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전력선통신에서 직접확산 스펙트럼(DSSS) 계의 성능 분석

(Performance Analysis of Direct-Sequence Spread Spectrum(DSSS) System in Power Line Communications)

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요 약

본 논문에서는 전력선통신에서 발생하는 잡음에 대해서 DSSS을 적용할 수 있는 가능성을 분석했다. 이 잡음은 4가지가 있는데, 이들 잡음을 분석하기 위해서 특성에 따라서 실제로 전력선에서 발생하는 잡음원을 만들었다. 이들 잡음모델을 대상으로 DSSS을 적용한 BPSK의 BER 성능을 DSSS을 적용하지 않는 BPSK의 경우와 비교해서 모의실험하고 분석했다. 그 결과, DSSS을 적용한 BPSK의 경우가 DSSS을 적용하지 않는 BPSK의 경우에 비해서 8 dB 개선되었음을 알 수 있었다.

Abstract

In this paper, we first analysed the ability of DSSS resistance against noises, which are main interferences to the four types in power line communications. Based on the characteristic of these noises, we made a noise source of power line which is similar with the result measured, in practice. We simulated and analysed the BER performance of BPSK with DSSS over this noise model and one without the DSSS, for comparison. Result showed that the BPSK with DSSS system has improved by 8 dB, as compared to those without the DSSS, as against power line noises.

Keywords: Direct-Sequence Spread Spectrum communication (DSSS), BPSK, power line communications.

I. Introduction

Electrical power lines which is a convenient and it also serves as an alternative to our daily communication needs. They can be found in all buildings and at residential areas. In rural areas, access to the telecommunication companies is difficult. Radio coverage and reception is poor and it is also very expensive to access through one way satellite. Whereas, communication through the power lines is more feasible and is much better than the above. As such, the electrical power supply system is on its way, to integrate with the pure energy distribution network, and into a multipurpose medium of delivering, such as, energy, voice and various data services. In particular, Internet access is currently the focus in the various research activities [1].

As power line network is designed for electrical energy delivery, rather than for data transmission, it differs considerably in topology, structure and physical properties, as opposed to the conventional media, such as, twisted pair, coaxial or the fiber optic cables. The characteristics of power line are time-varying and it has various types of noises. An example would be the losses of signal on power line which vary on different time. Hence, interference of noises to the power line is an extremely serious case which needs to be looked into. Therefore, power line

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system is receiving a hostile approach [3].

In order to have an appropriate system design in a computer simulations, modelling the transfer characteristics of the main network and finding the advanced signal processing method are of major interest[2].

Many studies were done on the finding of the various types of noises in the power line [4, 5, 6, 9, 10]. Sources of noise, such as from motors or radio signals may result in a noise curve in the power supply, which also depends on the location and the timing of the incident. In general, the channel of noises may varies in accordance to the frequency, load, timing of the day and the geographical location. There are four types of noises in the power line system, as follows: (a) Colored background noise which is the summation of low power sources, such as universal motors, whose power spectral density is frequency-dependent and it decreases when frequencies increased. (b) Periodic impulse noise stemming from appliances that produced harmonics of 50 or 100 Hz. (c) Narrow band noise which consists of sinusoidal signals with modulated amplitudes (radio stations, the horizontal retrace frequency for television, etc). (d) Asynchronous impulse noise (noise burst from switching operation).

Attenuation, as well as impulse and background noise measurement, were reported [7]. The noise power level ranges according to the distance between the noise and the receivers, and the impulse noise is much higher than the background noise. Whereas, the Power spectral density can be more than 60 dB above the background noise level.

For a better performance on the power line communication, selection of modulation scheme is important for overcoming the noise in the power line network. According to the various types of noises in the power line, the selection of a modulation scheme for power line communication, have to consider these three factors: (a) The presence of noise and impulse disturbances, causing a relative low SNR. (b) The time-varying frequency selective nature of the channel, and (c) Regulatory constraints with regards to electromagnetic compatibility, that limits the transmitted power. In [8, 11, 12], the advantages of the interference suppression of DSSS is highlighted, but there is no experimental data exhibited.

