# ANALYSIS OF SPREAD SPECTRUM SYSTEM PARAMETERS FOR DESIGN OF HIDDEN TRANSMISSION

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## Abstract

*A short analysis of spread spectrum communication system is performed with respect to the determination of its fundamental system parameters for transmitted signal hidden in the noise. The paper shows dependence of processing gains on the correlation circuits at the receiver side. The distance, from which the transmitter signal is hidden is noise, depends on the spread spectrum factor and the transmitted power. At a given interference power density and at a given requirement of transmitted signal hiding we can calculate the spreading factor of system. A processing gain of spread spectrum system determines a depth of signal hiding in the noise. A transmission range of spread spectrum communication system is given by the transmitted power and the processing gain of the system.*

## Keywords:

Spread spectrum factor, processing gain, spread spectrum system, signal hiding in the noise, transmission range.

## 1. Introduction

The reliability and security of the channel can be improved by increasing its immunity against a jamming or by hiding the transmitted signal in the noise [1]. For this reason, the often requirement on special communication systems is to hide a transmitted signal in the interference and noise. The hidden transmission of signal can be detected only by a correlation detector, which is able to detect known address signal under the level of noise. The spread spectrum system is able to transmit a signal under the noise.

After the short analysis of fundamental spread spectrum system parameters, we will discuss how to determine and calculate the hidden space of spread spectrum signal and the transmission range of the spread spectrum system.

## 2. Analysis of base spread spectrum system parameters for hidden transmission

### 2.1 Spreading Factor and Hiding of Transmitted Signal

The hiding of radio signal in the noise depends on thepower spectral density of interference and on the spread spectrum factor (spreading factor) of the transmitted signal, which is define by

$$F = \frac{B_{ss}}{B_i}\,, \tag{1}$$

where $B_{ss}$ is a bandwidth of spread transmitted signal and $B_i$ is a bandwidth of information signal before spreading as it is shown in Fig.1a. We can suppose, that the both data modulator and spreading modulator are the same and the data rate and clock rates of PN generator are $f_i$ and $f_{PN}$ respectively, than the spreading factor can be written

$$F = \frac{f_{PN}}{f_i}\,. \tag{2}$$

The same result we can get by modulation system show in Fig.1b, where data and PN sequence are added by EX-OR circuit and than they are connected to the common PSK modulator.

The transmission range depends on the mean transmitted power $P_t$, on the interference power density $p_n$ at the receiving point, but does not depend on the spread spectrum factor $F$ of the transmitted signal.

Transmitted radio signal is hidden, only when its spectral power density is smaller than the interference and noise of transmission channel.. The spectral power density before spreading at the transmitter is $p_t = P_t \,/\, B_i$ . The spectral power density after spreading by address signal will be

$$p_{ss} = \frac{p_t}{F}. \tag{3}$$

The spreading factor is realised in the modulator, Fig.1. We can say that the hiding of signal is performed by signal spreading in the modulator. The relations among the frequency bandwidths and densities of signals are drawn in Fig.2.

Consider the signal transmission in the free space without the additional attenuation,, then the power spectral density at the distance $r$ from the transmitter will be

