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주파수 체배기를 이용한 K-Band용 Hair-pin 발진기

A K-Band Hair-pin Oscillator Using a Frequency Doubler

현안선* · 김훈석* · 김종헌* · 이종철* · 김남영** · 정원채*** · 홍의석*

An-Sun Hyun* · Hoon-Seok Kim* · Jong-Heon Kim* · Jong-Chul Lee* · Nam-Young Kim** · Won-Chae Jung*** · Ui-Seok Hong*

요 약

본 논문에서는 hair-pin 공진기, GaAs MESFET, 그리고 주파수 체배기로 구성된 K-Band용 발진기가 제안되며, 하이브리드 초고주파 집적회로(HMIC) 형태로 제작되고, 그 마이크로파 동작 특성이 발표된다. $\lambda_g/4$ 개방 스터브가 hair-pin 공진 발진기의 출력인 9 GHz의 기본 주파수를 억제하기 위해 주파수 체배기에서 사용되며, 출력 정합 회로가 2차 고조파 주파수인 18 GHz에서 최적화된다. 제안된 발진기는 −0.83 dBm의 출력, −23 dBc의 기본 주파수 억압, 그리고 18.2 GHz에서 −86 dBc/Hz의 위상 잡음을 갖는다.

Abstract

In this paper, a K-band oscillator which is composed of a hair-pin resonator , a GaAs MESFET, and a frequency doubler, is suggested, implemented by HMIC(Hybrid Microwave Integrated Circuits) form, and characterized for its microwave performance.

A $\lambda_g/4$ open stub is used in frequency doubler to suppress the fundamental frequnecy of 9 GHz which is the output of the hair-pin resonator oscillator and output matching network is optimized for its second harmonic freuency of 18 GHz. For the oscillator, the output power of −0.83 dBm, the fundamental frequency suppression of −23 dBc, and phase noise of −86 dBc/Hz at 18.20 GHz are obtained.

I. Introduction

An oscillator as the signal source is one of the key components in microwave communication systems for getting the IF signal and modulating or demodulating the RF signal. The K-Band(18.0~26.5 GHz) is useful for point-to-point communication, in direct frequency modulator, narrow-band microwave wireless LAN, or wireless transmission. It is very hard to obtain this range of frequency by a single oscillator due to its limitation of fabrication for hybrid microwave integrated circuits (HMIC). Insteads, frequency doubling has

*RFIC/MMIC Research & Education Center, Dept. of Radio Science & Engineering, Kwangwoon Univ.
**RFIC/MMIC Research & Education Center, Dept. of Electronic Engineering, Kwangwoon Univ.
***RFIC/MMIC Research & Education Center, Dept. of Electronic Engineering, Kyonggi Univ.
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been used for the oscillator output of microwave or millimeter wave frequency. There are two kinds of frequency doubling mechanisms, which are the push-push method[1] and the frequency doubler method[2],[3]. The former has some difficulties in the fabrication due to its strict requirements for the reliable operation by same fundamental frequencies in two oscillators. The latter has the design flexibility for its possibility of separate design of the oscillator and the frequency doubler. Also, it has good conversion gain, broad-band operation, low input power, high active region, and good isolation between the input and output compared to the push-push method.

In this paper, the frequency doubler is used for the realization of the K-band oscillator with a hair-pin resonator. A microwave design tool, HP EEsof Libra ver. 6.1 is used for the nonlinear circuit design. A single oscillator which output frequency is 9 GHz is first designed and the frequency doubler with the input frequency of 9 GHz and the output frequency of 18 GHz is designed. Then, an impedance matching network is designed and inserted between these two circuits. Finally, the data comparison between the design and the measurement is performed.