In this research, we analysed the performance of DSSS in suppressing power line both theoretically and practically. According to the property of power line noises, we realized that the power line noises consists of various single frequency sine noise, white Gaussian noise and impulse noise. And if DSSS is able to suppress the above three kinds of noises, as well as the power line noises. Then, our simulation test for the above is clearly illustrated, which showed an improvement of 8 dB in the DSSS.

This paper is organized as follows. In Section Ⅱ, we discuss the property of DSSS and its performance resisting single frequency noise, white Gaussian noise and impulse noise in theory. In Section Ⅲ we construct a model of power line noise. Using the model, we conducted simulations to check whether DSSS is suitable for power line communications. We concluded our discussion in Section Ⅳ, References are followed.

Ⅱ. Theoretical Analysis of DSSS in Suppressing Noises

In order for us to gauge the direct spread spectrum system resistance, as against the interference, we introduced the processing gain G_p, which is an important factor for this analysis. From here, we are able to tell that there is an improvement in performance of the Signal to Noise Ratio (SNR). The processing gain is defined as [14],

$$G_p = \frac{\text{SNR of receiver multiplexer output}}{\text{SNR of receiver multiplexer input}} = \frac{\left(\frac{S}{N}\right)_o}{\left(\frac{S}{N}\right)_i} = \frac{N_i}{N_o} \tag{1}$$

In the equation (1), we realized that the ability of the DSSS system resisting against interference is strong, when the processing gain is high. There are

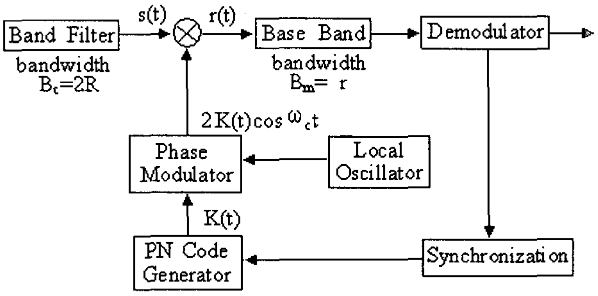


그림 1. 직접확산 스펙트럼 수신기를 모델한 도
Fig. 1. A diagram modelled after direct-spread spectrum receiver.

many kinds of noises, interferences, but these all categorized into three kinds of interference, which are, white noise, equal amplitude single frequency interference and other spread spectrum signal or impulses. As for spread spectrum system, it can resist these interferences.

1. Power spectrum of DSSS signal

The signal spread spectrum is assumed as random sequences, one of which is a dipole rectangle pulse, whose amplitude is 1 and code width of PN code is T_C. The probability p of sending '0' or sending '1' is $1/2$ respectively. $\mathcal{F}[g(t)] = G(f)$. The power spectrum is

$$S_c(f) = f_s p(1-p)|G_1(f) - G_2(f)|^2 + \sum_{m=-\infty}^{\infty} |f_s p G_1(mf_s) + (1-p)G_2(mf_s)|^2 \delta(f - mf_s) \quad (2)$$

for dipole wave, $g_1(t) = -g_2(t) = g(t)$

$$S_c(f) = 4f_s p(1-p)|G(f)|^2 + \sum_{m=-\infty}^{\infty} |f_s G_1(2p-1)(mf_s)|^2 \delta(f - mf_s) \quad (3)$$

when $p = 1/2$ and square pulse,

$$S_c(f) = f_s|G(f)|^2 \quad (4)$$

$$G(f) = T_c\left(\frac{\sin\pi f T_c}{\pi f T_c}\right) = T_c S_a(\pi f T_c) \quad (5)$$

With equations (4) and (5),

$$S_c(f) = f_s\ T_s\left(\frac{\sin\pi f T_c}{\pi f T_C}\right)^2 = T_c\ S_a\left(\frac{w}{2}\right)T_c^{\ 2} \quad (6)$$

where $G_1(f)$ and $G_2(f)$ are the frequency spectrum of '0' code and '1' code respectively, and $f_s = 1/T_c$ is the PN code rate, and $S_a(x) = \sin x/x$. The bandwidth ($R = f_s$) of an occupied signal varies with PN code rate.

