이미지 센서 모듈을 위한 자동-초점 기능의 전력-효율적인 구동 방법에 대한 연구

A Research of Power-Efficient Driving Scheme for Auto-Focus on Image Sensor Module

차 상 현*, 박 찬 우, 이 연 중, 황 병 원, 권 오 조, 박 득 희, 권 경 수, 이 재 신, 황 신 환
(Sanghyun Cha, Chanwoo Park, Yuenjoong Lee, Byoungwon Hwang, Ohjo Kwon, Deukhee Park, Kyoungsoo Kwon, Jaeshin Lee, and Shinhwan Hwang)

Abstract: We present a power-efficient driving scheme that consists of piezoelectric actuator and driver IC for AF (Auto-Focus) on ISM (Image Sensor Module). The piezoelectric actuator is more power-efficient than conventional voice coil motor actuator. And high power-efficiency driver IC is designed. So the proposed driving scheme using designed piezoelectric actuator and driver IC is more close to recent trend of green IT. The diver IC should guarantee fast and accurate performance. So, the optimum driving method and high accurate frequency synthesizer are proposed. The die area of designed driver IC is 2.0 x 1.6mm^2 and power consumption is 2.8mW.

Keywords: auto-focus, driver IC, piezoelectric actuator, power-efficient, image sensor module

I. INTRODUCTION

The ISM (Image Sensor Module) is applied to various applications such as robot eyes, digital camera, CCTV (Closed-Circuit Television), mobile phone and so on. The applications commonly demand high quality of image. So AF (Auto-Focus) feature has become almost mandatory [1,2]. There are two choices to implement AF, which are VCM (Voice Coil Motor) actuator and piezoelectric actuator. The actuators are used for accurate control of physical displacement of lens. Numerous ISMs apply VCM actuator for AF, because the structure of VCM actuator is simple and so low-cost can be achieved [3]. But VCM actuator needs static power consumption to hold lens at appointed location, and has size limitation. On the other hand, piezoelectric actuator could not demand static power consumption. Also the piezoelectric actuator has advantages in terms of hardware size operating speed and ease of controllability [4,5].

In this paper, the piezoelectric actuator and driver IC for AF on ISM is proposed. The conventional scheme for driving piezoelectric actuator should two IC that MCU and analog switch IC. So waste of resources occurs such as power consumption, package and module size. With proposed scheme, two IC for driving actuator are merged in one-chip. The driver IC is specially designed power-efficient. So designed piezoelectric actuator and driver IC is more close to recent trend of green IT that puts emphasis on energy efficiency.

The designed driver IC is fabricated in a 0.35μm CMOS technology. For high accuracy of lens position, driving signal cause of switching noise is blocked at sensing period. A high accurate and small size frequency synthesizer which combines novel DAC, VCO and control logic generates the accurate driving sweep frequency in linear step, so the variation of the resonant frequency of the piezoelectric actuator can be compensated. The designed driver IC is implemented in small area and low power consumption.

This paper is organized as follows, Section II and III shows the development of piezoelectric actuator and driver IC, respectively. Section IV presents measurement results and hardware implementation of the designed IC, and the paper concludes in Section V.

II. PIEZOELECTRIC ACTUATOR

Fig. 1 shows cross-section of the piezoelectric actuator, where top electrode are divided by 2 sections to form channel 1(Ch1) and channel 2(Ch2). Bottom electrode is uniform and mutual ground(GRN) to Ch1 and Ch2. The corresponding internal electrodes are connected to top and bottom electrodes through two side electrodes and one end electrode. When Ch1 is driven with an electrical signal, top left side, middle and bottom right sides of the piezoelectric ceramic layers are excited. Similarly, when Ch2 is driven, top right side, middle and bottom left sides of the piezoelectric ceramic layers of the stator are excited. The

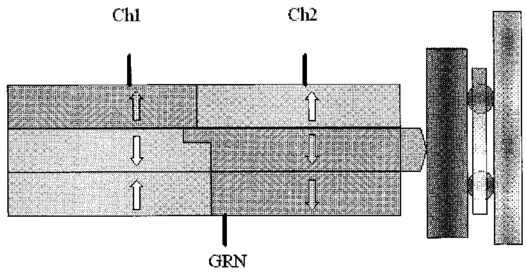

그림 1. 3개의 터미널(Ch1, Ch2, Ground)을 가진 피에조일렉트릭 모터의 단면도.

