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ICEIC 2025

International Conference on Electronics, Information,
and Communication 2025



JAN. 19 (SUN) - 22 (WED) 2025

Osaka International House, Japan



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CONTENTS

01. Welcome to ICEIC 2025	2
02. Technical Program Overview	5
03. Committee	
- Organizing Committee	7
- Technical Program Committee	9
04. Time Table	10
05. Floor Map	12
06. Conference Information	
- Social Program	15
- Registration	16
- Presentation Guidelines	18
07. Plenary Talks	19
08. Invited Talks	23
09. Tutorials	26
10. Technical Program	
- Oral Sessions	34
- Poster Sessions	68
11. Venue & Accommodation	111
12. OSAKA in JAPAN	112



15 **Unmanned Aerial Vehicles Network in Disaster Areas: IBF-based Mission Transfer to Reduce Latency and Communication Overhead**

Nari Yoon and Hyesook Lim
Ewha Womans University, South Korea

16 **Research on the Configuration of an Operation Loss Tracking System for Improving the Productivity of EUV Lithography Equipment**

Kyunghwan Joo¹, Sangmin Hwang², and Prof. Jae Wook Jeon¹
¹Sungkyunkwan University, South Korea, ²Samsung Electronics, South Korea

17 **Development of an Analytical Model for Frequency Selective Surface and Plasma Structures Using an Equivalent Circuit Model**

Minsu Choi¹, Si-Jun Kim², Changseok Cho³, Yongshik Lee³, Inho Seong¹, Young-Seok Lee¹, Shinjae You¹, Cheonyoung Kim, Hyunsoo Lee⁴, and Jungje Ha³
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18 **Design of Wide Beam-Angle Parasitic Antenna for Automotive SRR/MRR/LRR Sensors in W-Band**

Jiwon Jang and Chul Ki Kim
Soongsil University, South Korea

19 **Evaluation of Visual Performance of Transparent Antennas for Smartphone Display**

Min-Sang Kim, HyeonSik Ahn, Seongmin Pyo, and Yoonseuk Choi
Hanbat National University, South Korea

20 **Design of a Narrow Beamwidth Antenna for Next-Generation Railway Communication Networks**

Jae Geun Lee and ByungKuon Ahn
Soongsil University, South Korea

21 **Narrowband Interference Cancellation in LEO SCFDE System**

Woong-Jong Yun, Seung-Mi Yun, and Eui-Rim Jeong
Hanbat National University, South Korea

22 **Design of 5.8 GHz Rectenna for Wireless Power Transmission and Energy Harvesting**

Jiyeong Byun, Jaegeun Lee, and Sun K. Hong
Soongsil University, South Korea

23 **Optimization of Nanosheet Thickness in 4-Stack Nanosheet FETs for Sub-2nm Logic Technology**

Jimyoung Lee, Seki Hong, and Jongwook Jeon
Sungkyunkwan University, South Korea

24 **Performance Characterization of CXL Memory: Effectiveness of On-Device Cache**

Junbum Park¹, Wonyoung Lee¹, Taejeong Kim¹, Minjin Park¹, Yongho Lee², and Seokin Hong²
¹Samsung Electronics, South Korea, ²Sungkyunkwan University, South Korea

25 **Re-Search: Efficient Search for ReRAM Digital PIM**

Junyong Oh and Joon-Sung Yang
Yonsei University, South Korea

26 **2-Step Middle-Level ZQ Calibration for PAM-3 Signaling in High-Speed Memory Interfaces**

Joonyoung Kim^{1,2}, JunHa Lee^{1,2}, DongHo Shin^{1,2}, and Kang-Yoon Lee^{1,3}
¹Sungkyunkwan University, South Korea, ²Samsung Electronics, South Korea, ³SKAIChips, South Korea

27 **A Power-Efficiency 6 bit 10 MS/s Asynchronous Loop-Unrolled SAR ADC**

Beom-jin Kim, Hyeon-gi Hwang, Sang-won Oh, Da-yeon Kim, Han-jun Kim, Jae-kang Lee, Ji-min Kim, Chae-yeon Kim, Ye-won Yun, Yoon-seo Jang, Sang-hyun Ko, and Dong-ryeol Oh
Jeju National University, South Korea