PN code is modulated by a carrier, and the phase shift keying signal $P(t)$ is made. The modulated signal power spectrum is

$$P(w) = \frac{A^2}{4R} T_c\ S_a\left(\frac{w - w_1}{2} T_c\right)^2 \quad (7)$$

where A is the amplitude of digital modulated signal, w_1 is the transmit frequency, and B_c is the modulated signal bandwidth. $B_c = 2R$. The autocorrelation function of random sequence, $\rho(\tau)$, is

$$\rho(\tau) = \begin{cases} 1 - \dfrac{|\tau|}{T_c}, & \tau \leqq T_C \\ 0, & \tau > T_c \end{cases} \quad (8)$$

where τ is the duration.

In Fig. 1, PN code generates pseudo code $K(t)$, and the output of phase modulator, $P_1(t)$, is

$$P_1(t) = 2K(t)\cos w_c t \quad (9)$$

where w_c is the local oscillating frequency at receiver. The bandwidth of a base band filter, B_m, is r, and $r = R$.

$$P_1(w) = T_c\ S_a\left(\frac{w - w_0}{2} T_c\right)^2 \quad (10)$$

If the useful signal is received,

$$S(t) = \sqrt{2S}C(t)m(t)\cos(w_1 t + \varphi) \quad (11)$$

where S is signal power, $C(t)$ is information code, $m(t)$ is transmit spread spectrum random code, w_1

is signal carrier frequency at transmitter , and ϕ is phase shift. It is showed that $\triangle w = w_0 - w_1$ is within base band filter bandwidth. This means that, when $K(t) = m(t)$, the transmit and received PN code are the same. The received signal power can be completely recovered.

2. Ability of resisting three kinds of interference

We discuss the resistance ability of DSSS system with three kinds of interferences, as mentioned above, where the input is one of the three kinds of interferences.

가. Ability of resisting White Gaussian Noise (WGN)

Assume that WGN double side power spectrum density is $N_0/2$, and the bandwidth of input broad band filter is ignored, as imaginable in practice. Then, the output interference of correlator is

$$\begin{aligned} R(w) &= \frac{1}{2\pi}\frac{N_0}{2} * P_1(w) \\ &= \frac{1}{2\pi}\frac{N_0}{2} * T_c\ S_a\left(\frac{w-w_0}{2}T_c\right)^2 \\ &= \frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{N_0}{2}T_c\ S_a\left(\frac{w-w_0-\sigma}{2}\right)^2 d\sigma \end{aligned} \tag{12}$$

if we let $x = (w - w_0 - \sigma)T_c/2$,

$$\begin{aligned} R(w) &= \frac{1}{2\pi}\frac{N_0}{2}\int_{-\infty}^{\infty} 2\left(\frac{sinx}{x}\right)^2 d\sigma \\ &= \frac{N_0}{2} \end{aligned} \tag{13}$$

Equation (13) shows that the power spectrum density of WGN passed through correlator has not changed. Because the bandwidth of input and output filter is $2R$ and r respectively, the processing gain, G_p, is

$$\begin{aligned} G_p &= \frac{\left(\frac{S}{N}\right)_o}{\left(\frac{S}{N}\right)_i} = \frac{N_i}{N_o} \\ &= \frac{2R}{r} \end{aligned} \tag{14}$$

The spread spectrum system has very high processing gain which is directly proportional to the ratio of PN code rate, as to information rate. This is the reason which showed that it can resist interference strongly.

In general, PN code rate is some hundred Mb/s to thousand Mb/s(extremely high rate). But the information rate passed through the encoder is very low; for example, the voice signal rate is about 32~64 Kb/s, and therefore the processing gain is very high.