II. Design of a Hair-pin Resonator Oscillator at 9 GHz

Generally, the oscillator for microwave systems is composed of an active element and a resonant circuit for the selective frequency. In this paper, a miniature hair-pin resonator which structure is planar type suitable for the microwave integrated circuits(MIC) is used for the generation of predetermined frequency. The resonant condition for the hair-pin resonator is determined by ABCD matrix which is determined from the parallel coupled transmission line model. From this ABCD matrix and the resonant condition for input admittance, following Eq. (1) can be obtained.

$$\begin{aligned}&(Z_{pe}Z_{po}\cot\theta_p - Z_s^2\tan\theta_p)\sin\theta_s + \\ &Z_s(Z_{pe}+Z_{po})\cos\theta_s - Z_s(Z_{pe}+Z_{po}) = 0\end{aligned} \quad (1)$$

where Z_s is the characteristic impedance of the microstrip, θ_s is the electrical length of the microstrip, Z_{po} and Z_{pe} are odd and even mode characteristic impedances of parallel coupled transmission lines, respectively, and θ_p is the electrical length of the parallel coupled transmission lines. Z_s, θ_p, Z_{po}, and Z_{pe} can be obtained at fundamental resonant frequency. Then, θ_s is determined from these parameters and Eq. (1). The parameters used in this paper are given as follows. A fundamental resonant frequency is 9 GHz, the dielectric constant and the thickness of the teflon substrate are 2.6 and 0.54 mm, respectively. The design parameters for hair-pin resonator obtained from Eq. (1) are Z_s=59.33Ω, θ_p=41.0°, Z_{pe}=78.53Ω, and Z_{po}=44.83Ω. In this hair-pin resonator, even and odd modes exist simultaneously at resonant frequencies[4]. A coupled line of 180° is used for enough coupling with the resonator, and the separation width of 0.18 mm between the resonator and the coupled line is applied for the minimum allowable margin of fabrication. A 50 Ω resistor is attached to the end of transmission line to suppress the spurious modes and hysteresis. Linear analysis for the single oscillator at 9 GHz is first executed and then nonlinear analysis for expecting the output power, fundamental oscillating frequency, the suppression of second harmonics, and phase noise is performed.

Fig. 1 shows the block diagram for a single oscillator using the hair-pin resonator.

Fig. 2 shows the simulation results for output power of the hair-pin resonator oscillator.

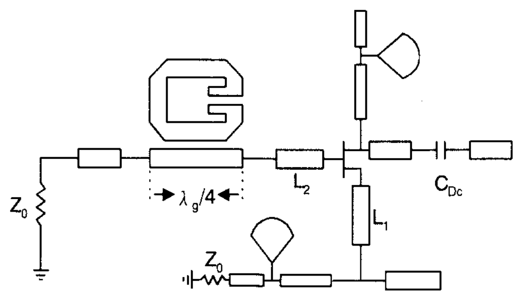

Fig. 1. Block diagram for the single hair-pin resonator oscillator.

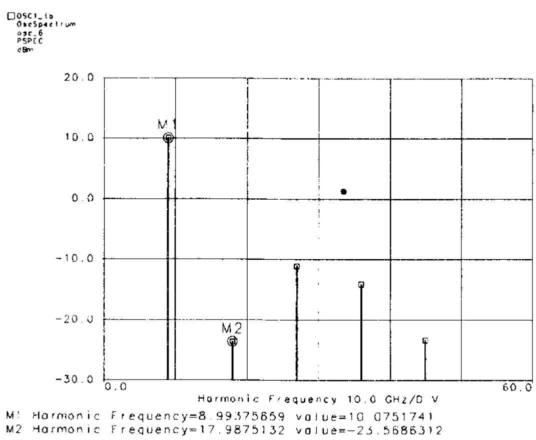

Fig. 2. Output of the hair-pin resonator oscillator.

Fig. 3 shows the simulation results for phase noise. The specification for the design in this paper are the output power of 10 dBm at 9 GHz, suppression of 33 dBc or more between

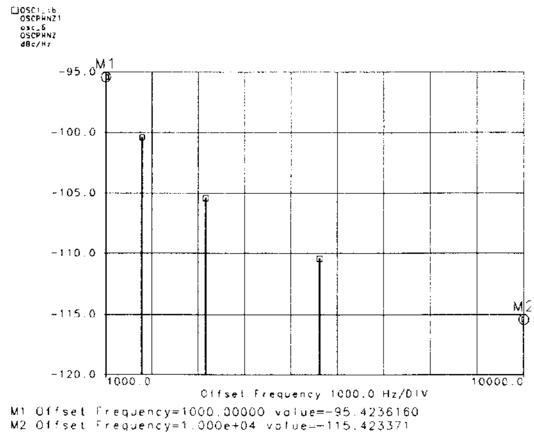

Fig. 3. Phase noise of the hair-pin resonator oscillator.

the fundamental and second harmonics, and phase noise of −95 dBc/Hz at offset frequency of 1 KHz.