28 **A Design of a 96.8% Efficiency Triple Mode DCDC Boost Converter for True Wireless Stereo Cradle**

Ji-Hoon Song¹, Jae-Hyung Jang¹, Byeong-Gi Jang², Yeon-Jae Jung², and Kang-Yoon Lee¹
¹Sungkyunkwan University, South Korea, ²SKAIChips, South Korea

29 **A 3-Phase DC-DC Buck Converter with Auto Phase Shedding Control**

Ji Hun Woo, Seung Hwan Lim, Young Gyu Lee, Yun Gwan Kim, and Kang Yoon Lee
Sungkyunkwan University, South Korea

30 **Fault Diagnosis of Motors Using AI: A Multi-Channel Signal Processing Approach with Analog Front-End and ADC**

Sung June Byun, Dae Young Choi, Dong Gyun Kim, Jong Wan Jo, Young Gun Pu, and Kang-Yoon Lee
Sungkyunkwan University, South Korea

31 **A Design of Wide Input voltage and Load current range LDO for SC converter**

Jun Hyeok Choi, Dong Min Kim, Kyung Duk Choi, and Kang Yoon Lee
Sungkyunkwan University, South Korea

32 **A current balancing control for a 6-phase DC-DC buck converter with a 0-6A load range**

Seung Hwan Lim, Ho Jin Kwark, Ji Hun Woo, Young Gyu Lee, Yun Gwan Kim, and Kang-Yoon Lee
Sungkyunkwan University, South Korea

33 **A Wide Frequency Range 13.98 ~ 18.22 GHz Linear Transconductance VCO with Low Phase Noise for FMCW Radar Signal**

Hyeon Min Song, Minsu Park, Ho Won Kim, and Kang-Yoon Lee
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Narrowband Interference Cancellation in LEO SC-FDE System

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To transmit high-speed data in LEO (low earth orbit) environments, it is essential for the receiver to easily perform channel equalization. Among various transmission schemes, orthogonal frequency division multiplexing (OFDM) and single carrier frequency domain equalization (SC-FDE) are widely used communication techniques due to the simplicity of receiver equalization [1-2]. Between them, SC-FDE is preferable for its low peak to average power ratio (PAPR) [3]. Military LEO communication systems must always be prepared for adversary deliberate radio frequency attacks, known as jamming attacks. The most effective jamming signal is a narrowband strong signal. SC-FDE systems, utilizing single-carrier transmission, are known to be more vulnerable to wideband interference compared to OFDM systems [4].

In this study, a novel approach for mitigating narrowband interference in SC-FDE systems is proposed. The proposed method utilizes fast Fourier transform (FFT) to detect and remove interference by recognizing its presence and frequency. If interference is detected, its position in the FFT spectrum is set to zero. Although this process enables simple jammer removal, there is one issue. If the frequency of the jammer is not an integer multiple of F_s/N , where F_s represents the sampling clock and N represents the FFT size, the performance of jammer removal can be significantly degraded. To address this issue, fine frequency shifting is proposed before FFT, and this makes the interference frequency become an integer multiple of F_s/N . Through computer simulation, the proposed method is compared with methods that do not perform interference removal and methods that use simple FFT for interference removal in environments where interference exists. According to the results, the proposed method exhibits the least degradation in receiver performance in environments with interference.

I. System Model

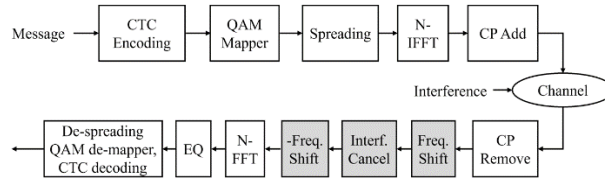


Fig. 1. System model for transmitter and receiver

Fig. 1 depicts the transmitter and receiver system model considered in this paper. The transmitted message undergoes convolutional turbo code (CTC) encoding and quadrature amplitude modulation (QAM) mapping before performing spread spectrum. Spread spectrum is utilized to ensure reception performance against interference signals or to secure reception performance in low signal-to-noise ratio (SNR) regions.

The received signal can be expressed as

$$y(n) = \mathbf{x}^T(n)\mathbf{h} + z(n) \quad (1)$$

where \mathbf{h} is $\mathbf{h} = [h(0), \dots, h(L_h - 1)]^T$, a channel vector and $\mathbf{x}(n)$ is $\mathbf{x}(n) = [x(n), x(n - 1), \dots, x(n - L_h + 1)]^T$, the transmitted signal vector.

