Volga State University of Technology

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Correction for dispersion distortions of frequency response of wideband HF radio channel with the use of the deconvolution method

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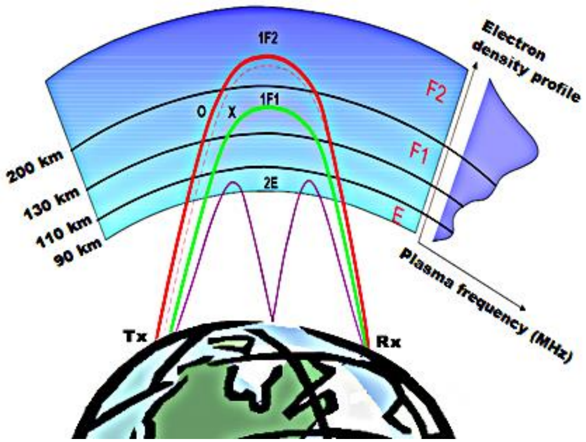
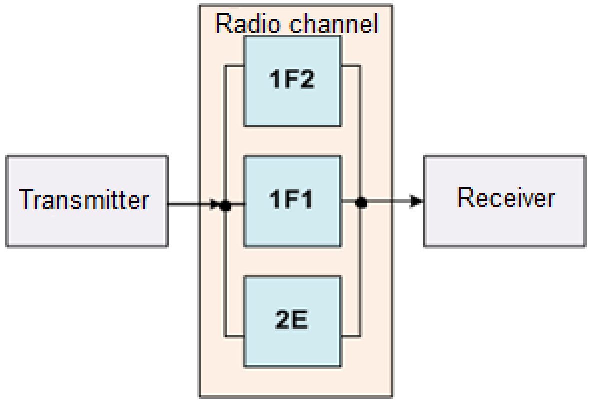
Propagation of HF signals in the Earth's ionosphere





Frequency response (FR) of ionospheric channel:

$$H(j\omega,t) = H(\omega,t)\cdot\exp[-j\varphi(\omega,t)]$$

Impulse response (IR) of ionospheric channel:

$$h(\tau,t) = F^{-1}\left[H(j\omega,t)\right]$$

Signal $u_T(t)$ transmitted over an ionospheric radio link and received signal $u_R(\tau,t)$ are related by the convolution operator:

$$u_R(\tau,t) = u_T(t)\otimes h(\tau,t)$$

where τ – fast time (signal delay) and t – slow time (geophysical time).

In the frequency domain the relation is as follows:

$$U_R(j\omega,t) = H(j\omega,t)\cdot U_T(j\omega)$$

where $U_{T,R}$ – spectra of the transmitted and received signals, respectively.

Function $u_T(t)$ can be derived by applying inverse filtering:

$$u_T(t) = F^{-1}\left[U_R(j\omega,t)/H(j\omega,t)\right] = F^{-1}\left[U_R(j\omega,t)\cdot H^{-1}(j\omega,t)\right]$$

General approach to solving the problem of deconvolution of a wideband HF signal

Wideband communication systems operate over a varying ionospheric radio channel, that can be modeled by a linear system with the following frequency response:

(1) $$H(j\omega,t)=\begin{cases} H(\omega,t)\cdot\exp[-j\varphi(\omega,t)], & if \quad \omega\in\left[\omega_c-\Omega_{ch}/2,\omega_c+\Omega_{ch}/2\right] \\ 0, & if \quad \omega\notin\left[\omega_c-\Omega_{ch}/2,\omega_c+\Omega_{ch}/2\right] \end{cases}$$

where ω - angular frequency, ω_c - channel mid-band frequency, Ω_{ch} - channel bandwidth, $H(\omega,t)$ - amplitude-frequency response and $\varphi(\omega,t)$ - phase-frequency response of the channel.

