論 文

The Performance Evaluation of FH-SSMA Radio Systems

Hyoung Rae Cho* Kyeong Won Kang** Chang Eon Kang* *Regular Members*

주파수 도약 대역확산 다중 시스템의 성능평가

正會員 趙 炯 來* 正會員 康 耿 源** 正會員 康 昌 彦*

ABSTRACT

In this paper, a practical model for evaluating and comparing the bit error rates(BERs) due to adjacent channel mutual interference in a synchronous and asynchronous frequency hopped spread spectrum multiple access(FH-SSMA) radio communication systems is proposed. After implementing the actual FH radio in both the synchronous and asynchronous case, the BER is computed and measured. An experiment of this system in mobile tactical environments reveals that the performance in the asynchronous case is lower than that of the synchronous case. The computer simulation model is an efficient tool for designing practical FH radios in mobile communication environments.

要 約

본 논문에서는 주파수 도약 방식을 이용한 대역확산 다중 통신 시스템에서, 인접채널 상호간섭에 의한 BER을 계산하고, 비교하기 위한 실제적인 모델이 제시되었다. 이때 BER은 망동기가 되었을 경우와 안되었을 경우에 대하여 각각 계산 및 측정하여 비교하였다. 동기식과 비동기식의 두 가지 경우에 있어서 주파수 도약 시스템을 제작하였으며 BER이 측정되었다.

본 연구의 결과에 의하면, 동기식이 비동기식 보다 성능이 우수하다는 것이 입증되었다. 또한 이러한 컴퓨터 시뮬레이션 모델은 향후 이동통신 환경에서 실제적인 주파수 도약 시스템을 설계하는데 매우 유용하다.

Ⅰ. Introduction

The frequency hoping method is a method of spread spectrum communication mainly used in VHF and UHF wireless communication systems. The frequency hopping method entails either randomly altering the transmitted frequency or periodically changing a transmitted set of frequencies. With the frequency hopped spread spec-

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* 延世大學校 電子工學科
Dept. of Electronics, Yonsei University
**金星精密(株)研究所
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trum multiple access(FM-SSMA) communication systems, there exist two cases : one is the synchronous case when the hop frame of each user coincides, and the other, the asynchronous case, when the hop frame of each user does not coincide. In both the synchronous and asynchronous FH-SSMA systems, interpreting the mutual interference of adjacent channels becomes difficult.

In the synchronous case, the probability density function of the squared envelope of a sum of random phase vectors has been recursively calculated [1]. In the asynchronous case, an analysis of FH-SSMA communications has been performed [2],[3],[4]. It is important to that with practical FH-SSMA systems, the above literature will not be appropriate for analyzing the mutual interference of adjacent channels.

We consider a synchronous and asynchronous slow frequency hopping spread specturm multiple access(SFH-SSMA) communication systems. Unlike the direct sequence receiver, the frequency hopping receiver cannot reduce narrow band interference by averaging it over a message bit interval. Thus, when an interference exists near one of the hopping frequencies, its effect on the receiver during that hop is essentially the same as it would be for a typical unhopped FSK receiver. Interference in the receiver output is reduced, because the receiver hops near the interfering signal only a small fraction of the time. Since the interference at the receiver output is intermittent, the use of an output signal-to-noise ratio(SNR) as a measure of receiver performance is no longer appropriate. Instead, it is preferable to consider the bit error probability of message as a measure of quality.

In this paper, a practical model is proposed for evaluating and comparing the bit error rates (BERs) due to adjacent channel mutual interference in synchronous and asynchronous FH-SSMA radio communication systems. The adjacent channel characteristics of the receiver are considered in order to simulate the environment of the actual FH radio system. The theoretical background of these system models are used to implement the frequency hopping radio and measure the BERs

Ⅱ. Practical Model

A practical model of FH-SSMA communication systems consisting of a pair of transmitted and received radios and the strongest interferer is shown in Fig.1.For a radio at a given distance d_T (in km) from the received radio and with a transmitted power (in dBm), the power at the received radio, $S_R(d_T,f)$, is given by

$$\begin{aligned} S_R(d_T,f) &= \text{Effective radiated power} - \text{path loss} \\ &= ERP - L(d_T,f)(dBm) \qquad (1) \end{aligned}$$

where f is the carrier frequency. The path losses in the city area, the rural area and the open area, make a difference, In this paper, the experimental results of the path loss were used in the simulation. Furthermore, the assumptions of this model before the analysis and the experiments performed are below.