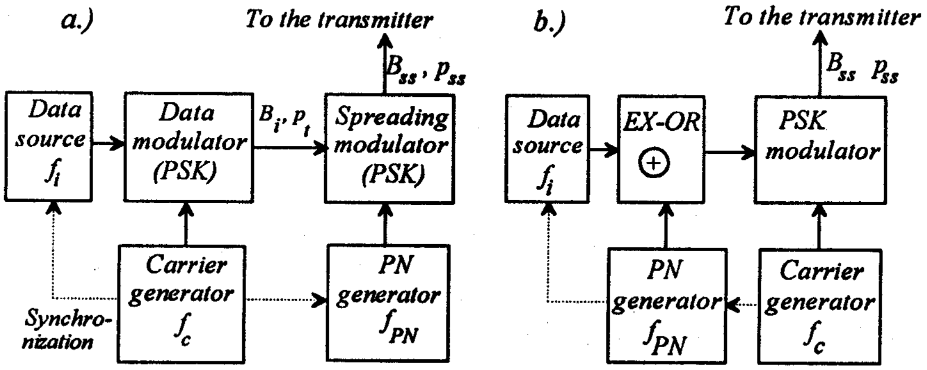


Fig.1 Principle diagrams of spread spectrum modulation systems

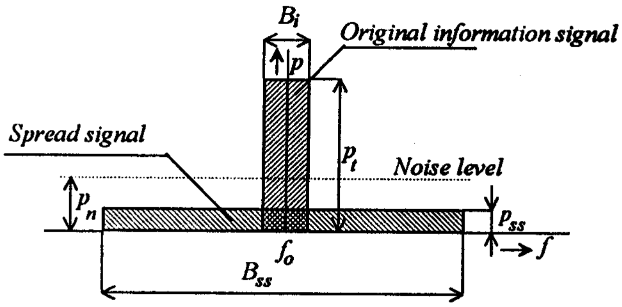


Fig.2 The spectral power densities and bandwidths of signals

$$p(r) = \left(\frac{\lambda}{4\cdot\pi\cdot r}\right)^2 \frac{P_t}{B_i\cdot F}, \tag{4}$$

where $P_t$ is the isotropic transmitted power.

Suppose the power density of interference and noise is a constant value, which does not depend on the distance from the transmitter. If the signal power density $p(r_s)$ is lower than the interference power density $p_n$

$$p(r_s) \le p_n , \tag{5}$$

then the communication system is hidden in the noise from the distance $r_s$ the transmitter. The transmitted signal will be hidden far from the distance [2]

$$r_s = \frac{\lambda}{4\pi}\sqrt{\frac{P_t}{B_i\cdot p_n\cdot F}} . \tag{6}$$

The radius, from which the electromagnetic transmitted energy is hidden, depends on the transmitted power $P_t$ and spreading factor $F$. The transmitted power is designed according to the range of transmission. The signal hiding will depend namely on the spreading factor $F$. The dependence of signal hiding on the spreading factor and the distance $r$ is drawn in Fig.3. The value of spectral power density depends on the wavelength $\lambda$, therefore the power signal density is drawn in a dependence on the ratio $r_s/\lambda$.

The spreading factor ($F$=*1, 10, 100* and *1000*) is a parameter of curves on Fig.3 . The curves are drawn for the transmitted spectral power density $p_t = P_t/B_i = 2.10^{-4}$ [W/Hz]. For example, for the signal of 200 MHz ($\lambda$ = 1,5 m) at $F$= 1000, the signal will be hidden from the transmitter of distance ~10,5 m (7λ) and for $F$ = *10* it will be $r_s$~115,5 m (77 λ).

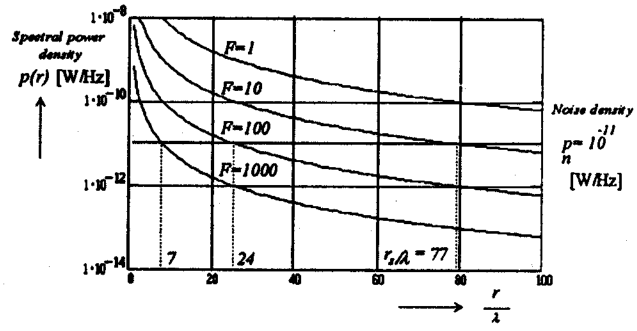


Fig.3 The power signal density on the distance from the transmitter

## 2.2 The processing gains and detection of hidden signal

In the published literature [3], [4] and other, the processing gain is incorrectly defined by the same equation as it is done by the same equation as for our spreading factor (eq. (1), (2)). The spreading factor depends on the modulator of transmitter, but the processing gain is realised by a receiver correlation [5], Fig.4

$$G_p = \frac{B_{ss}}{B_{pn}} , \tag{7}$$

where $B_{ss}$ is a bandwidth of spreaded signal and $B_{pn}$ is a noise bandwidth of the integrating narrow band filter of the correlator in the receiver. Equation (7) gives the processing gain of data channel.