Employed wideband spread spectrum signals can be represented in the frequency domain as follows:

(2) $U_T(j\omega)=U(\omega)\cdot\exp j\phi(\omega)\cdot\hat{U}_T(\omega)$, where $U(\omega)$ - amplitude-frequency response and $\phi(\omega)$ - phase-frequency response of a communication signal, $\hat{U}_T(\omega)$ - carrier spectrum.

Signal spectrum at the receiver input :

(3) $$U_R(j\omega,t)=H(\omega,t)\cdot\exp[-j\varphi(\omega,t)]\cdot U(\omega)\cdot\exp j\phi(\omega)\cdot\hat{U}_T(\omega)$$

Filtration of both the channel components and the carrier signal is performed by applying deconvolution as inverse filtering together with the matched filtering. So, that operation is represented as follows:

(4) $$U_R(j\omega,t)\cdot\frac{\exp[j\varphi(\omega,t)]}{H(\omega,t)}\cdot\hat{U}_T^*(j\omega)=U(\omega)\cdot\exp j\phi(\omega)\cdot|\hat{U}_T(\omega)|^2$$

The problem of noise that corrupts channel FR measurements and influence deconvolution of a wideband HF signal

Time instant $t = t_1$:

$$H(j\omega,t)=(I_H(\omega,t)+x(\omega,t))+j(Q_H(\omega,t)+y(\omega,t))=\tilde{I}_H(\omega,t)+j\tilde{Q}_H(\omega,t)$$

, where $x(\omega,t)$; $y(\omega,t)$ - noise quadrature components.

Calculation of FR of the inverse filter

$$K(j\omega,t_1)=\frac{1}{H(j\omega,t_1)}=\frac{H^*(j\omega,t_1)}{H^2(\omega,t_1)}=\frac{\tilde{I}_{1H}(\omega,t_1)-j\tilde{Q}_{1H}(\omega,t_1)}{\tilde{I}_{1H}{}^2+\tilde{Q}_{1H}{}^2}$$

Time instant $t = t_2$:

$$H(j\omega,t_2)=(I_{1H}+x(\omega,t_1)+x(\omega,t_2))+j(Q_{1H}+y(\omega,t_1)+y(\omega,t_2))=$$
$$=H(j\omega,t_1)+(x(\omega,t_2)+jy(\omega,t_2))$$

Effect of the inverse filter on new samples of the FR

$$K(j\omega,t_1)\cdot H(j\omega,t_2)=\frac{H(j\omega,t_2)}{H(j\omega,t_1)}=1+\frac{(x(\omega,t_2)+jy(\omega,t_2))}{H(j\omega,t_1)}=$$
$$=1+M_0K(j\omega,t_1)\cdot[\frac{x(\omega,t_2)}{M_0}+j\frac{y(\omega,t_2)}{M_0}]$$

, where $M_0=\left\langle\sqrt{I_H{}^2+Q_H{}^2}\right\rangle\Big|_{\omega}$

IR of the corrected channel under the influence of noise

The frequency dependence of $M_0 K(j\omega, t_1)$ is derived from experimental data. The values x and y are specified relatively M_0 (in fractions of that value) and defined by the signal-to-noise ratio in the channel. We assumed that they have a normal distribution with the same standard deviations ($\frac{\sigma_x}{M_0} = \frac{\sigma_y}{M_0}$), but they do not correlate with each other, i.e. the samples are independent.

Let us denote: $\xi = -20\log\left(\frac{\sigma_x}{M_0}\right) = -20\log\left(\frac{\sigma_y}{M_0}\right)$

Rapidly changing noise will influence IR of the corrected channel:

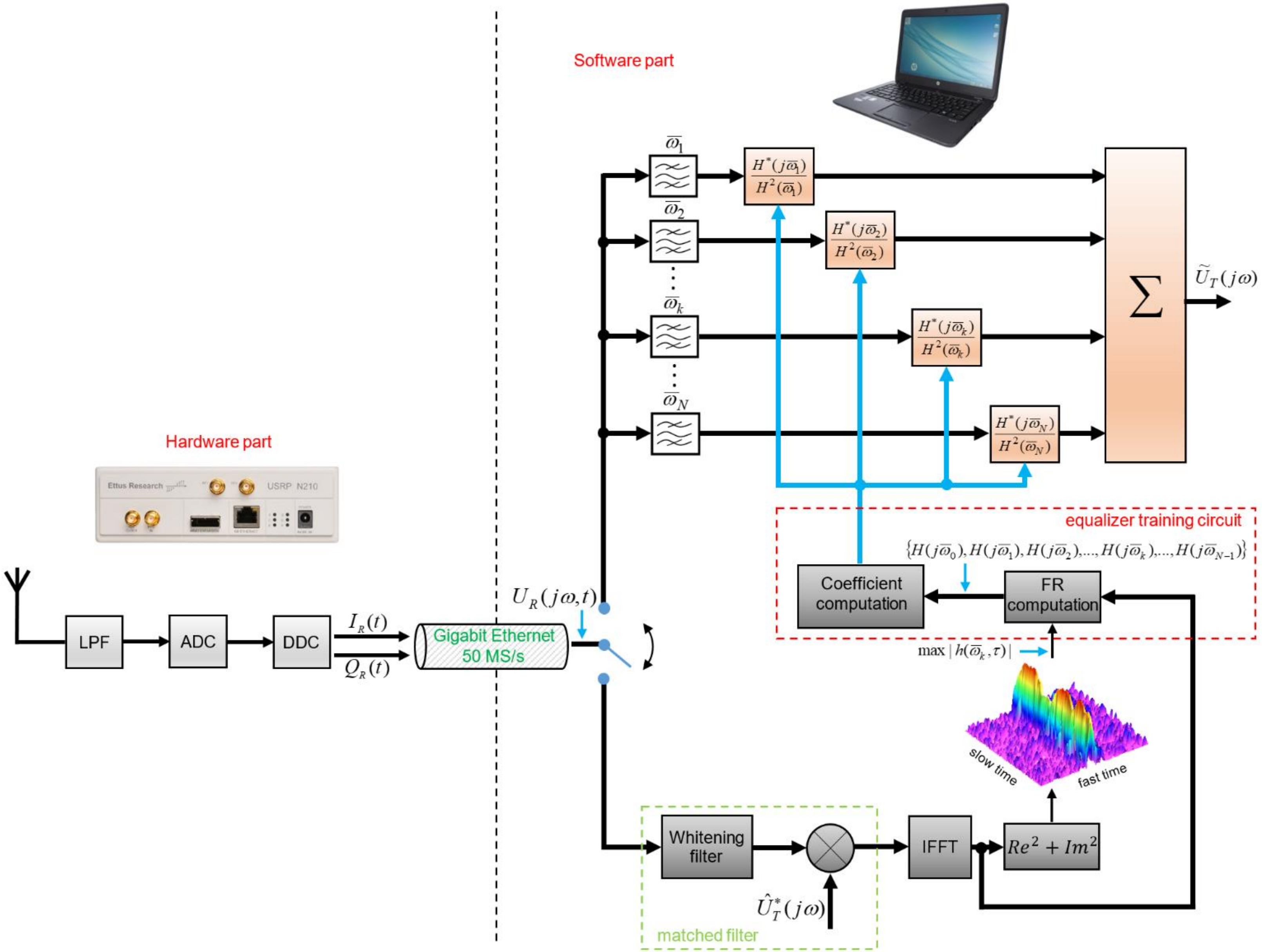
$$h(\tau, t_1) = \int_{\omega_1}^{\omega_2} K(j\omega, t_1) \cdot H(j\omega, t_1) \cdot \exp j\omega\tau \frac{d\omega}{2\pi} \quad (5)$$

$$h(\tau, t_2) = \int_{\omega_1}^{\omega_2} K(j\omega, t_1) \cdot H(j\omega, t_2) \cdot \exp j\omega\tau \frac{d\omega}{2\pi} =$$

$$= h(\tau, t_1) + \int_{\omega_1}^{\omega_2} \left[M_0 K(j\omega, t_1) \cdot \left(\frac{x(\omega, t_2)}{M_0} + j\frac{y(\omega, t_2)}{M_0}\right) \right] \exp j\omega\tau \frac{d\omega}{2\pi} = h(\tau, t_1) + u_N(\tau, t_2) \quad (6)$$