Fig. 1. Cross-sectional view of the piezoelectric motor that has 3 terminals (Ch1, Ch2 and Ground).

* 책임저자(Corresponding Author)
논문접수: 2009. 9. 10., 수정: 2009. 10. 5., 채택확정: 2009. 10. 30.
차상현, 박찬우, 이연중, 황병원, 권오조, 박득희, 권경수, 이재신, 황신환: 삼성전기 기술총괄 UM 솔루션랩
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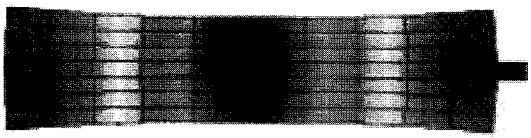
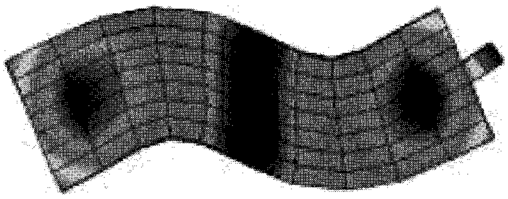


(a) Longitudinal resonance frequency.



(b) Second bending resonance frequency.

그림 2. 피에조일렉트릭 액츄에이터의 모드별 형태.

Fig. 2. Mode shape of piezoelectric actuator.

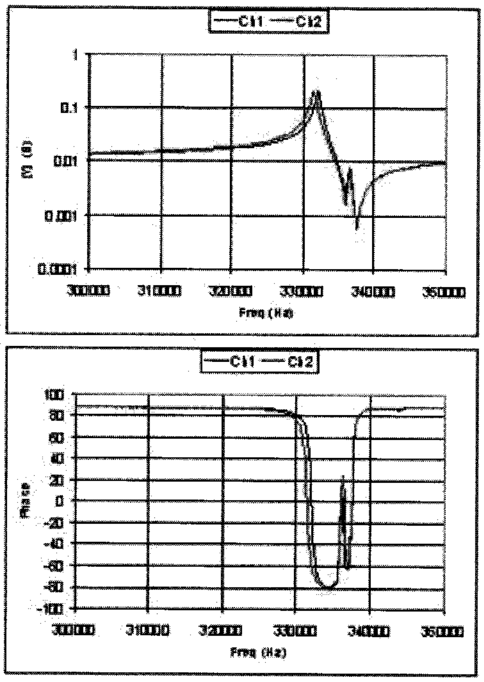


그림 3. 액츄에이터의 어드미턴스와 위상.

Fig. 3. Admittance and phase spectra of an actuator.

dimension of the stator is designed so that two orthogonal modes, which are first longitudinal, L1(see Fig. 2(a)) and the second thickness bending, B2(see Fig. 2(b)) mode resonance frequencies to be equal.

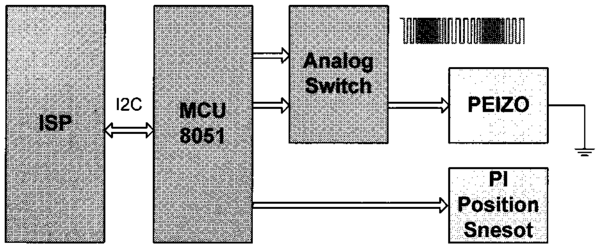
Fig. 3 shows a typical admittance spectrum for Ch1 and Ch2 where the two resonance modes are seen for both channels. The second bending mode is in between first longitudinal resonance and anti-resonance frequency. When one channel is driven with an electrical signal at a frequency in between the first longitudinal (L1) and the second thickness bending (B2) mode frequencies, the two resonance modes are excited at the same time causing the piezoelectric vibrator to make an elliptical motion. The elliptical motion is then transferred to slider through frictional force.

III. PIEZOELECTRIC ACTUATOR DRIVER IC

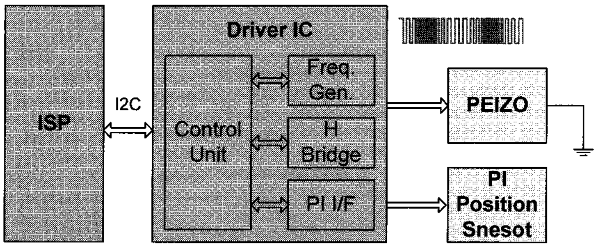
A conventional driving scheme of piezoelectric actuator is shown in Fig. 4(a). The 8051 microcontroller unit (MCU) calculates position of lens using communicating with image signal processor (ISP) and controls analog switch IC. By control signal generated in MCU, an analog switch IC drives sweep frequency. The conventional scheme should have wasting of resource such as large power consumption, additional package and increasing module size, and so on.