Data transmission is able only when the synchronisation of the transmitter and receiver is reached. The process of starting of synchronisation is most difficult from all steps (stages) of communication. After the

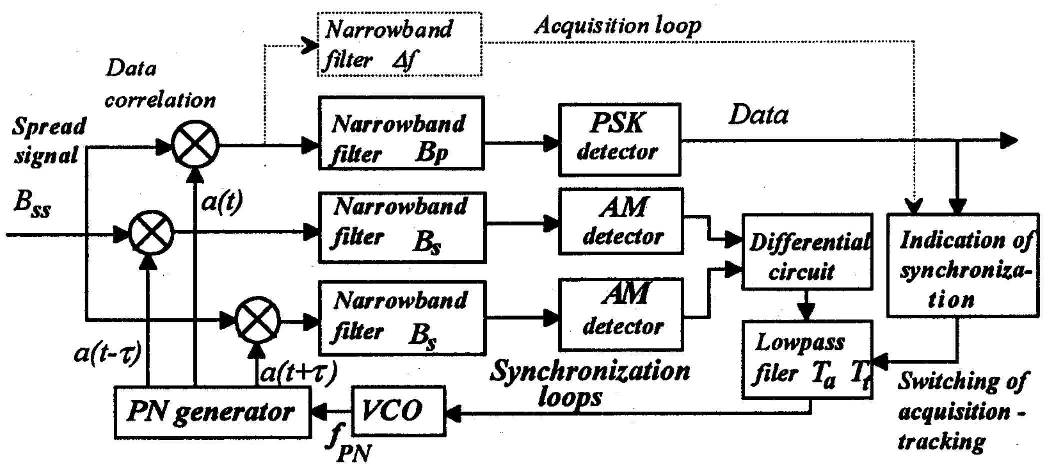


Fig.4 The receiver correlators

acquisition of synchronisation (address) signal, we must ensure a synchronisation during the all time of communication. Synchronisation of system consist of the two steps :

1. **Acquisition** - which must detect the PN signal and find the correct phase of PN sequence.
2. **Tracking** - which must keep the synchronisation of PN sequence of the transmitter and receiver.

The processing gain of synchronisation depends on the total integration time of the correlation filter. The acquisition processing gain depends on the scan rate of PN sequence coming from the transmitter. Maximum searching (acquisition) time of PN sequence depends on the length $L_s$ and on the frequency difference of the PN generator clock frequency at the transmitter and receiver

$$T_v = \frac{L_s}{\Delta f}, \tag{8}$$

where $\Delta f = f_{PNrec.} - f_{PNtran.}$. The mean value of searching time will be half of maximum value

$$T_{vs} = \frac{L_s}{2 \cdot \Delta f} \ . \tag{9}$$

The effort of user is usually to shorten the acquisition time, for this reason the PN sequence for the acquisition of synchronisation is chosen shorter as it is possible. The short sequence contains expressive strong spectral lines. After the acquisition, during data transmission, the PN sequence is switched over to the longer sequence.

The acquisition processing gain can be defined in the general form as a ratio of the integration time $T_{int}$ to the clock period of PN sequence $\tau$

$$G_{sa} = \frac{T_{int}}{\tau} \ . \tag{10}$$

When the PN sequence contains Ls chips and when the integration in the correlator will continue during the time of one sequence period, then the integration time will be

$$T_{int} = L_s \cdot \tau \tag{11}$$

and in this case the acquisition processing gain will be equal to sequence length $G_{sa} = L_s$.