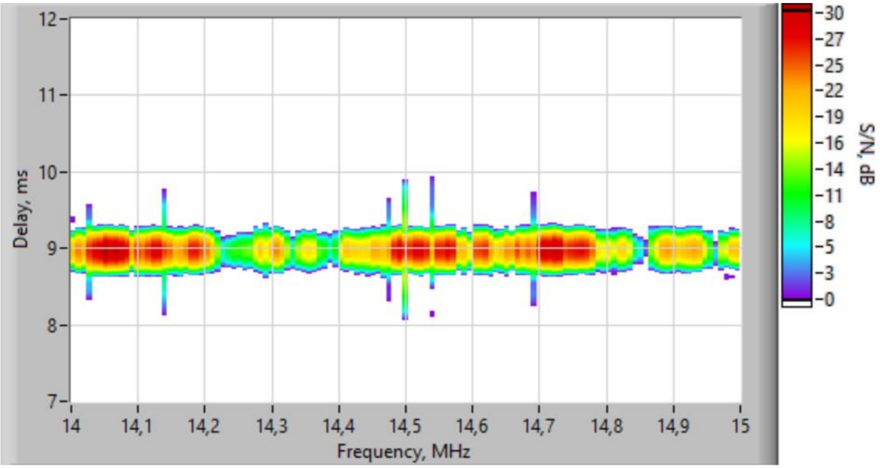
Equations (5) and (6) allowed to numerically calculate these integrals and determine the signal-to-noise ratio in the first $SNR_1[dB]$ and second $SNR_2[dB]$ cases. They were used to estimate the losses due to inverse filtering when measurements are corrupted with errors and noise: $\eta_{loss} = SNR_1 - SNR_2$

Test facility of system of adaptive correction for frequency dispersion in a wideband channel

