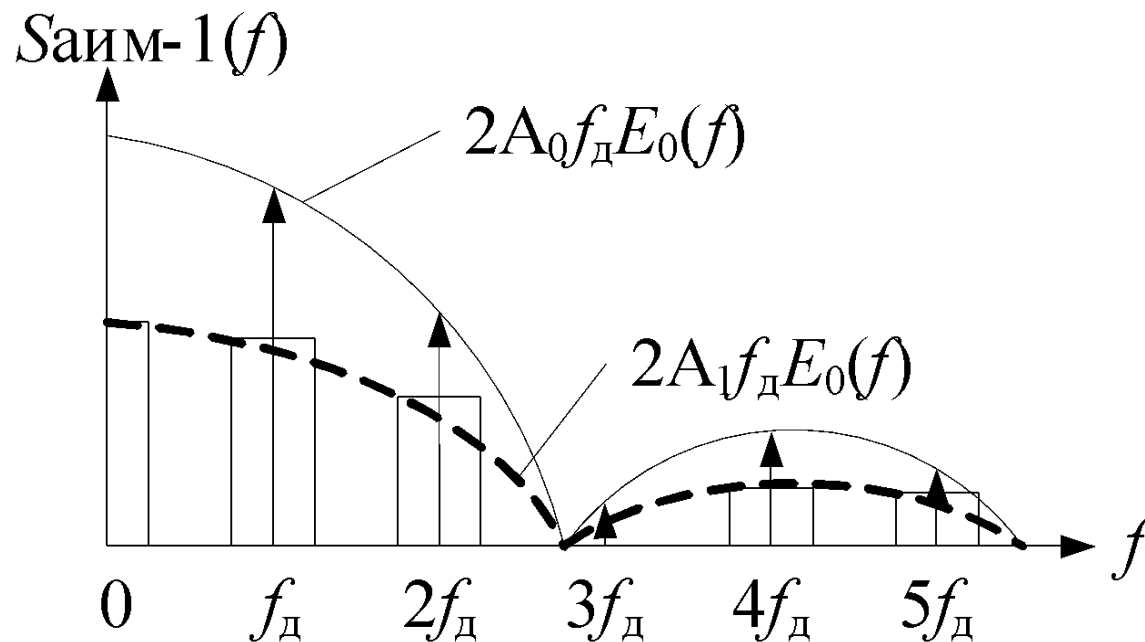
$$\sum_k e_0(t - kT_d) = f_d E_0(0) + 2f_d \sum_{n=1}^{\infty} E_0(n\Omega_d) \cos n\Omega_d t$$

$$s_{\text{АИМ-1}}(t) = A_0 f_d \left\{ E_0(0) + 2 \sum_{n=1}^{\infty} E_0(n\Omega_d) \cos n\Omega_d t \right\} +$$

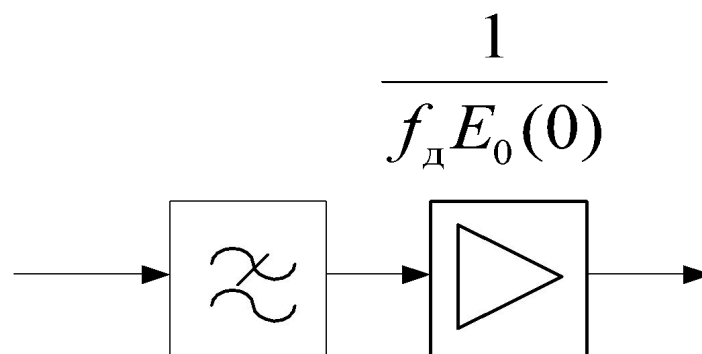
$$+ A_1 f_d \left\{ E_0(0) \cos \Omega t + \sum_{n=1}^{\infty} E_0(n\Omega_d) [\cos(n\Omega_d - \Omega)t + \cos(n\Omega_d + \Omega)t] \right\}$$