The sequence of length $L$ will be searched during the time $T_{sa} = L \ / \ \Delta f$ . The searching of sequence is performed $L$ times, it means that the searching time will be $T_{sa} = L.T_{int}$ . From these equations for $L_s = L$ we can get

$$T_{sa} = L_s^2 \cdot \tau \ . \tag{12}$$

We can see that the searching time will increase by the square of sequence length $L_s$. The integration time will be

$$T_{int} = \frac{1}{\Delta f} \tag{13}$$

and the frequency difference between the receiver's and transmitter's clock sequence frequency

$$\Delta f = \frac{1}{L \cdot \tau} \ . \tag{14}$$

Until this time the autocorrelation function was supposed as ideal. Suppose the main peak of autocorrelation function is $L$ and the next peak is $P$, than the acquisition processing gain is decreased by the factor

$$K = 1 - \frac{P}{L} \ . \tag{15}$$

The acquisition processing gain can be written by

$$G_{sa} = \frac{1}{\tau} \cdot \frac{1}{\Delta f} \cdot K \ . \tag{16}$$

At the optimal filtration (eq. 14) and at the ideal autocorelation function (only one main peak of value $L$) the acquisition processing gain will be equal to the sequence length $L$. We can say that the acquisition processing gain will be higher when the integration time $T_{int}$ will be longer and the frequency difference $\Delta f$ will be smaller.

In the case that the data correlation filter of bandwidth $B_p$ will be used, then the real acquisition processing gain will be

$$G_{sar} = \frac{1}{\tau} \cdot \frac{1}{B_{pn}} \cdot K \tag{17}$$

For acquisition the pseudonoise sequence of maximal length is suitable to use. At the length of sequence $L = 2^n - 1$ and at the given processing gain $G_{sa}$, the synchronisation PN sequence will be generated by the shift register of length $n = log_2 G_{sa}$. For this case and for the given spreading factor the "sliding" frequency can be calculated by the equation [3]

$$\Delta f = \frac{B_{ss}}{G_{sa}} \ . \tag{18}$$

The optimum value of the correlation filter is $\Delta f = B_p$. The integration time at acquisition depends on the correlation filter bandwidth $B_{sa}$

$$G_{sa} = \frac{B_{ss} \cdot K}{B_{sa}} \ . \tag{19}$$

The phase tracking of the receiving PN sequence is performed by the tracking synchronisation loop, which form the time discriminator. The processing gain of the tracking loop is given by

$$G_{st} = \frac{B_{ss}}{B_s} + T_d B_{ss} \ , \tag{20}$$

where $B_s$ is a frequency bandwidth of correlation filter and $T_d$ is additional integration in next circuits of tracking loop. The processing gain at tracking can be realised more easily then the previous processing gains. The value of the tracking processing gain is recommended higher than data or acquisition gains. The disturbance of synchronisation during the transmission will produce the interruption of communication for longer time, because the acquisition must be performed usually by the working pseudonoise sequence, which is longer then the synchronisation pseudonoise sequence at acquisition time.

## 3. Conclusion

In this paper we have studied the performance analysis of a fundamental spread spectrum parameters in communication systems, which will be used for hidden transmission or as antijamming communication systems. These parameters are explained in many references [3], [4] very roughly and incorrectly. Introduced definitions of these parameters in references depend on the transmitted signals and they produce fundamental errors in a system design. The processing gains are realised in receiver, therefore our definitions depend on the circuits of receivers. According to the Fig.3 we can determine the distance, from which the transmitted signal is hidden in the noise, at given spread factor and noise density. Simultaneously we can determine the value of the processing gain, which is necessary for a demodulation of hidden signal in the noise. The designers of such systems can design the transmitter receiver circuits (clock frequency of PN sequence, transfer rate of data, frequency bandwidth of correlation filters, integration time, ...) for given fundamental parameters of transmission.

## 4. References

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