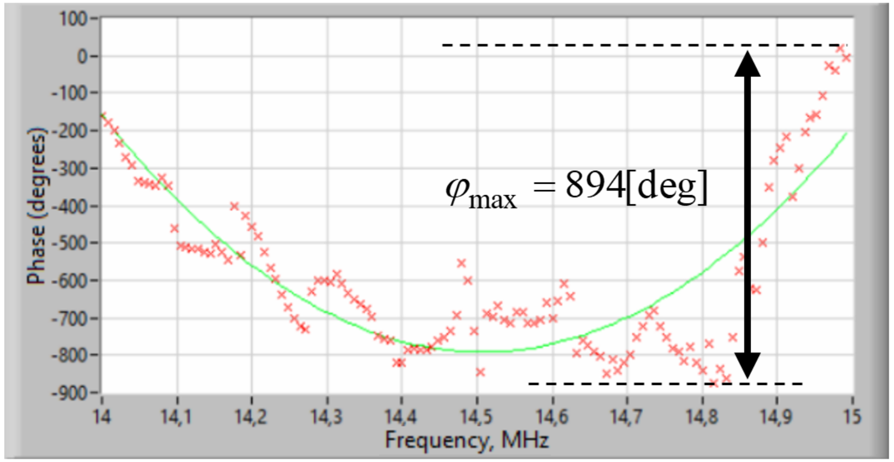


Experiments on sounding ionosphere and wideband (1 MHz) radio channels

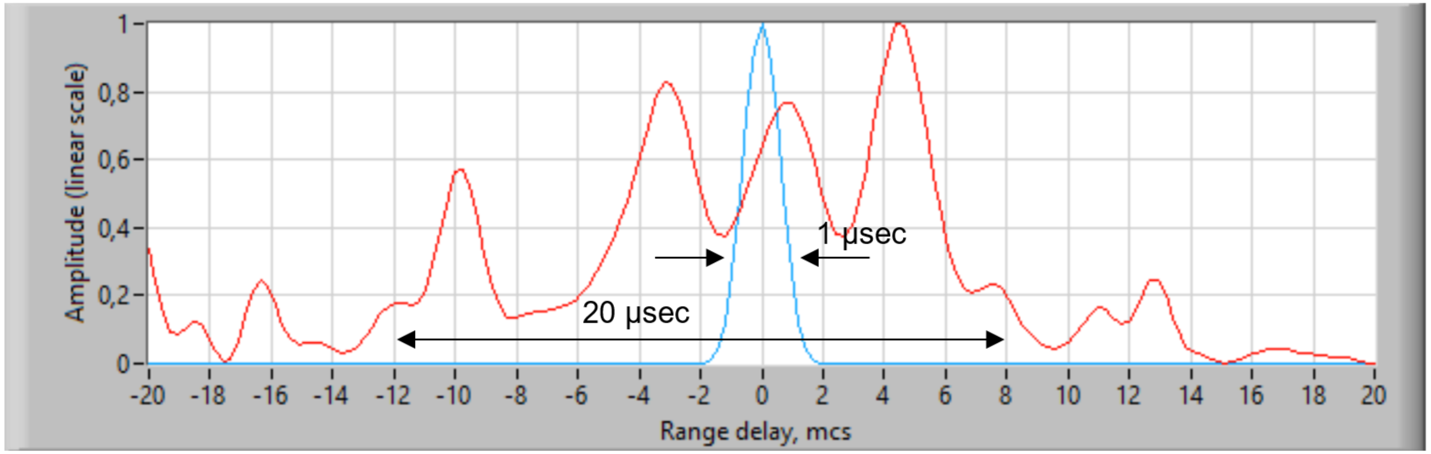
Amplitude-frequency response of the 1 MHz single-mode channel



Phase-frequency response of the 1 MHz channel and its approximation



IR of the 1 MHz radio channel before and after correction without error



Experimental estimation of losses after signal deconvolution

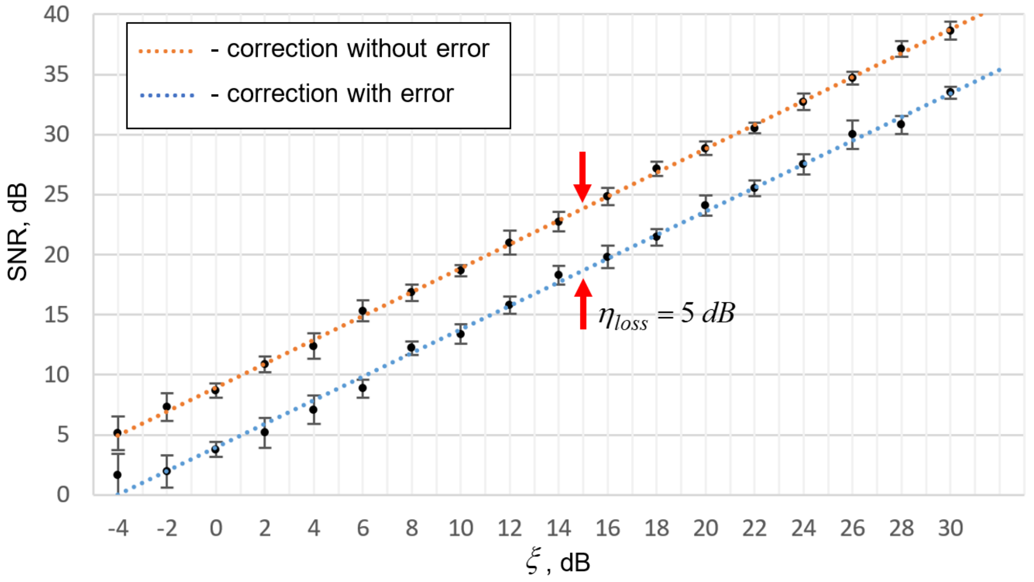
Signal-to-noise ratio losses after deconvolution for a 1 MHz channel with a fading depth of up to 20 dB