나. Ability of resisting single-frequency SINE interference

Assume the single frequency SINE interference is, as imaginable as practice,

$$i(t) = \sqrt{2I}cos w_1 t \tag{15}$$

where I is its power. The output of correlator is

$$\begin{aligned} r(t) &= 2i(t)K(t)cos w_o t \\ &= 2\sqrt{2I}K(t)cos w_1 t cos w_o t \\ &= \sqrt{2I}K(t)[cos(w_1 - w_o)t + cos(w_1 + w_o)t] \end{aligned} \tag{16}$$

Observing the $(w_1 - w_o)$ part, interference occurs when $(w_1 - w_o)$ is in pass band. According to the formulation of power spectrum above and modulation theory, we can know that the power spectrum density is

$$\begin{aligned} R(w) &= \frac{(\sqrt{2I})^2}{4R}\left(S_a\frac{w - w_1 + w_o}{2}T_c\right)^2 \\ &= \frac{I}{2R}\left(S_a\frac{w - w_1 + w_o}{2}T_c\right)^2 \end{aligned} \tag{17}$$

Similarly, interference occurs when its frequency is in the bandwidth of baseband lowpass filter followed correlator. Interference signal power spectrum can be regarded as DSB signal, when its approximate peak value is $I/2R$. Thus the power of interference passed through base band filter is

$$I_1 = 2\frac{I}{2R}B_m = \frac{Ir}{R} \tag{18}$$

Input and output SNR of correlator are

$$(SNR)_i = \frac{S}{I}$$
$$(SNR)_o = \frac{S}{Ir/R} \tag{19}$$

Processing gain is

$$G_p = \frac{(SNR)_o}{(SNR)_i} = \frac{R}{r} \tag{20}$$

The processing gain for single frequency interference is equal to the ratio of PN code rate to information rate. In this case there is no 2 times processing gain of DSB.

다. Ability of resisting other spread spectrum signal interference

For other spread spectrum signal interference entering receiver, it is given

$$i(t) = \sqrt{2I}m(t)cosw_1t \tag{21}$$

where $m(t)$ is the other spread spectrum code. The rate is the same to PN code rate, but it does not correlate to PN code, amplitude has attribute to 1, I is the signal power, and w_1 is carrier of interference. Its autocorrelate function is

$$\begin{aligned}\rho_i(t) &= \frac{1}{2T}\int_{-T}^{+T}[m(t)\sqrt{2I}cosw_1t] \\ &\quad [m(t-\tau)\sqrt{2I}cosw_1(t-\tau)]dt \\ &= \begin{cases} I\left(1-\frac{|\tau|}{T_1}\right)cosw_1\tau, & \tau \leqq T_1 \\ 0, & \tau > T_1 \end{cases}\end{aligned} \tag{22}$$

When local referenced signal is

$$P_1(t) = 2K(t)cosw_0t \tag{23}$$

By the same method above, the correlate function is

$$\rho_{P_1}(t) = \begin{cases} 2\left(1-\frac{|\tau|}{T_1}\right)cosw_0\tau, & |\tau| \leqq T_1 \\ 0, & |\tau| > T_1 \end{cases} \tag{24}$$

The output of correlator is

$$r(t) = 2i(t)K(t)cosw_0t \tag{25}$$

Due to the unrelated of two signals (assume that the two code width are the same), the correlated function, the product of the two correlate function, is

$$\begin{aligned}\rho_r(\tau) &= \rho_i(\tau)\rho_{P_1}(\tau) \\ &= \begin{cases} 2I\left(1-\frac{|\tau|}{T_1}\right)^2 cosw_0\tau cosw_1\tau, & |\tau| \leqq T_1 \\ 0, & |\tau| > T_1 \end{cases}\end{aligned} \tag{26}$$

thus, power spectrum density is

$$\begin{aligned}R(w) &= \int_{-\infty}^{+\infty}\rho_r(\tau)exp(-jw\tau)d\tau \\ &= \frac{4IT_1}{(w-w_2)^2T_1^2}\; 1-\frac{sin(w-w_2)T_1}{(w-w_2)T_1}\end{aligned} \tag{27}$$

where $w_2 = w_0 - w_1$.

$$R(w_2) = R_{\max} = \frac{2}{3}IT_1 \tag{28}$$

If w is within passed band, the interference occurred again. The interference power evaluated by maximum value is

$$\begin{aligned}I_1 &= 2\left(\frac{2}{3}IT_1\right)B_m \\ &= \frac{4}{3}IB_mT_1\end{aligned} \tag{29}$$