Ⅲ. Design of a frequency doubler at 9/18 GHz

A frequency doubler is composed of an input and output matching circuit, a feedback circuit, and an active device. The frequency doubler can be realized by following two methods. One is using the filter at output to suppress the signal at fundamental mode and to improve the one at the second harmonics. The other is using a $\lambda_g/4$ open stub, corresponding to the fundamental frequency, which acts as a trap for the signal at fundamental frequency and a bypass element toward output for the second harmonic signal[5]. In this paper, the second method is adopted for reducing the circuit size. Fig. 4 illustrates the structure of the frequency doubler.

Input and output matching circuits are constructed so that the impedance is matched for the fundamental frequency, f_0 at the gate port

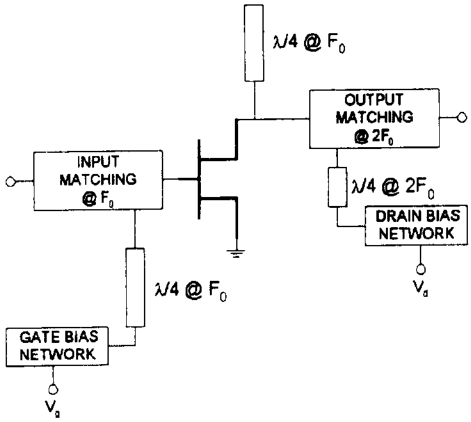

Fig. 4. Structure of the frequency doubler.

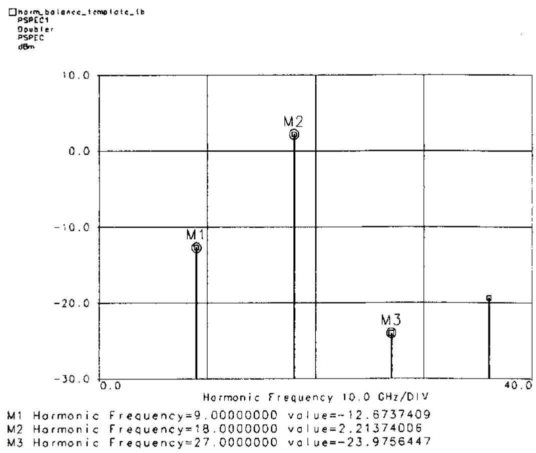

Fig. 5. Harmonic characteristics for the fre- quency doubler.

and for the doubled frequency $2f_0$ at the drain port of the FET, respectively. Matching circuits affect the optimum output and the minimum conversion loss for the circuit within the operating frequency range. In this doubler structure, a $\lambda_g/4$ open stub as feedback loop is inserted so that the signal from the FET of frequency f_0 feels RF short at this stub and that of frequency $2f_0$ feels RF open. Therefore, it acts as a trap and a bypasses element toward the output for the signal of frequency f_0 and frequency $2f_0$, respectively.

The frequency doubler consists of feedback circuit connected with the drain of the FET and the input and output matching circuits. The frequency doubler needs two bias circuits because the frequencies of the drain and gate of the FET are different compared with the case of an oscillator or an amplifier[6]~[11]. The frequency doubler which input and output frequencies are 9 GHz and 18 GHz, respectively is designed so that the oscillator operated at 9 GHz acts as a source for the frequency doubler. Input and output ports are matched first to improve the gain through the linear analysis. Then, output power is maximized and fundamental frequency is suppressed through the nonlinear analysis. Fig. 5 shows the harmonic characteristics for the frequency doubler. For the input signal which frequency and power are 9 GHz and 10 dBm, respectively, the output signal is found to have the power of 2.2 dBm at the doubled frequency of 18 GHz. Also, it shows the power of −12.7 dBm at 9 GHz, which means the suppression of the fundamental frequency.

Furthermore, the matching circuit between the output of the oscillator and the input of the frequency doubler is inserted for reducing the loss.

Fig. 6 illustrates the output power for the K-band oscillator using the frequency doubler. It shows the output power of 2.9 dBm at 17.99 GHz and −24 dBm at 8.99 GHz, respectively.