Спектр сигнала АИМ-1

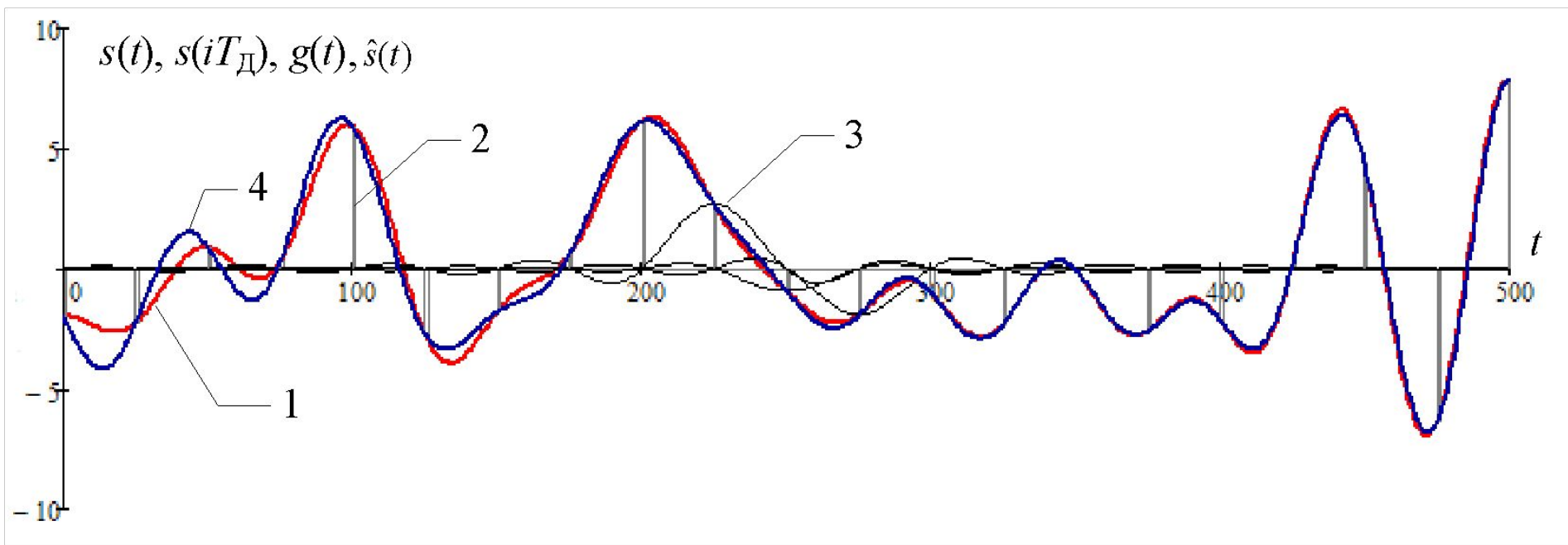
$$S_{\text{АИМ-1}}(\Omega) = \frac{U\tau}{T_d} S(\Omega) + \frac{2U\tau}{T_d} \sum_{k=1}^{\infty} \frac{\sin\left(\frac{k\Omega_d\tau}{2}\right)}{\left(\frac