1)A pair of transmitted and received radios exists in a region along with other radios operating in the same band.

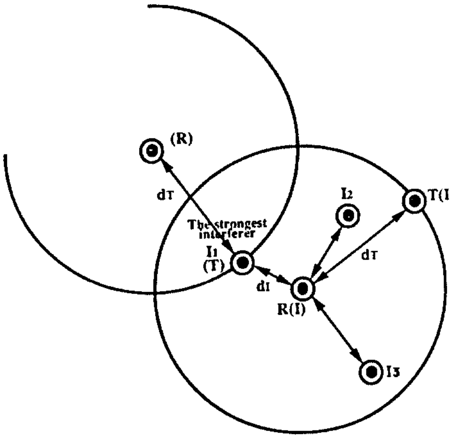


Fig. 1. Practical model for carrier-to-noise computation

2)The probability of having more than one inerferer is very low.

Although the above hypothesis seem to be vey restrictive, there are an accurate description of actual environments.

In Fig. 1, the received radio, R, acquires a long distance,d_T, with the transmitted radio, T, but attains a very close distance, d_I, with the interferer, I. The received radio as shown in Fig. 2 is made by the super-heterodyne method, and the level of the adjacent channel interference is determined by the distance between the received radio and the interferer. Thus, with practical systems, the system performance of the adjacent channel is determined by the selectivity of the received radio.

We assume that the received disturbance has a zero mean Gaussian random variable with noise power N_0+N_I. In this case, the bit error probability for a FSK modulation can be approximated by [5] :

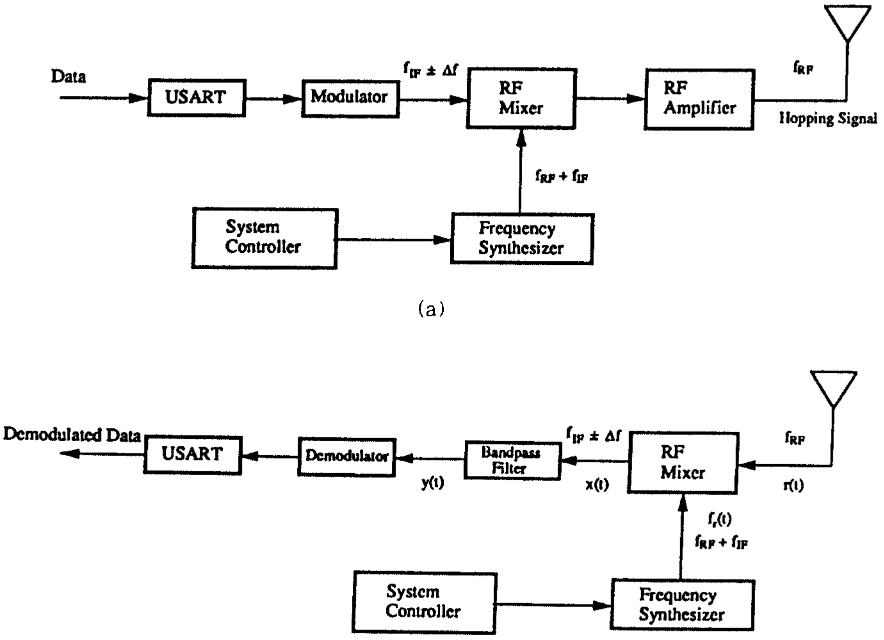
$$p_j(d_T,d_I,f_i,f_j)=\frac{1}{2}\exp\left[-\frac{S_R(d_T,f_j)}{2(N_0+N_I(d_I,f_j))}\right] \tag{2}$$

where $p_j(\,)$ is the bit error probability of the jth received frequency. The desired bit error rate, P_E, can be calculated by averaging $pj(d_T,d_I,f_I,f_j)$ with respect to $S_R/(N_0+N_I)$;

$$P_E=\frac{1}{2N}\sum_{i=1}^{N}\sum_{j=1}^{N}p_j(d_T,\,d_I,\,f_i,\,f_j) \tag{3}$$

where N is the total number of frequency hopping channels.