Fig. 7 shows the phase noise characteristics for the oscillator. From the figure, the phase noises of −96 dBc/Hz and −116 dBc/Hz at 1 KHz and 10 KHz offset frequencies, respectively are obtained.

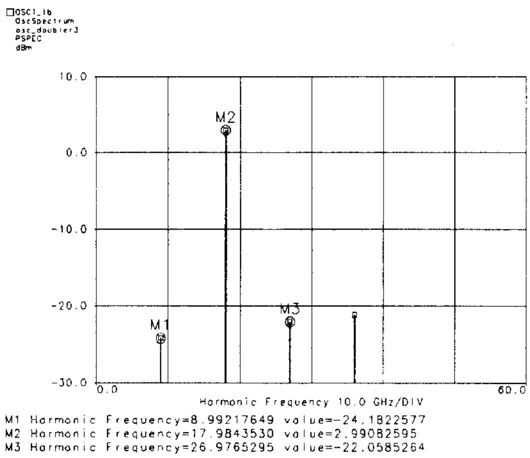

Fig. 6. The output power for the hair-pin oscillator using the frequency doubler.

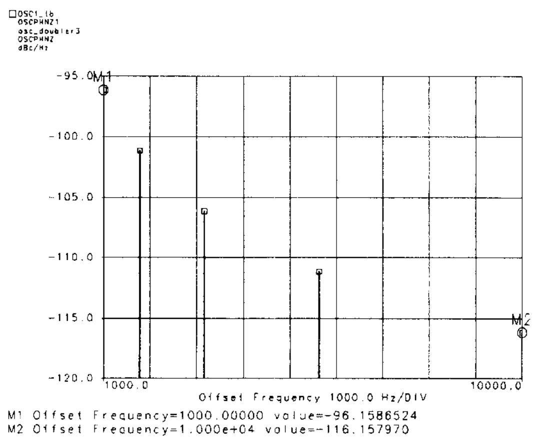

Fig. 7. The phase noise characteristics for the hair-pin oscillator using the frequency doubler.

Ⅳ. Experiments and Discussion

Fig. 8 shows the layout for the designed hair-pin oscillator using the frequency doubler. The circuit size is 5.7 cm x 3 cm.

The K-band oscillator is implemented by direct print method on the Teflon substrate which

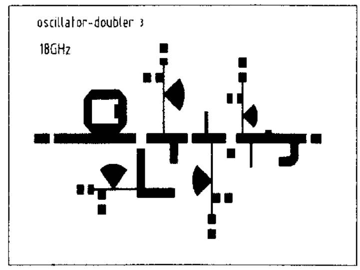

Fig. 8. Layout for the hair-pin oscillator using the frequency doubler.

dielectric constant is 2.6, height is 0.54 mm, and the thickness of the metal is 0.018 mm. A 50 Ω resistor is connected to the input port for the impedance matching, a capacitor is used for the DC block. Two MESFETs, ATF-13786 are used as active devices for the oscillator and the frequency doubler. The performance of the K-band oscillator is measured through an HP8563E spectrum analyzer.

Fig. 9 shows the photograph of the hair-pin oscillator using the frequency doubler.

Figs. 10. and 11 illustrate the harmonic characteristics and the spectrum with the span of 100 MHz for the implemented oscillator, respectively. Also, Fig. 12 shows the phase noise characteristics with the span of 1.0 MHz at the offset frequency of 100 kHz.

For the measurement, the bias voltage and current for the drain of the oscillator are applied as 3.2 V and 40 mA, respectively. Also, for the parts of the frequency doubler, the drain bias and the current are 3.6 V and 40 mA, respectively. With these conditions at room temperature, the oscillation characteristics can be observed from the figures as follows; the powers for the signal

Fig. 9. Photograph of the hair-pin oscillator using the frequency doubler.

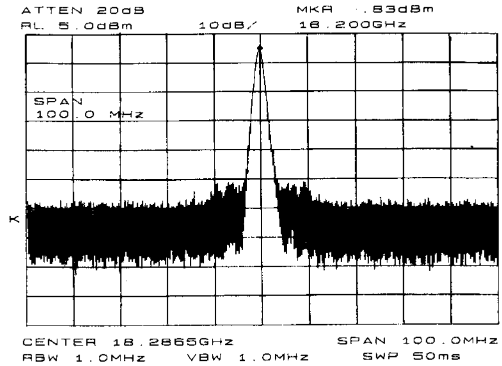

Fig. 11. Oscillation spectrum for the hair-pin oscillator.