{k\Omega_d\tau}{2}\right)} S(k\Omega_d \pm \Omega)$$



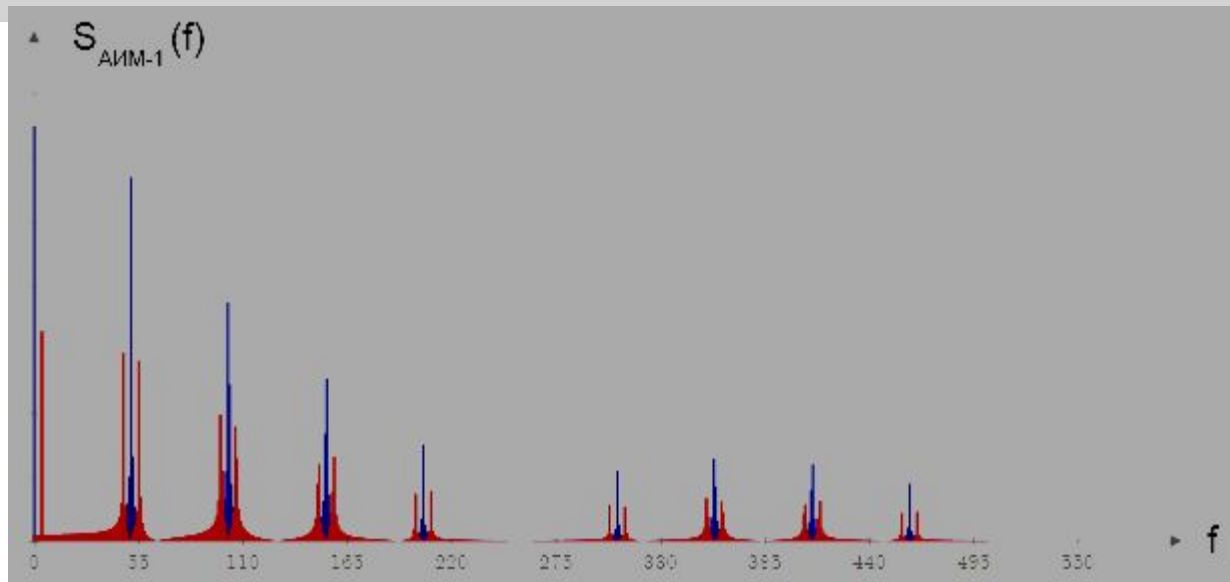
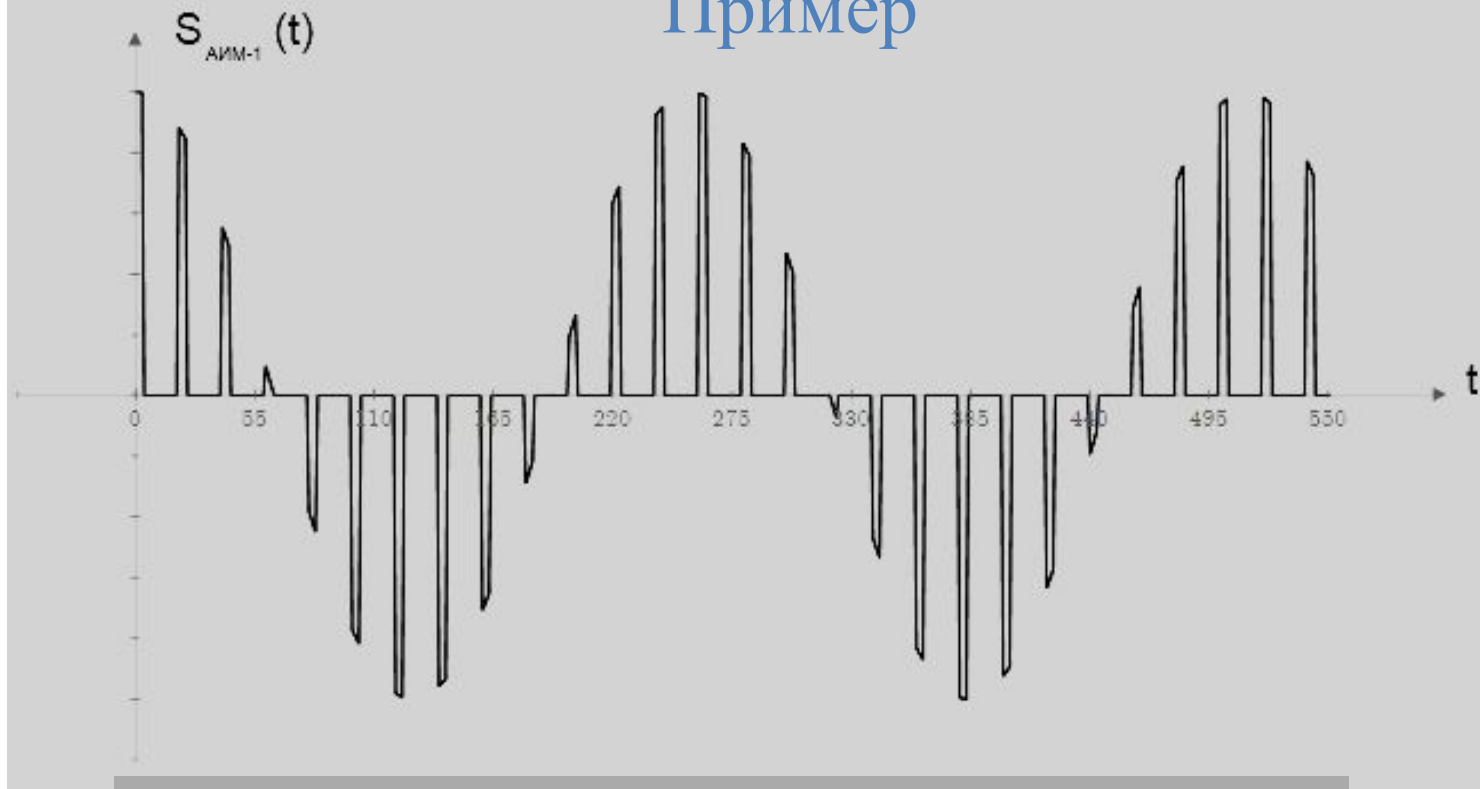
$$s_{\text{ВЫХ}}(t) = f_d E_0(0) [A_0 + A_1 \cos(ft)] \quad f_d E_0(0) < 1$$