We introduce Fig. 3 in order to analyze the BER of a SFH-BFSK in the synchronous and



(a)

(b)

Fig. 2. Block diagram of developed FH Transmitter and receiver
(a) Transmitter (b) Receiver

asynchronous case. In Fig. 3, τ is the frequency dwell time, while T is the frequency hop interval. In Fig. 3, if the interval when the interference occurs within the hop interval is T_I, the interference is restricted to the range of (4).

$$T-\tau \leq T_I \leq T-2\tau \tag{4}$$

A. Synchronous case

In the synchronous case, $T_I = T-\tau$, the hop interval of all radios coincides. Therefore, the freequency hopping pattern of the received frequencies is made orthogonal to the frequencies of the interferer, and retains the frequency separation given by (5).

$$f_{Ri} = f_{Ii} + n\Delta \tag{5}$$

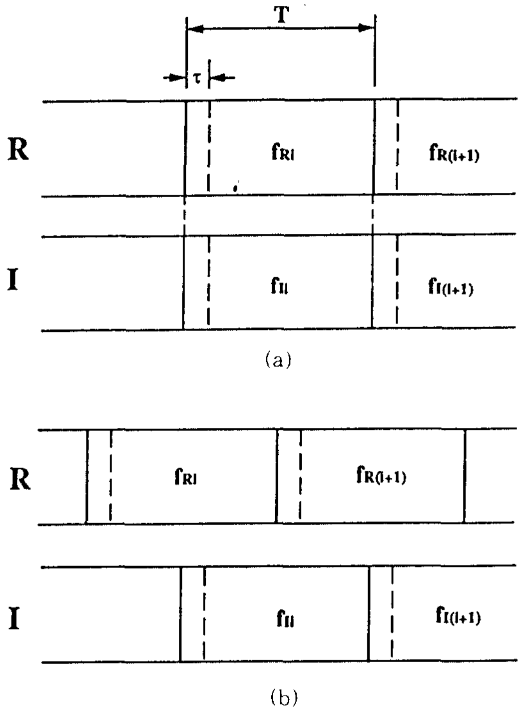


Fig. 3. Timing diagram for synchronous and asynchronous SFH systems.
(a) Synchronous case (b) Asynchronous case

where f_{Ri}, is the frequency of received radio at $t=t_i$, f_{Ii} is the frequency of interferer at $t=t_i$, n is frequency seperation number, and Δ is the channel space.

B. Asynchronous case

In the asynchronous case, the following two cases can be considered.

Case (1) $T-\tau \leq T_I \leq T-2\tau$: in this case, the interference can be made with one frequency. We can write the bit error probability, p_{AI}as :

$$p_{AI}(d_T, d_I, f_i, f_j) = \frac{T_I}{T-\tau}\, p_j(d_T, d_I, f_i, f_j) \tag{6}$$

and the desired BER, P_{AI} becomes

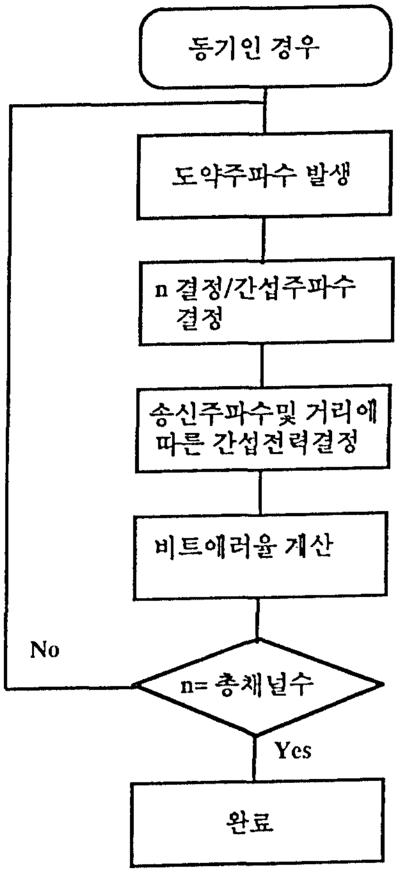


Fig. 4. Program flowchart of synchronous case

$$P_{A1} = \frac{1}{2N(T-\tau)} \sum_{i=1}^{N} \sum_{T} \sum_{j=1}^{N} T_I \, p_{A1}(d_T, d_I, f_i, f_j) \qquad (7)$$