Thus, the output SNR is

$$(SNR)_o = \frac{S}{\frac{4}{3}IB_mT_1} \tag{30}$$

S is restored power. The processing gain is

$$\begin{aligned}G_p &= \frac{(SNR)_o}{(SNR)_i} = \frac{\left(\frac{S}{\frac{4}{3}IB_mT_1}\right)}{\left(\frac{S}{I}\right)} \\ &= \frac{3}{4B_mT_1}\end{aligned} \tag{31}$$

As we have seen, because spread spectrum interference signal is spread again by correlator, the DSSS system also can resist against the spread spectrum signal interference. From Equation (31), we know that the processing gain is about R/r for many kinds of interference. So, we evaluated the system performance by R/r. Generally, the processing gain, G_p, is R/r. In actual application, one bit information code corres-ponds to a period of PN code. And the length of PN code is the processing gain of the system. A long PN code has high processing gain.

The processing gain of normal communication system is very low. To overcome all kinds of interferences, as mentioned above and to be able to communicate with others, the signal must be much stronger than the interference. Actually the processing gain of spread spectrum communication system can attain hundreds or thousands times in normal communication, even ten thousands. So that information power may be depressed to the level of noise power and the signal power is reduced with this method. The communication distance is extended.

Ⅲ. Theoretical Analysis of DSSS in Suppressing Noises

Noise on the power line communication system is a summation of four types of noises [4, 5, 6, 9, 10]. To evaluate the performance of DSSS resisting such kinds of noises, we have compared BERs of BPSK with DSSS with BER of BPSK without DSSS. We adopted the power line model in [15], which included all the characteristics of power line, depicted it in Fig. 2.

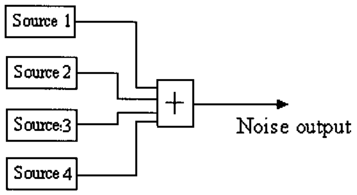
The parameters of this model are as follows:

a) background noise: always present, and having a power spectral density, on average equal to $N(f) = 10^{K-3.95e^{-5*f}}$[W/Hz], where K changes slowly in time and has approximately a Gaussian distribution with an average $\mu = -8.64$ and a standard deviation $\sigma = 0.5$; from worst case, we choose $K = \mu + 2\sigma$.

b) impulse noise: very powerful noise bursts normally taking no longer than 0.1 ms.

c) Noise synchronous to the power system frequency(that is, higher harmonics of 50 Hz). It is only measured occasionally with levels normally not exceeding -45 dB[W] per harmonic;

d) noise at frequencies unrelated to the frequency used in power system, normally at the horizontal line of television sets (15.625 kHz and higher harmonics for the European PAL system) with levels up to -45 dB[W] per harmonic (only the fifth harmonic was measured regularly). Also, sporadically very powerful narrow band disturbances unrelated to TV sets occurs.



Source 1: impulse noise; Source 2: higher harmonics of 50Hz
Source 3: background noise; Source 4: other noise unrelated to the power system

그림 2. 전력선통신에 발생하는 잡음의 브럭 도
Fig. 2. Block diagram of the noises at power line communication.

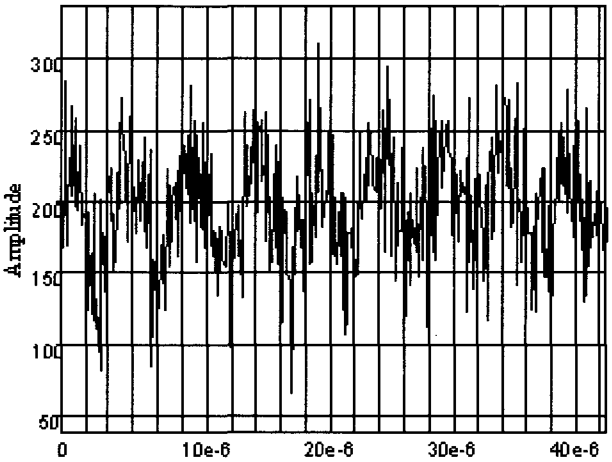


그림 3. 전력선통신에서 잡음
Fig. 3. The noise at power line communication.