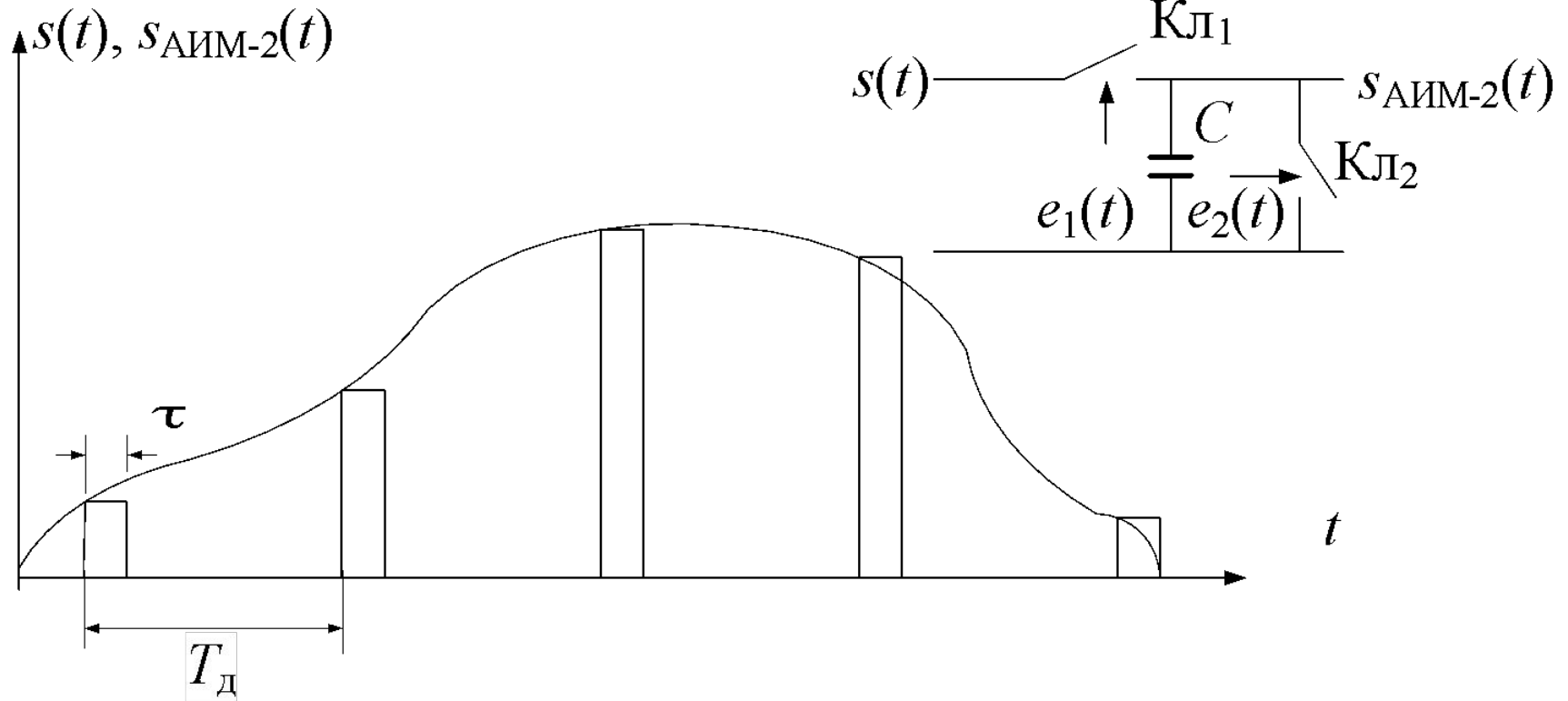
Демодулятор сигнала АИМ-1



Пример



Амплитудно-импульсная модуляция 2-го рода



$$s_{\text{АИМ-2}}(t) = \sum_k a(kT_d) e_0(t - kT_d)$$

$$s_{\text{АИМ-2}}(t) = \sum_k A_1 \cos \Omega kT_d \cdot e_0(t - kT_d)$$

$$e_0(t - kT_d) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} E_0(\omega) e^{-i\omega kT_d} e^{i\omega t} d\omega$$

$$\begin{aligned}
s_{AИМ-2}(t) &= A_1 \int_{-\infty}^{+\infty} E_0(\omega) e^{i\omega t} \frac{f_{\text{д}}}{2} \left[\sum_n \delta(\omega - \Omega - n\Omega_{\text{д}}) + \sum_n \delta(\omega + \Omega - n\Omega_{\text{д}}) \right] d\omega = \\
&= A_1 \frac{f_{\text{д}}}{2} \sum_n \left[E_0(n\Omega_{\text{д}} - \Omega) e^{i(n\Omega_{\text{д}} - \Omega)t} + E_0(n\Omega_{\text{д}} + \Omega) e^{i(n\Omega_{\text{д}} + \Omega)t} \right].
\end{aligned}$$

$$\begin{aligned}
s_{AИМ-2}(t) &= A_1 f_{\text{д}} \left[E_0(\Omega) \cos \Omega t + \sum_{k=1}^{\infty} E_0(k\Omega_{\text{д}} - \Omega) \cos(k\Omega_{\text{д}} - \Omega)t + \right. \\
&\quad \left. + \sum_{k=1}^{\infty} E_0(k\Omega_{\text{д}} + \Omega) \cos(k\Omega_{\text{д}} + \Omega)t \right].
\end{aligned}$$

$$E_0(-\omega) = E_0(\omega) \qquad \cos x = \frac{e^{ix} + e^{-ix}}{2}$$

$$\begin{aligned}
\sum_k \cos \Omega k T_{\text{д}} \cdot e^{-i\omega k T_{\text{д}}} &= \sum_k \frac{1}{2} \left[e^{i\Omega k T_{\text{д}}} + e^{-i\Omega k T_{\text{д}}} \right] e^{-i\omega k T_{\text{д}}} = \\
&= 1 + \frac{1}{2} \sum_{k=1}^{\infty} \left(e^{i(\omega - \Omega) k T_{\text{д}}} + e^{-i(\omega - \Omega) k T_{\text{д}}} + e^{i(\omega + \Omega) k T_{\text{д}}} + e^{-i(\omega + \Omega) k T_{\text{д}}} \right) = \\
&= \left\{ \frac{1}{2} + \sum_{k=1}^{\infty} \cos(\omega - \Omega) k T_{\text{д}} \right\} + \left\{ \frac{1}{2} + \sum_{k=1}^{\infty} \cos(\omega + \Omega) k T_{\text{д}} \right\}.
\end{aligned}$$

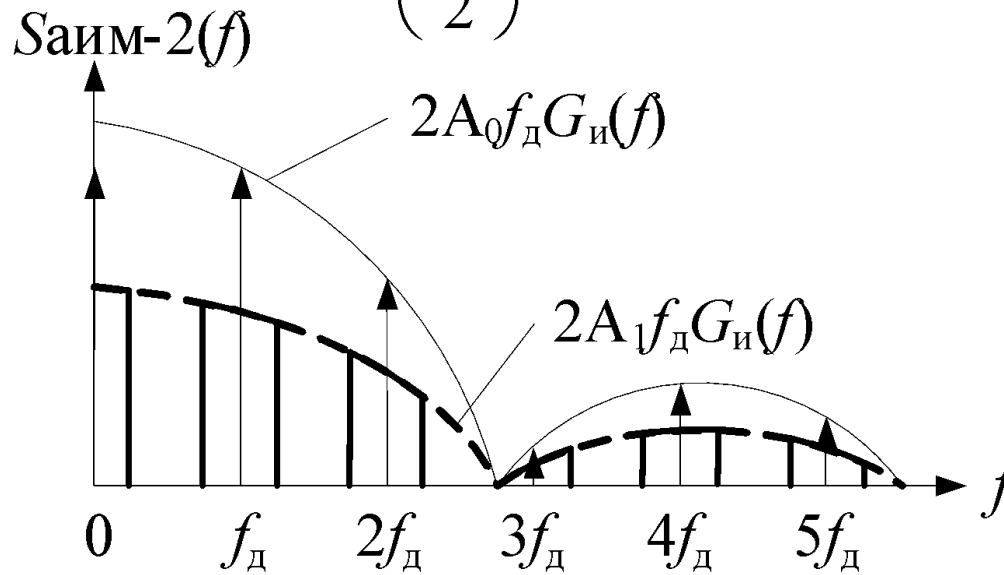
$$\left\{ \frac{1}{2} + \sum_{k=1}^{\infty} \cos z k x \right\} = \frac{\pi}{z} \sum_n \delta \left(x - n \frac{2\pi}{z} \right)$$