ξ, dB	SNR_1, dB	SNR_2, dB	η_{loss}, dB
-4	5.1±2.3	1.6±2.9	3.5
-2	7.3±1.9	1.9±2.2	5.4
0	8.7±0.9	3.8±1	4.9
2	10.8±1.1	5.1±2	5.7
4	12.4±1.7	7.1±1.9	5.3
6	15.3±1.4	8.9±1.2	6.4
8	16.8±1.1	12.2±0.9	4.6
10	18.7±0.7	13.4±1.3	5.3
12	21±1.6	15.8±1.2	5.2
14	22.7±1.3	18.3±1.2	4.4
16	24.9±1.2	19.8±1.5	5.1
18	27.1±1	21.4±1.1	5.7
20	28.9±0.9	24.1±1.4	4.8
22	30.5±0.7	25.5±1.1	5
24	32.7±1.1	27.5±1.4	5.2
26	34.7±0.8	30±1.9	4.7
28	37.1±1	30.8±1.2	6.3
30	38.6±1.2	33.5±0.8	5.1

Regression dependences of the signal-to-noise ratio in the channel for the cases of correction without error (1) and for the case with error (2):

$$SNR_1(\xi) = 0.994\xi + 8.938$$

$$SNR_2(\xi) = 0.981\xi + 3.957$$



Experimental estimation of losses in data transfer rate and gain in covertness of communication

Requirements for the modems that ensure data rates over the HF channel from 75 baud to 2400 baud, satisfying the STANAG 4539 standard

Data rate (baud)	SNR (dB)	Doppler spread (Hz)	Delay spread (ms)
2400	>14	<4	<5
1200	>7	<8	<5
600	>3	<12	<5
300	>0	<16	<5
150	>-3	<10	<5
75	>-7	<40	<16

Requirements for the modems that ensure data rates over the HF channel from 3200 baud to 9600 baud, satisfying the MIL-STD-188-110B standard

Data rate (baud)	SNR (dB)	Doppler spread (Hz)	Delay spread (ms)
9600	>18	<0.5	<3.5
8000	>15	<1	<4
6400	>13.5	<1.5	<4
4800	>10.5	<2	<4
3200	>10	<2.5	<5

Losses in the signal-to-noise ratio of up to 5 dB after signal deconvolution can lead to a decrease in the data transfer rate by 2 ... 4 times if the signal-to-noise ratio in the corrected channel do not exceed 18 dB.

The gain in the covertness increases by the value:

$$G = 10\log(B_s / b_s) = 10\log(B_s / R) = 10\log(B_s T_b)$$

For instance, a channel with bandwidth of **1 MHz** for a 100 bps data stream would provide the processing gain of **40 dB**. The margin of covertness can be used to increase the transmitted power and to compensate the losses in the data rate.

Conclusions:

- ✓ Experimental studies carried out on the mid-latitude radio path Cyprus-to-Yoshkar-Ola showed that losses due to signal deconvolution reaches up to 5 dB in a 1 MHz bandwidth single-mode channel with fading depth of up to 20 dB (the worst case of the operation of a communication system).
- ✓ These losses cause a decrease in the data transfer rate of spread spectrum communication systems by 2 ... 4 times, if the signal-to-noise ratio in the corrected channel do not exceed 18 dB.
- ✓ Since the gain in covertness of spread spectrum communications is defined by the product of bandwidth and data rate, a 1 MHz bandwidth channel for a 100 bps data stream would provide the processing gain of up to 40 dB.
- ✓ The margin of covertness can be used to increase the transmitted power and to compensate for losses in the data rate.

Thank you!

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