The proposed scheme of driving piezoelectric actuator needs one chip called driver IC. The driver IC includes control unit and frequency generator as shown in Fig. 4(b). So power consumption and module size is reduced. The proposed scheme is more environment-friendly and energy-efficient than conventional scheme.

The block diagram is shown in Fig. 5 for detail description. The system consists of frequency sweep control (FSC), control block, photo interrupt (PI) interface, I2C interface, clock generator, power management circuit, and EEPROM for infinite and macro position storage. The control block generates control signal for FSC, PI interface, and EEPROM, which consists of timing generator, EEPROM control logic, frequency sweep control logic and so on. FSC block generates sweep frequency which includes digital-to-analog converter (DAC), voltage controlled oscillator



(a) Conventional scheme.



(b) Proposed scheme.

그림 4. 피에조일렉트릭 액츄에이터 구동회로의 블록도.

Fig. 4. Block diagrams of driving circuits of piezoelectric actuator.

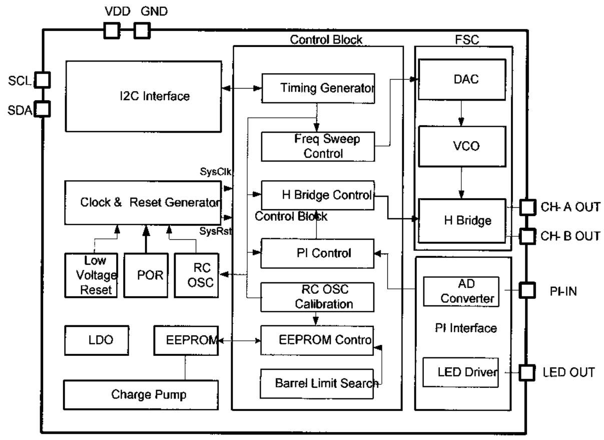


그림 5. 피에조일렉트릭 액츄에이터 구동 IC의 상세 블록도.

Fig. 5. Detail block diagram of the piezoelectric actuator driver IC.

(VCO) and H-bridge. PI interface consists of ADC and LED driver.

The driver IC should guarantee fast and accurate performance, so we need some design strategies in driving system. First of all, optimum lens positioning algorithm is needed. As the image sensor resolution increase, high accurate lens positioning for AF is required. But generally, because piezoelectric actuator with mechanical components is not good to control the motion accurately and the electrical noise due to driving signal can occur to lens position error, it is key issue to be solved [6]. Second, control of the driving frequency to compensate for variation of piezoelectric actuator characteristics on temperature, channels, manufacturing process is another key issue. Third, as a matter of course, small chip size is critical issue in mobile applications.

1. Precise Lens Positioning Algorithm

Piezoelectric driver IC has 2 output channels, which may connect to piezoelectric actuator (Ch1 and Ch2) and provide sweep frequency pulse for compensation of the resonance frequency in piezoelectric actuator. The operation procedure is as followings. After execution command OUTEXE is sent by ISP, output starts providing sweep frequency. It is only one channel which is internally selected and the other channel keeps Hi-Z. While output is active, IC keeps comparing its sampled current lens position data CurPos with target lens poison data TarPos which is sent by ISP. Output stop if CurPos is more/less than TarPos. The sequence of Output Execution is as Fig. 6.

Fig. 7(a) shows the operation in case CurPos < TarPos at entering OUTEXE mode, Ch1 output sweep frequency and then output stop if CurPos is more than TarPos. Fig. 7(b) shows the operation in case CurPos > TarPos at entering OUTEXE mode, CH2 output sweep frequency and then output stop if CurPos is less than TarPos.