$$\sum_k \cos \Omega k T_{\text{д}} \cdot e^{-i\omega k T_{\text{д}}} = \frac{\Omega_{\text{д}}}{2} \left[\sum_n \delta(\omega - \Omega - n\Omega_{\text{д}}) + \sum_n \delta(\omega + \Omega - n\Omega_{\text{д}}) \right]$$

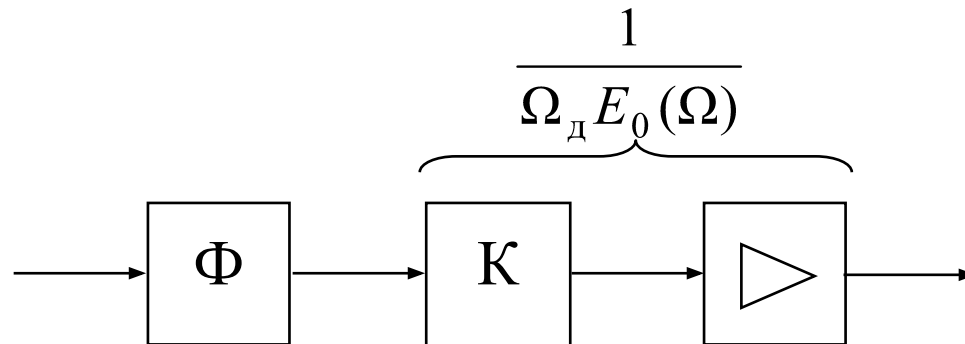
$$\begin{aligned}
s_{AIM-2}(t) &= A_1 f_{\text{д}} \left[E_0(\Omega) \cos \Omega t + \sum_{k=1}^{\infty} E_0(k\Omega_{\text{д}} - \Omega) \cos(k\Omega_{\text{д}} - \Omega)t + \right. \\
&\quad \left. + \sum_{k=1}^{\infty} E_0(k\Omega_{\text{д}} + \Omega) \cos(k\Omega_{\text{д}} + \Omega)t \right].
\end{aligned}$$

Спектр сигнала АИМ-2

$$S_{\text{АИМ-2}}(f) = \frac{U\tau}{T_d} \cdot \frac{\sin\left(\frac{f\tau}{2}\right)}{\left(\frac{f\tau}{2}\right)} \left[S(f) + 2 \sum_{k=1}^{\infty} S(k f_d \pm f) \right]$$



Демодулятор сигнала АИМ-2



АМПЛИТУДНО-ЧАСТОТНЫЕ ИСКАЖЕНИЯ

$$H(-\omega) = H(\omega)$$

Разложение амплитудно-частотной характеристики в ряд Фурье

$$H(\omega) = H_0 + H_1 \cos\left(\frac{2\pi}{T}\omega\right) + H_2 \cos\left(2\frac{2\pi}{T}\omega\right) + \dots + H_n \cos\left(n\frac{2\pi}{T}\omega\right) + \dots$$

$$\frac{2\pi}{T} = \frac{2\pi}{2\omega_{\max}} = \frac{1}{2f_{\max}} = \tau$$

$$H(\omega) = H_0 + H_1 \cos(\omega\tau) + H_2 \cos(2\omega\tau) + \dots + H_n \cos(n\omega\tau) + \dots$$