II. Proposed Interference Cancellation

If the received signal is contaminated with a single-tone interference, the received signal can be expressed as

$$y = \mathbf{x}^T(n)\mathbf{h} + g\exp(j2\pi f_j nT) + z(n) \quad (2)$$

where f_j represents the interference frequency, and g indicates the magnitude of the interference. If we denote the sampling frequency as $f_s (= 1/T)$, the interference removal performance deteriorates when f_j is not an integer multiple of f_s/N . In practical environments, such situations are likely to occur frequently, so this problem needs to be addressed. One method proposed in this paper to address this issue is to perform fine frequency shifting before interference removal, as shown in Fig. 1, to make the interference frequency closer to an integer multiple of f_s/N , and after removing the interference, shifting back by the same fine frequency shift to restore the original signal.

The FFT size for fine frequency estimation is defined as $N_o = PN$. P is a positive integer greater than 1, denoted as $N_o > N$. For precise interference frequency estimation, a larger value of P is preferable. Now, regarding the received signal $y(n)$, $N_o - FFT$ is performed.

$$Y_o(k) = \sum_{n=0}^{N_o-1} y(n) e^{-j\frac{2\pi}{N_o}kn}, 0 \leq k \leq N_o - 1 \quad (3)$$

Next, to find the frequency of interference, the maximum value among $Y_o(k)$ is identified, and if this value exceeds the threshold, it is considered that interference exists.

$$Y_{max} = \max_k |Y_o(k)|^2 \quad (4)$$

$$k_{max} = \operatorname{argmax}_k |Y_o(k)|^2 \quad (5)$$

The maximum value and its position in the spectrum are determined by (4) and (5) respectively, and the presence of interference is determined based on the Y_{max} value. If it exceeds $Y_{max} > \eta_m$, interference is deemed to exist; otherwise, interference is considered not to exist. If we denote the fine frequency shift as f_m , f_m is determined as

$$f_m = \begin{cases} \operatorname{mod}(k_{max}, P), & \text{if } \operatorname{mod}(k_{max}, P) < \frac{P}{2} \\ -P + \operatorname{mod}(k_{max}, P), & \text{else} \end{cases} \quad (6)$$

where $\operatorname{mod}(K, N)$ denotes the remainder when K is divided by N . The fine frequency shift is performed as follows:

$$y_m(n) = y(n) \exp(-j2\pi \frac{f_m}{N_o} n) \quad (7)$$

Frequency fine shifting and interference removal are performed only when interference exists. In the case of interference, the fine frequency shift is performed as shown in (6), and interference removal is performed as follows. First, an N-FFT is performed on $y_m(n)$.

$$Y_m(k) = \sum_{n=0}^{N-1} y_m(n) e^{-j\frac{2\pi}{N}kn}, 0 \leq k \leq N - 1 \quad (8)$$

Afterwards, interference removal is performed by substituting 0 into the spectrum corresponding to the interference frequency.

$$Y_m(k) = 0 \text{ if } |y_m(k)|^2 > \eta \quad (9)$$

The magnitude of interference is defined by the signal-to-interference ratio (SIR). A larger interference results in a smaller SIR, while a smaller interference leads to a larger SIR.

$$SIR = \frac{\sum_{l=0}^{Lh} |h(l)|^2}{|g|^2} \quad (10)$$

Fig. 2 demonstrates the bit error ratio (BER) performance when the SIR is 5 dB. In the simulation, the interference frequency is randomly generated within the signal bandwidth. Despite the power of the received signal being greater than that of the interference, failure to remove interference results in a BER floor. However, when interference is removed, the BER performance improves. It can be observed that without fine frequency shifting, the BER floor still occurs. Conversely, applying the proposed method eliminates the BER floor, and this effect becomes more pronounced with significant spreading gain.

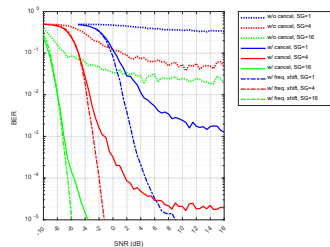


Fig. 2. BER performance for SIR = 5 dB

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