Once lens move by driving signal, sensing signal is generated by photo reflector (NJL5901) which combines LED and Photo Diode. The amplitude of sensing signal is proportional to lens moving distance. This analog sensing signal is converted to digital data CurPos by Analog-to-Digital Converter (ADC) inside of

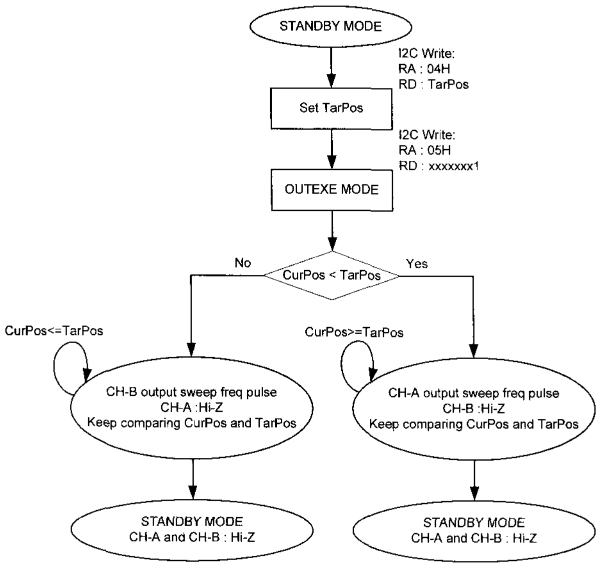
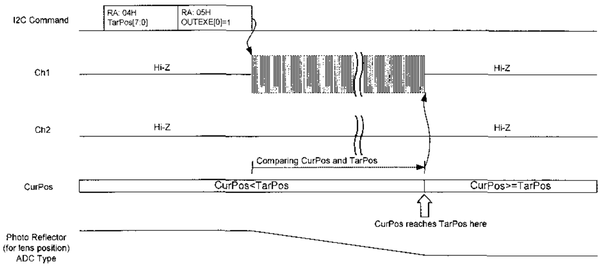
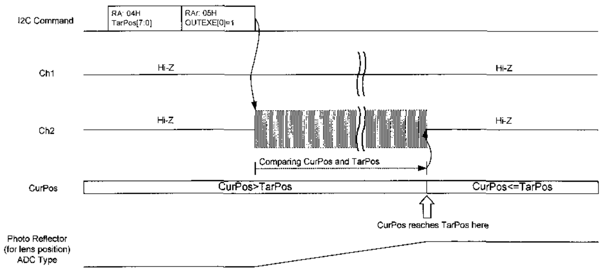


그림 6. 순서도.

Fig. 6. Execution sequences.



(a) CurPos < TarPos at entering OUTEXE mode.



(b) CurPos > TarPos at entering OUTEXE mode.

그림 7. 타이밍 차트.

Fig. 7. Timing chart.

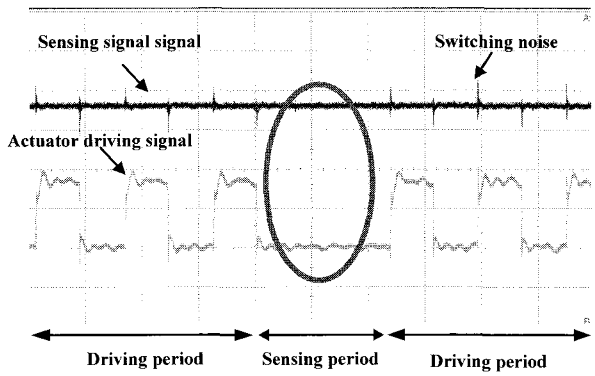


그림 8. 시분할 구동 동작.

Fig. 8. Time Division Driving (TDD) operation.

piezoelectric driver IC. Because driver compare CurPos and TarPos and then stop if CurPos reaches TarPos, this sensing analog signal is very critical to precise lens positioning characteristic. Actually, but this sensing signal is very noisy due to piezoelectric actuator driving signal. Because the piezoelectric actuator is modeled by large capacitance (about 20nF), hundreds mili-ampere is dissipated for piezoelectric actuator driving. That is, the driving signal affects the sensing signal that has lens position information. To avoid contamination of the sensing signal, we propose Time Division Driving (TDD) and displays operation driving signal affects the sensing signal that has lens position information. To avoid contamination of the sensing signal, we propose Time Division Driving (TDD) and displays operation of TDD in Fig. 8. As shown in figure, piezoelectric actuator driving period and lens position sensing period can be separated to minimize the effect of error due to driving signal. The precision of lens position is improved by TDD, namely.