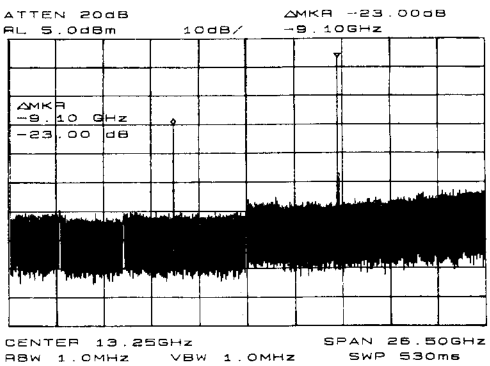

Fig. 10. Harmonic characteristics for the hair-pin oscillator.

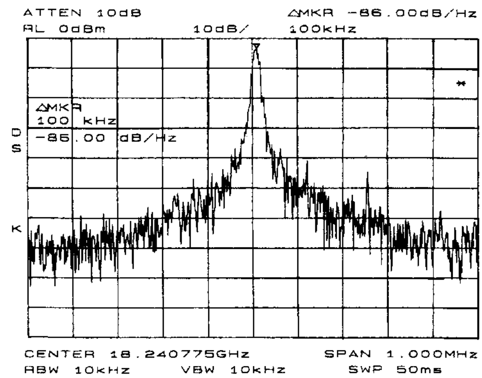

Fig. 12. Spurious characteristics for the hair-p

at the fundamental and the second harmonic frequency are −23.83 dBm at 9.1 GHz and −0.83 dBm at 18.20 GHz, respe- ctively. Also, the suppression characteristic for the fundamental frequency is observed to be −23 dBc. Therefore, the data of frequency and power from the measurements are in good agreements with those from the nonlinear design.

Table 1 shows the characteristics for the implemented K-band hair-pin oscillator.

These results can be compared with the data of several references [12]~[14]. The output power is very similar to each other and superior to that of ref. 14, and the phase noise is also comparable to others and superior to that of ref. 12.

V. Conclusion

In this paper, the K-band oscillator has been designed by the microwave design tool, HP EEsof Libra (ver. 6.1), in which the planar hair-pin microstrip resonator is used and the

Table 1. The characteristics for the implemented K-band hair-pin oscillator

Oscillation frequency	18.20 GHz
Output power level	-0.83 dBm
1st Harmonic suppression	-23 dBc
Phase Noise @offset Freq. of 100KHz	-86 dBc/Hz
Power supply for the Oscillator (drain)	3.2 V
Power supply for the Freq. Doubler (gate, drain)	-0.2 V, 3.6 V
Current consumption	40 mA
Dimension	5.7×3.0 cm

K-band output signal is obtained thorough the frequency doubler after the oscillator. Using the frequency doubler, the signal at the fundamental frequency of 9 GHz is suppressed and the one at the second harmonic frequency of 18 GHz is maximized. The output power of −0.83 dBm at the oscillation frequency of 18.20 GHz, the suppression characteristic of −23 dBc for the fundamental frequency, and the phase noise of -86 dBc/Hz at the offset frequency of 100 kHz are obtained for the K-band hair-pin oscillator using the frequency doubler, which all satisfy the specification suggested in this paper.

This K-band hair-pin resonator oscillator is expected to be used in the areas on mobile communication systems, direct frequency modulator, and narrow band microwave wireless LAN.

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An-Sun Hyun

An-Sun Hyun received his B.S. degree in electronic material engineering from Suwon Univ. in 1997. He is currently working on his Master's Degree at Kwangwoon University. His research interests are EMI, frequency multiplier, and oscillator.

Hoon-Seok Kim

Hoon-Seok Kim received his B.S. degree in electronic material engineering from Suwon Univ. in 1997. He is currently working on his Master's Degree at the Dept. of Radio Science and Eng., Kwangwoon University. He is interested in the area on microwave coupler, frequency multiplier, and oscillator.