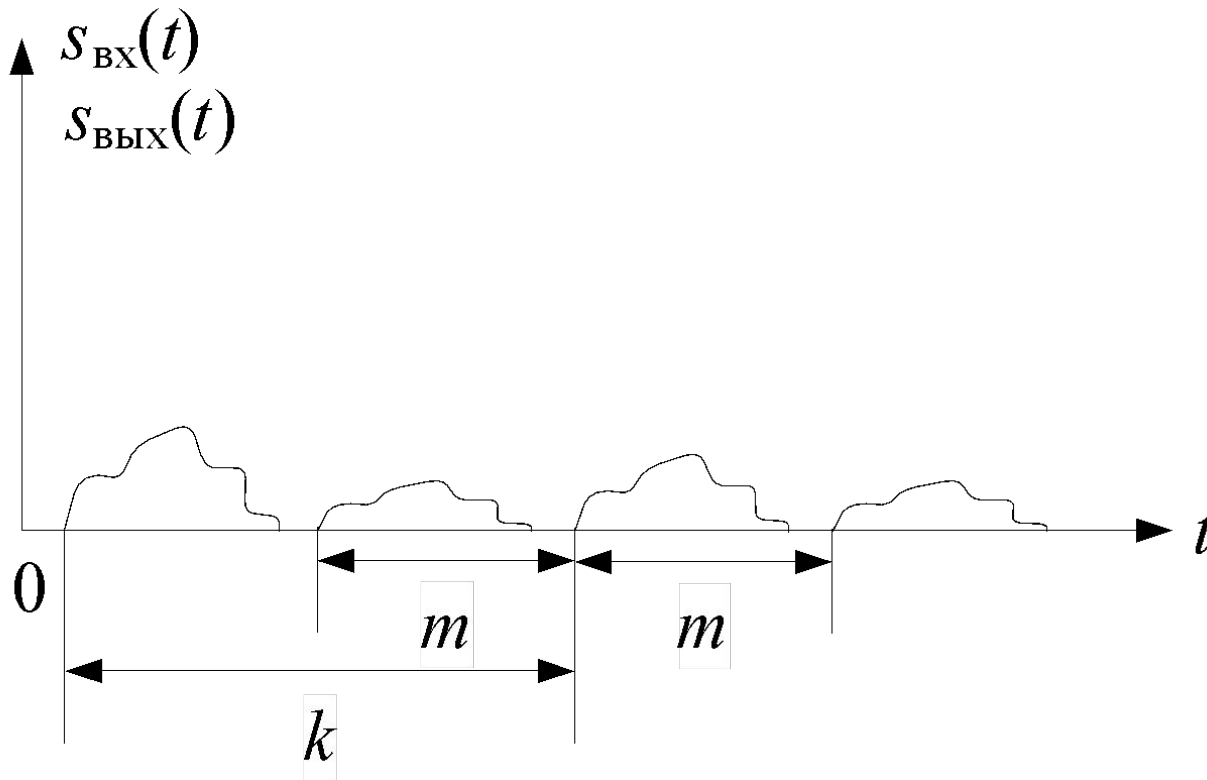
$$\varphi_k(\omega) = k\omega \pm 2\pi n$$

$$\begin{aligned} \mathcal{S}_{\text{ВЫХ}}(\omega) &= \mathcal{S}_{\text{ВХ}}(\omega)(H_0 + H_n \cos n\omega\tau) \exp(-jk\omega) = \\ &= \mathcal{S}_{\text{ВХ}}(\omega)(H_0 + H_n \cos m\omega) \exp(-jk\omega) \end{aligned}$$

$$s_{\text{ВЫХ}}(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \mathcal{S}_{\text{ВХ}}(\omega)(H_0 + H_n \cos n\omega\tau) \exp(j\omega(t - k)) d\omega$$

$$s_{\text{ВЫХ}}(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} S_{\text{ВХ}}(\omega) H_0 \exp(j\omega(t-k)) d\omega +$$

$$+ \frac{H_n}{4\pi} \left[\int_{-\infty}^{\infty} S_{\text{ВХ}}(\omega) \exp(j\omega(t-k+m)) d\omega + \int_{-\infty}^{\infty} S_{\text{ВХ}}(\omega) \exp(j\omega(t-k-m)) d\omega \right]$$



Сигнал на входе и выходе канала передачи с амплитудно-частотными искажениями.

ФАЗО-ЧАСТОТНЫЕ ИСКАЖЕНИЯ

$$\varphi_K(-\omega) = -\varphi_K(\omega)$$

Разложение амплитудно-частотной характеристики в ряд Фурье

$$\varphi_K(\omega) = k\omega + \varphi_{K1} \sin(\tau\omega) + \varphi_{K2} \sin(2\tau\omega) + \dots + \varphi_{Kn} \sin(n\tau\omega) + \dots$$

$$\varphi_K(\omega) = k\omega \pm \varphi_{Kn} \sin(m\omega)$$

$$t_{\text{гр}}(\omega) = \frac{d\varphi_K(\omega)}{d\omega} = k + m\varphi_{Kn} \cos(m\omega)$$

$$\mathcal{S}_{\text{ВЫХ}}(\omega) = \mathcal{S}_{\text{ВХ}}(\omega) H_0 \exp(-j(k\omega + \varphi_{Kn} \sin(m\omega)))$$