2. Frequency Sweep Control

In this work, to compensate the variation of the piezoelectric actuator characteristic on temperature, channels and manufacture-

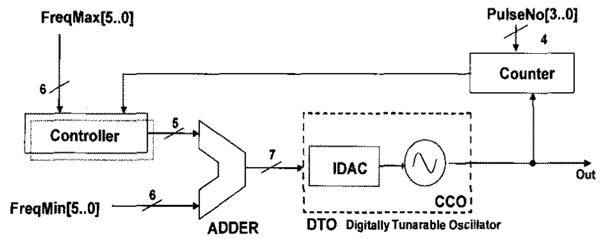


그림 9. 주파수 스윕 제어 블록.

Fig. 9. Frequency sweep control block.

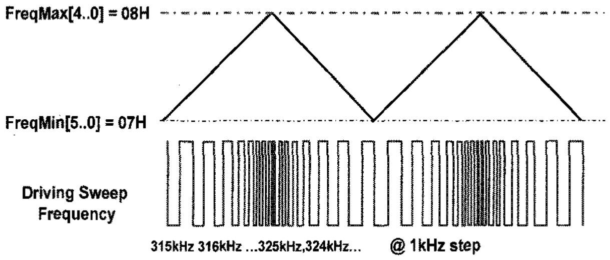


그림 10. 주파수 스윕 제어 동작.

Fig. 10. Frequency sweep control operation.

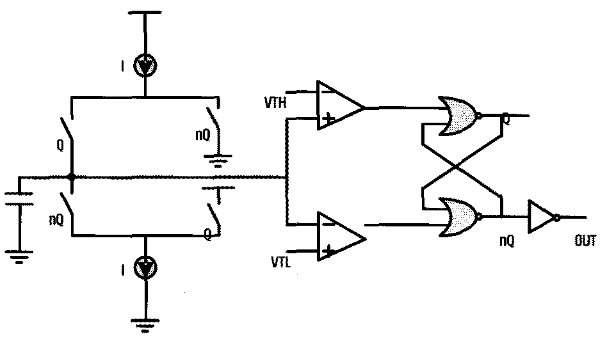


그림 11. 전류 제어 발진기.

Fig. 11. Current controlled oscillator.

ing process, frequency sweep method is chosen and architecture is shown in Fig. 9. The frequency sweep controller received three types of data which are FreqMin[5:0], FreqMax[5:0] and PulseNo[3:0]. The driving sweep frequency range is set by FreqMin[5:0] and FreqMax[5:0]. The driving pulse number is set by PulseNo[3:0]. Fig. 10 shows a frequency sweep operation. For example if user set FreqMin[5:0] is 07H data x0011101 and FreqMax[5:0] is 08H data x0001010, driving sweep frequency is from 315kHz to 325kHz in 1kHz step.

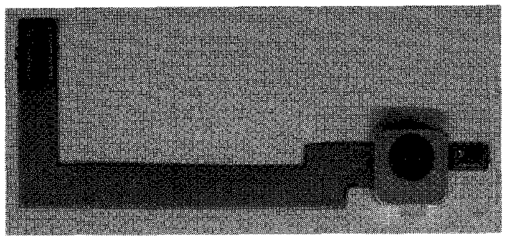
The driving signal is generated by current controlled oscillator (CCO) as shown in Fig. 11 and oscillation frequency can be expressed as (1).

$$Frequency = \frac{I}{2C_{ox}(V_{TH} - V_{TL})} \quad (1)$$

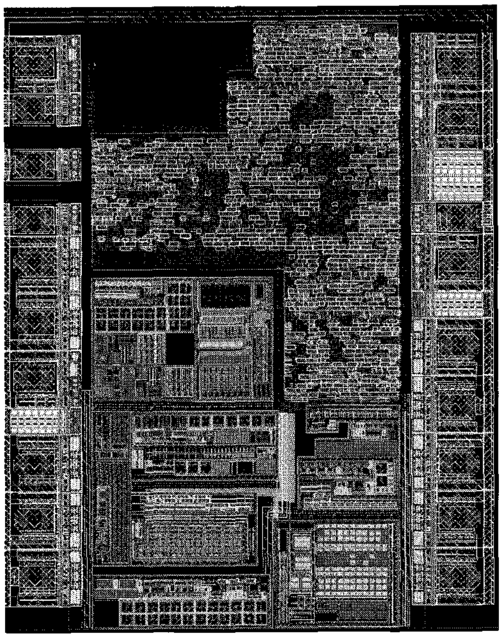
The oscillation frequency is controlled by current DAC (IDAC) [7,8]. After all, high accurate IDAC is required for frequency sweep in a 1kHz step. It is no wonder that building a precise IDAC requires careful layout, so a common-centroid method is used.