Jong-Heon Kim

Jong-Heon Kim was born in Seoul, Korea in 1961. He received the B.S. degree in electronic communication engineering from Kwangwoon Univ. in 1984, the M.S. degree in electronic engineering from Ruhr Univ. Bochum, Germany, in 1990, and the Ph.D. degree in electronic engineering from Dortmund Univ., Germany, in 1994. Since March 1995, he is an assistant professor in the Dept. of Radio Science and Engineering at Kwangwoon Univ. His research interests are in the areas of microwave and photonics device, microwave environment, microwave measurement and sensors.

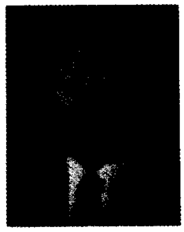
Jong-Chul Lee

Jong-Chul Lee was born in Seoul, Korea in 1960. He received the B.S. and M.S. degrees in electronic engineering from Hanyang University, Seoul, Korea. in 1983 and 1985, respectively. He received the M.S. degree from Arizona State University, Tempe, Arizona in December 1989 and the Ph. D. degree from Texas A&M University, College Station, Texas in May 1994, all in electrical engineering. From June 1994 to February 1996, he was a senior researcher in Photonic Devices Lab., System IC R&D Lab., Hyundai Electronics Ind. Co., Ltd., Ichon, Kyounggi-do, where he was involved in the development of several high speed laser diodes and photodiodes, and transmitter/receiver modules. Then, he joined the Department of Radio Science and Engineering at Kwangwoon University, Seoul, where he is currently an assistant professor. His research interests include Optoelectronics, RF-Photonics, MMIC, and OEMIC. He is a member of IEEE, KEES, and KIEEME.

Nam-Young Kim

Nam-Young Kim was born in Seoul, Korea in 1960. He received the B.S. degree in Electronics Engineering from Kwangwoon Univ. in 1987, the M.S. and the Ph.D. degrees from State Univ. of New York at Buffalo in 1991 and 1993, respectively. He was research scientist of CEEM at SUNY at Buffalo in 1994. Since September 1994, he has been an assistant professor in the Dept. of Electronic Engineering at Kwangwoon University. His research fields are in the areas of semiconductor device modeling, RFIC and MMIC design.

Won-Chae Jung



Won-Chae Jung received the B.S. and M.S. degrees in Electronic Engineering from Hanyang University in Seoul, Korea in 1981 and 1983, respectively and M.S. and Ph.D. degrees in Electronic Engineering from Erlangen-Nürnberg University in Erlangen, Germany in 1989 and 1994, respectively. From 1989-1993 he was a research-engineer as a coworker in Fraunhofer Institute, Erlangen Germany. From 1994 to 1995 he was a senior researcher at Lucky-Goldstar Siltron Institute. Since March 1995 he joined as a Full-time lecturer in the Department of Electronic Engineering, Kyonggi University of Suwon, Korea. Currently, he is an assistant professor at the same university. His current research interests include 'process simulation and special semiconductor device technology.

Ui-Seok Hong

Ui-Seok Hong received the B.S. degree in communication engineering from Kwangwoon University in 1968, the M.S. degree in electrical engineering from Yonsei University in 1973, and the Ph. D. degree in electrical engineering from Technical University, Aachen, Germany in 1982. He joined the Kwangwoon University at the Dept. of Application Electronic Engineering in September 1973 as a Full- Time Lecturer and was promoted to an Associate Professor and a Professor in Electronic Communi- cation Eng. in January 1983 and March 1987, respectively. Since March 1992 he is with the Dept. of Radio Science and Engineering. From March 1995 to December 1996, he served as Dean of Engin- eering and from August 1997 to present, he has served as Dean of Graduate School at Kwangwoon University. From February 1986 to February 1987, he was in electrical engineering, University of Texas at Austin as a vising professor. So far, he has supervised 10 Ph. D. and more than 40 M.S. graduates. Dr. Hong has authored and coauthored over 25 papers on wireless, mobile, and satellite communication systems. He received Achievement Award from the Korean Institute of Communication Sciences. Dr. Hong has been nominated by several academic and industrial organizations as follows: From January 1997 to December 1997, the chief of editor and From January 1998 to present, the Educational board of director for the KICS. Since January 1991, board of director for the KEES, Since March 1993, the chief judge of telecommunication equipment for Korea section of the International Vocational Training Corporation. Since June 1994, the chief of the communication section for the Sanhakyeon Research Institute of a Coporation.