Case (2) $T_I = T - 2\tau$: in this case, the interference has been made with two frequencies. We can write the bit error probability, p_{A2}, as the equation :

$$p_{A2} = Ap_m + (1-A)p_n \qquad (8)$$

where $0 < A < T\text{-}2\tau$, and p_m and p_n are the bit error probabilities of the mth and nth interference channels, respectively. Therefore the desired BER, P_{A2}, can be calculated as the following.

$$P_{A2} = \frac{1}{3N(T-2\tau)} \sum_{i=1}^{N} \sum_{A} \sum_{m=1}^{N} \sum_{n=1}^{N} p_{A2} \qquad (9)$$

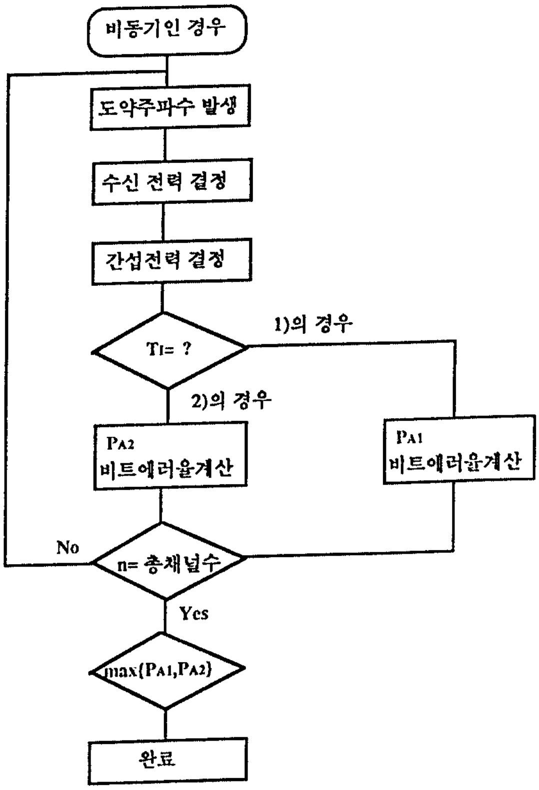


Fig. 5. Program flowchart of asynchronous case

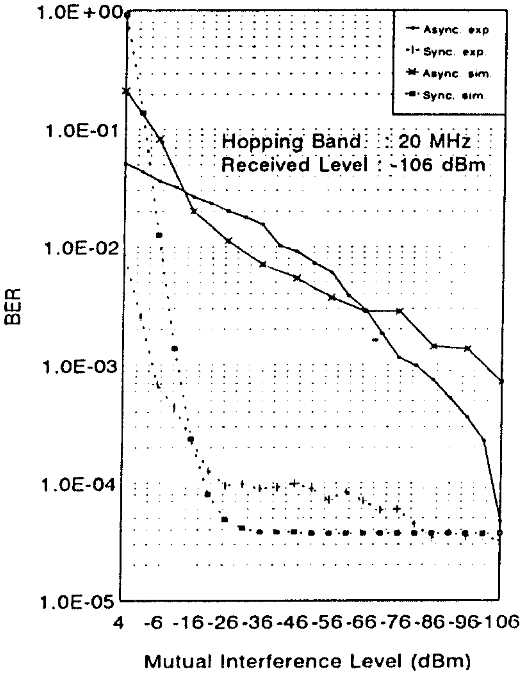
For the received radio, we take the desired BER, P_A, as the maximum value between P_{A1} and P_{A2},

$$P_A = \max\{P_{A1}, P_{A2}\} \qquad (10)$$

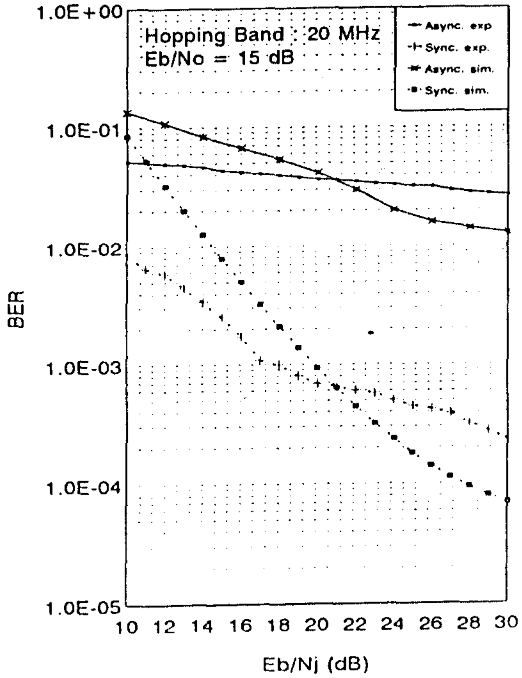
In the synchronous and asynchronous FH /SSMA systems, the flowchart for evaluating the BER are shown im Fig. 4 and Fig. 5, respectively.