IV. Hardware Implementation and Measurement Results

We developed a piezoelectric actuator and driver IC for AF on ISM. The driver IC is fabricated in a 0.35μm 2-poly 4-metal CMOS technology. The driving frequency range of output is from 300kHz to 700kHz for driving of various types of piezoelectric motors. The photographs of ISM with AF and designed driver IC are shown in Fig. 12. The total area of driver IC is $3.2mm^2$. The areas of MCU and analog switch for conventional scheme are $18mm^2$ and $4mm^2$, respectively. The area of designed IC is only 15% of area of two-chip for conventional scheme.



(a) ISM with AF



(b) layout of driver IC.

그림 12. 하드웨어 구현.

Fig. 12. Hardware implementation.

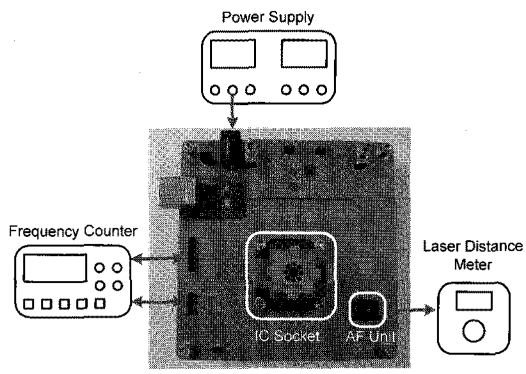


그림 13. AF 실험 환경.

Fig. 13. Test environment for AF.

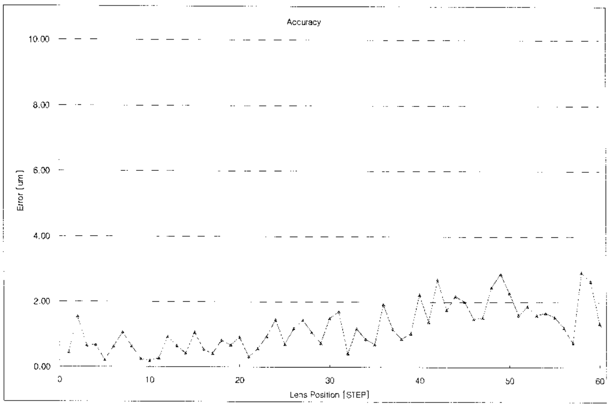


그림 14. 렌즈 위치 오차 측정 결과.
Fig. 14. Measurement results of lens position error test.

표 1. 구동 IC의 성능 요약.
Table 1. Performance Summary of Driver IC.

Specifications	Results
Interface	I2C
Driving Frequency Range	300kHz ~ 700kHz
Driving Current Capability	< 500mA
Lens Position Accuracy	< 3μm
Power Supply	3.3V
Power dissipation	2.8mW
Chip size	2000 x 1650 μm^2
Technology	0.35μm 2P4M CMOS

To verify lens position error, the lens position is swept and position error of each step is measured on test environment shown in Fig. 13. The error should be under 10μm to guarantee AF operation. As shown in Fig. 14, the measured error is under 3μm.

For a single supply voltage of 3.3V, the power consumption is 2.8mW which is less 10~20% than power consumption of conventional scheme. The characteristics of the piezoelectric driver IC are summarized at Table I.

V. CONCLUSIONS

The AF feature for ISM can be implemented as piezoelectric actuator and VCM actuator. The piezoelectric actuator consumes static power dissipation less than VCM actuator. The conventional scheme of driving piezoelectric actuator consists of two IC such as MCU and analog switch. Therefore resources such as power consumption, package and module size are wasted.

In this paper, new driving scheme is proposed. The MCU and analog switch are replaced as a designed driver IC. So the proposed scheme has advantages of power-efficiency and chip area. Because of these advantages, the new scheme is suitable recent trend of green IT that places emphasis on energy efficiency.

Also the proposed solution allows for fast and optimal AF performance and compact ISM. To achieve the goal, positioning algorithm and TDD method are used.