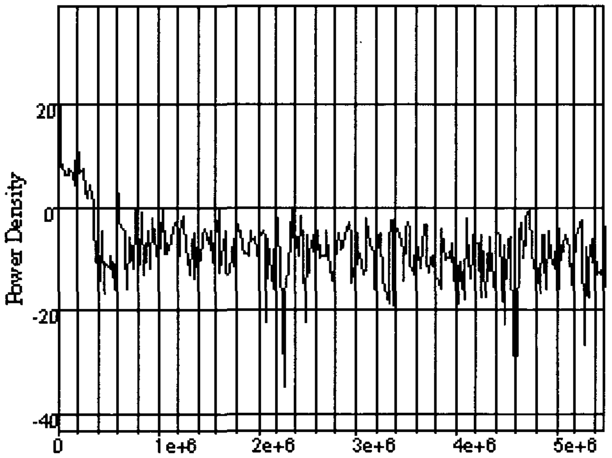
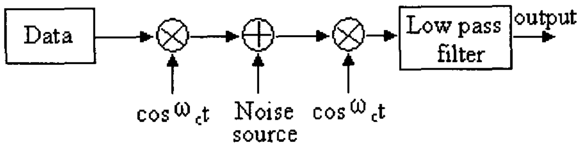
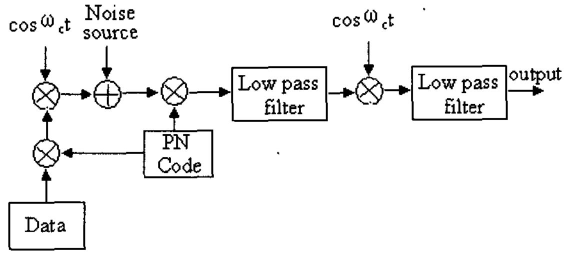


그림 4. 전력선통신에 발생하는 잡음의 스펙트럼
Fig. 4. Spectrum of the noise at power line communication.



a) BPSK without DSSS



b) BPSK with DSSS

그림 5. 실험한 방법을 설명하는 도

Fig. 5. The experimental diagram.

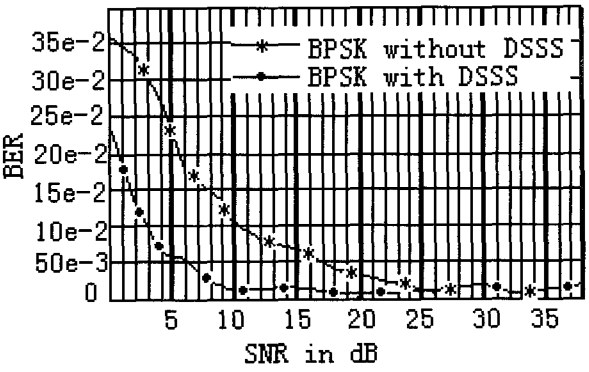


그림 6. DSSS을 적용한 경우와 DSSS을 적용하지 않은 경우의 BPSK 성능

Fig. 6. Performance of BPSK with DSSS and BPSK without DSSS.

The noise and its spectrum are drawn in Fig. 3 and 4. From the figures we could see that the interference is quite serious and the spectrum varies in a very large range. BPSK is an attractive modulation method on the complexity and performance. To illustrate the performance of DSSS, we tested the BERs of BPSK with DSSS and BPSK without DSSS respectively. The experimental diagram is shown in Fig. 5, and the result is shown in Fig. 6. This result shows that, with DSSS, the performance of BER can be improved about 8dB. We could confirm that the BPSK with DSSS is more proper than BPSK without DSSS.

IV. Conclusion

DSSS has a perfect performance against Gaussian noise, high order harmonic waves and impulses, when there are mainly those noises in power line, where DSSS must be adopted. From these experiment, our conclusion is that DSSS is the best method to be used in the high frequency power line communication.

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