Ⅲ. Numerical Results

In Fig. 6. we display the BER for the 20 MHz hopping band for both synchronous and asynchronous cases while in Fig. 7, we exhibit the BER for the 51.4 MHz hopping band for synchronous and asynchronous cases. In the simulations, the received level of the desired signal is-106 dBm. In all cases, it is clear that the synchronous case performs better than the asychronous one. Futhemore, as the hop band widens and the frequency seperation enlarges, a performance improves.

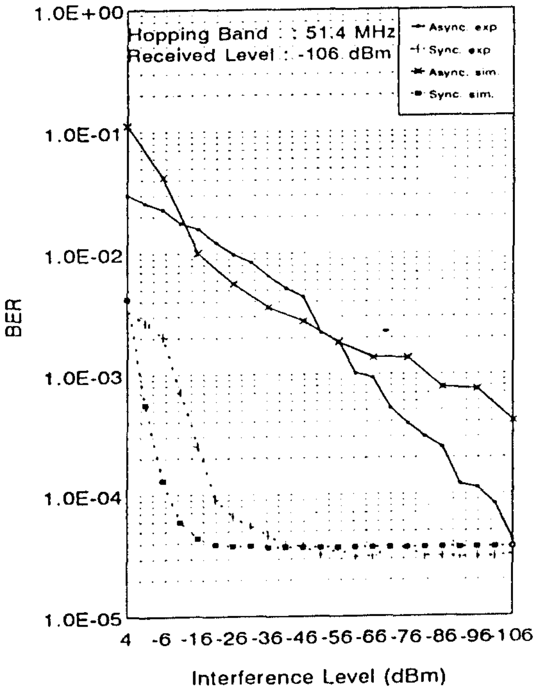


(a)versus the received level of interferer

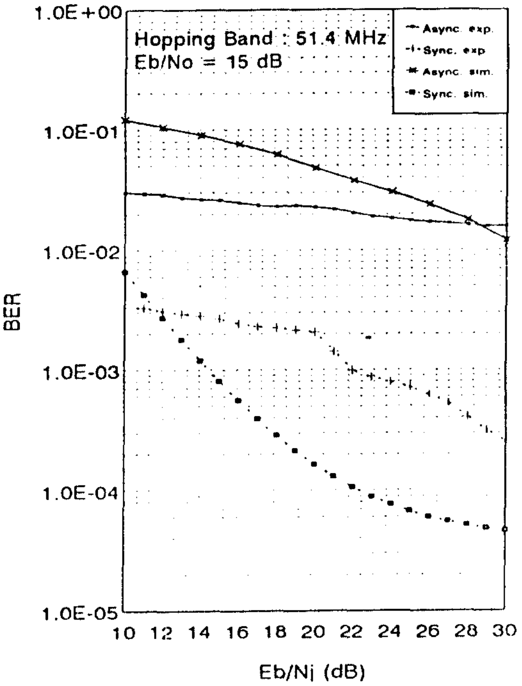


(b)versus Eb/Nj

Fig. 6. Numerical and empirical results of BER in a 20 MHZ hopping band (continued).



(a) versus the received level of interferer



(b)versus Eb/Nj

Fig. 7. Numerical and empirical results of BER in a 51.4 MHz hopping band(continued).

Ⅳ. Implemented FH Systems

The block diagram of actual FH systems is shown in Fig. 2. Data compression must be performed in order to transfer the input data by the FH method. Data compression and expansion are both achieved through USART. The processed data is modulated and the modulated signal is added to the FS in order to be made into RF. The received RF passes the tuner and changes into IF by FS. Furthermore, through the demodulation and data expansion IF is changed into the source data.