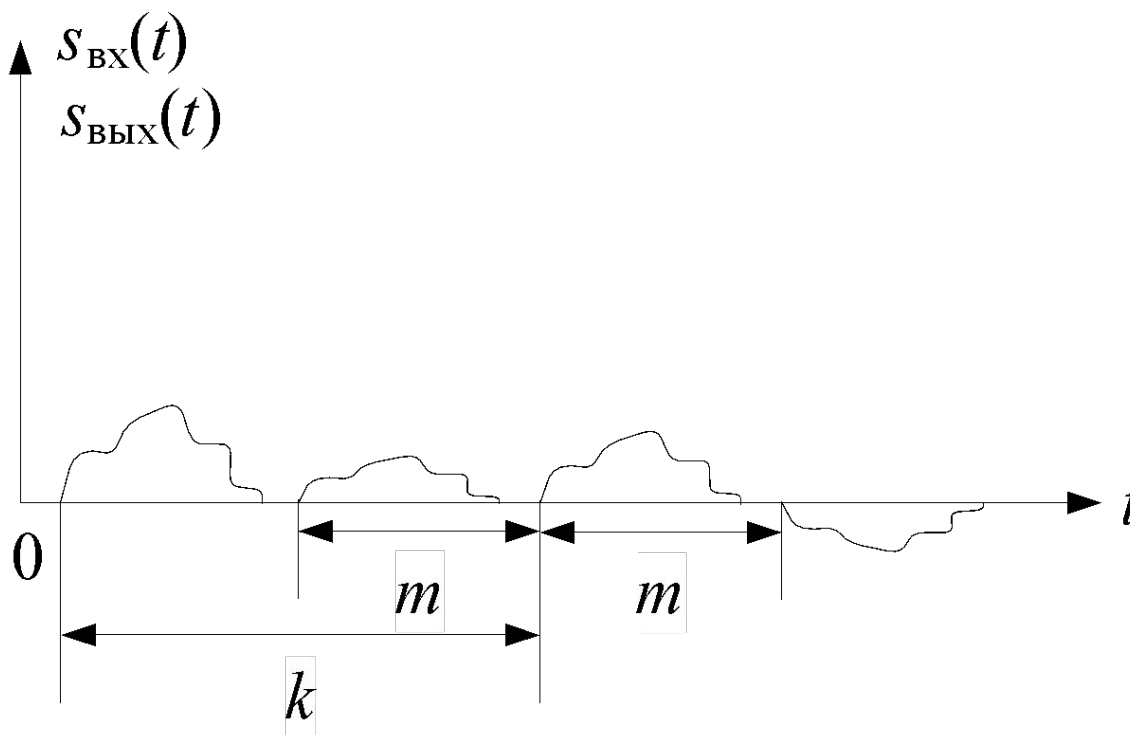
$$s_{\text{ВЫХ}}(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \mathcal{S}_{\text{ВХ}}(\omega) H_0 \exp(-j(k\omega + \varphi_{Kn} \sin(m\omega))) \exp(j\omega(t-k)) d\omega$$

$$\exp(-j\varphi_{Kn} \sin(m\omega)) \cong J_0(\varphi_{Kn}) + J_1(\varphi_{Kn}) \exp(-jm\omega) - J_1(\varphi_{Kn}) \exp(jm\omega)$$

$$e^{-j\varphi_{Kn} \sin(m\omega)} \cong \frac{H_0}{2\pi} \int_{-\infty}^{\infty} \mathcal{S}_{\text{ВХ}}(\omega) e^{j\omega(t-k)} \left[J_0(\varphi_{Kn}) + J_1(\varphi_{Kn}) e^{-jm\omega} - J_1(\varphi_{Kn}) e^{jm\omega} \right]$$

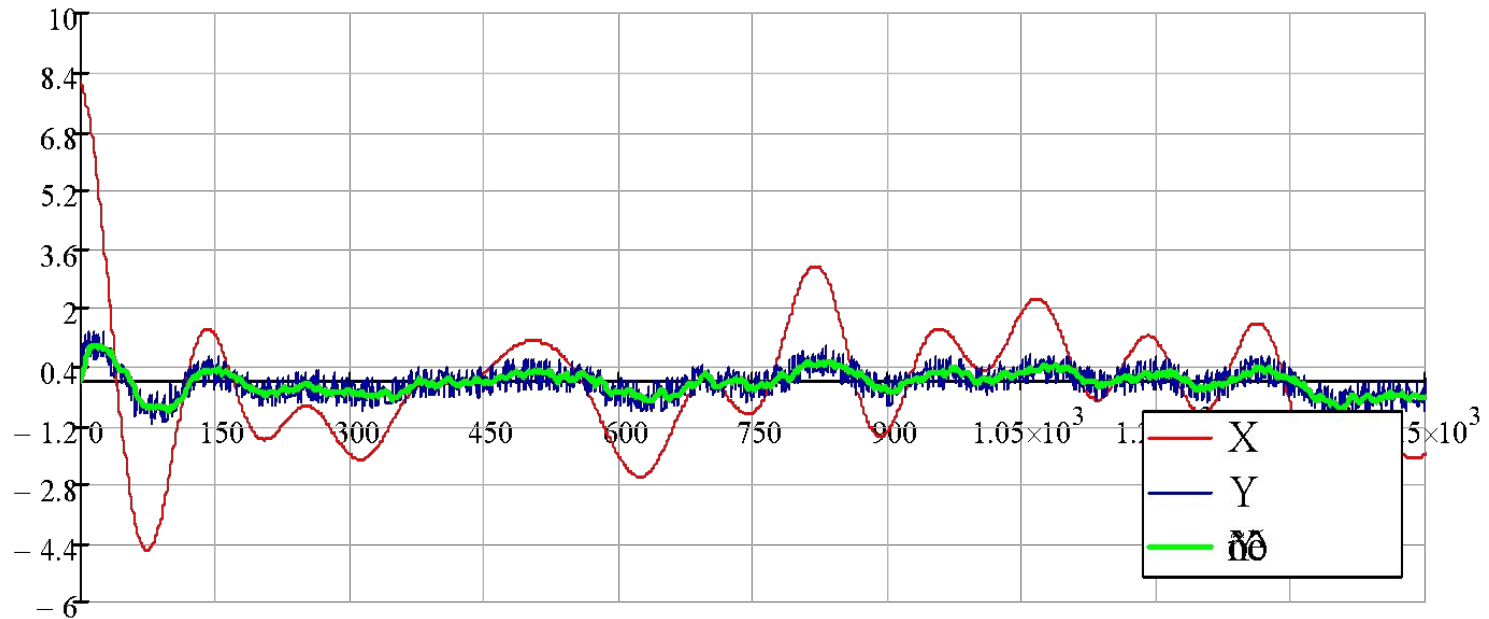
$$e^{-j\varphi_{kn} \sin(m\omega)} \cong \frac{H_0}{2\pi} \int_{-\infty}^{\infty} \boxed{s}_{\text{BX}}(\omega) e^{j\omega(t-k)} \left[J_0(\varphi_{kn}) + J_1(\varphi_{kn}) e^{-jm\omega} - J_1(\varphi_{kn}) e^{jm\omega} \right] =$$

$$= A_0 J_0(\varphi_{kn}) s_{\text{BX}}(t-k) + A_0 J_1(\varphi_{kn}) s_{\text{BX}}(t-k-m) - A_0 J_1(\varphi_{kn}) s_{\text{BX}}(t-k+m)$$