The selectivity of a superheterodyne receiver is determined solely by the selectivity of the IF amplifier. Here the selectivity may be obtained by using selective networks such as tuned circuits, crystal filters, or both. Selectivity is needed when several signals are simultaneously presented to the receiver. Assuming that these signals are in close proximity to the desired signal, such as adjacent channels in a channelized network, the receiver must reject everything but the desired channel.

A typical communication network will assign specific frequencies to each channel, and each frequency will be spaced by a fixed amount from the frequencies of adjacent channels. In a high density environment, maximum utilization of the RF spectrum requires that the channel spacing must be minimized and determined by the follwing conditions :

-. the spectral bandwidth of the transmitted signal
-. the frequency inaccuracies of the transmitter
-. the frequency inaccuracy of the receiver

This situation is illustrated in Fig. 6. The solid line of the reciver selectivity curve is shown to include the desired channel(f_d) within a reasonably flat part of its response. Being non-ideal, the response falls off but is not totally exclusive from channels $f_d+\Delta$ and $f_d-\Delta$, etc. Therefore, signals within these adjacent channels may cause interference to the desired channel, f_d, and under certain conditions cause complete communications failure.

In Fig. 4 and 5, we demonstrate the empirical results of the BER for the implemented FH radio with the FH interferer. As shown in the simulation results, the desired level of the received signal is −106 dBm. From the experiment described above, it shows that when the received level of the interferer is below -20dBm, the BER difference between the empirical results and the simulated results is within 3dB. And the asynchronous case exhibits a lower performance level than the synchronous case. In the synchronous case, BER makes no influence when the received level of the interferer is up to -26 dBm. Therefore, for an Eb/Nj below 30dB, when the interferer is near, the synchronous case performs 10~20 dB BER better than the asynchronous case.

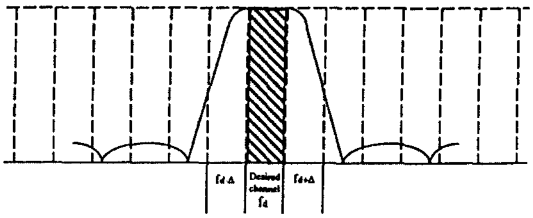


Fig. 8. Channelized spectrum with a typical receiver selectivity curve.

V. Conclusion

A practical method to calculate the bit error rate in a FH-SSMA radio system in the presence of attenuation of the radio system in the adjacent channel interference has been proposed. The BER for both the asynchronous and synchronous case has been computed and compared. After implementing the actual FH radio, the BER measurement can be obtained.

By simulating each radio configuration and using closed form expressions whenever possible, this method offers an extremely flexible and efficient means to design practical systems in radio environments.

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趙 炯 來(Hyoung Rae Cho) 정회원
1959년 6월 30일생
1982년 2월 : 광운대학교 응용전자공학과(공학사)
1984년 2월 : 연세대학교 대학원 전자공학과(공학석사)
1984년 1월 ~ 1990년 6월 : 금성전기 특수기술연구소 선임연구원
1989년 3월 ~ 현재 : 연세대학교 대학원 전자공학과 박사과정
1990년 8월 ~ 현재 : 광운대학교 전자통신학과 강사
1992년 3월 ~ 현재 : 연세대학교 강사

康 昌 彦(Chang Eon Kang) 正會員
1938年 8月 26日生
1960年 : 延世大學校 電氣工學科(工學士)
1965年 : 延世大學校大學院 電氣工學科(工學碩士)
1969年 : 美國미시간주립大學校大學院 電氣工學科(工學碩士)
1973年 : 美國미시간주립大學校大學院 電氣工學科(工學博士)
1967年 ~ 1973年 : 美國미시간주립大學校 工業研究所 先任研究員
1973年 ~ 1981年 : 美國노던일리노이大學校 電氣工學科 助教授, 副教授
1982年 ~ 現在 : 延世大學校 電子工學科 教授
1987年 ~ 1988年 : 本 學會 副會長
1989年 ~ 1990年 : 本 學會 會長

康 耿 源(Kyeong Won Kang) 정회원
1962년 6월 28일생
1980년 3월 ~ 1984년 2월 : 한양대학교 전자통신학과 졸업(공학사)
1984년 1월 ~ 현재 : 금성정밀(주) 연구소 선임연구원
※주관심분야 : 대역확산 통신시스템, 무선통신