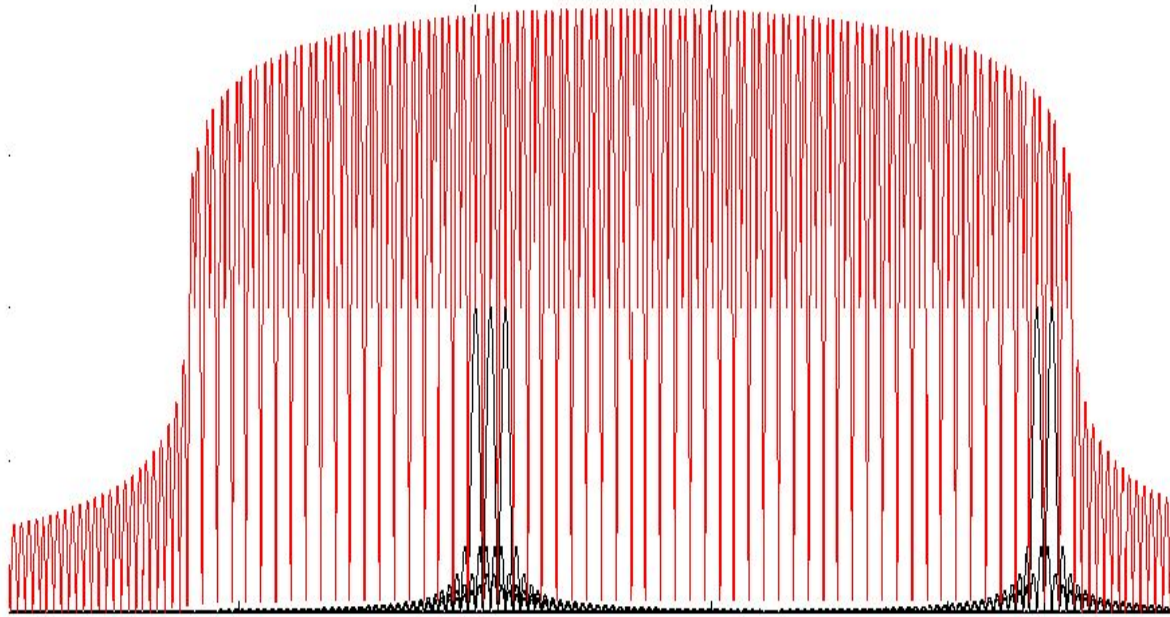


$$\boxed{H}(j\omega) = \boxed{H}_1(j\omega) \boxed{H}_2(j\omega) \boxed{H}_3(j\omega) \dots \boxed{H}_M(j\omega)$$

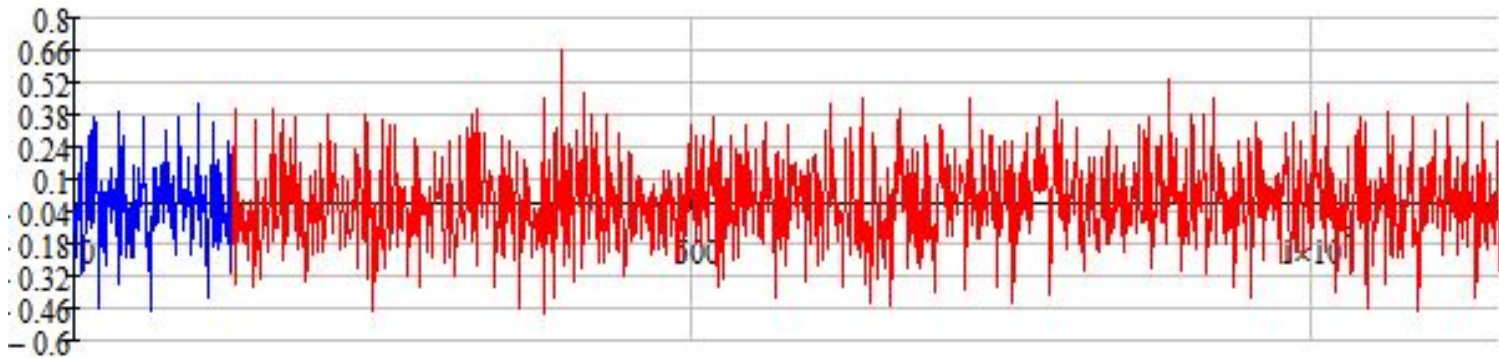
Пример работы фильтра скользящего среднего



Спектр сигнала OFDM



Сигнал OFDM



Обнаружение начала символа OFDM по циклическому префиксу и преамбуле