For more attractive solution for green IT trend, we are developing the lower-power driver IC and piezoelectric actuator. Also we are researching for combination with peripheral circuits to reduce the resources such as power consumption, package and module size.

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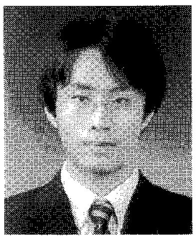
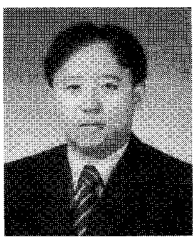


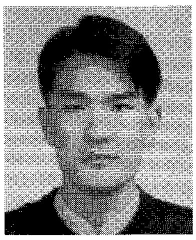
차 상 현

1979년 12월 13일생. 2005년 서울시립대학교 전자전기컴퓨터공학부(공학사). 2007년 서울시립대학교 전자전기컴퓨터공학부(공학석사). 2007년~현재 삼성전기 기술총괄 UM 솔루션랩 선임연구원. 관심분야는 아날로그 및 혼성신호 집적회로 설계.



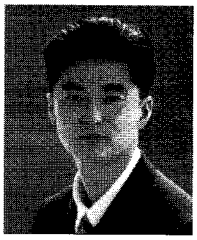
박 찬 우

1976년 10월 11일생. 1999년 한국외국어대학교 전자공학과(공학사). 2001년 한국외국어대학교 전자공학과(공학석사). 2003년~현재 삼성전기 기술총괄 UM 솔루션랩 책임연구원. 관심분야는 디지털 집적회로 설계.



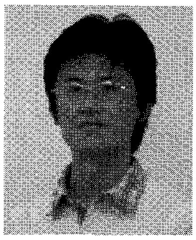
이 연 중

1972년 6월 28일생. 1999년 서강대학교 전자공학과(공학사). 2004년 한양대학교 전자공학과(공학석사). 1999년~현재 삼성전기 기술총괄 UM 솔루션랩 책임연구원. 관심분야는 아날로그 및 혼성신호 집적회로 설계.



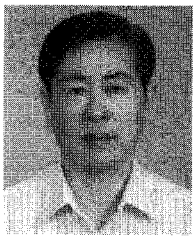
황 병 원

1974년 7월 10일생. 2000년 건국대학교 전자공학과(공학사). 2000년~현재 삼성전기 기술총괄 UM 솔루션랩 책임연구원. 관심분야는 디지털 집적회로 설계.



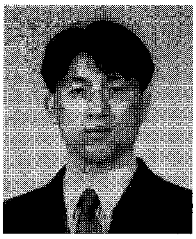
박 득 희

1973년 12월 25일생. 1992년 건국대학교 전자공학과(공학사). 2009년 성균관대학교 이동통신공학과(공학석사). 2000년~현재 삼성전기 기술총괄 UM 솔루션랩 책임연구원. 관심분야는 아날로그 및 혼성신호 집적회로 설계.



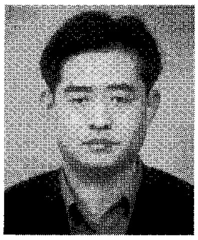
이 재 신

1962년 7월 15일생. 1983년 부산대학교 전자기계공학과(공학사). 1985년 부산대학교 전자공학과(공학석사). 2002년 고려대학교 전자공학과(공학박사). 1985년~2007년 삼성전자. 2008년~현재 삼성전기 기술총괄 UM 솔루션랩 수석연구원. 관심분야는 아날로그 및 디지털, 혼성신호 집적회로 설계.



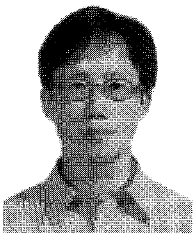
권 오 조

1975년 1월 20일생. 2001년 고려대학교 전기공학과(공학사). 2001년~현재 삼성전기 기술총괄 UM 솔루션랩 선임연구원. 관심분야는 아날로그 및 혼성신호 집적회로 설계.



권 경 수

1964년 4월 15일생. 1988년 중앙대학교 전자공학과(공학사). 2007년 아주대학교 전자공학과(공학석사). 1989년~현재 삼성전기 기술총괄 UM 솔루션랩 수석연구원. 관심분야는 아날로그 및 디지털, 혼성신호 집적회로 설계.



황 신 환

1964년 3월 25일생. 1986년 서울대학교 제어계측공학과(공학사). 1988년 서울대학교 제어계측공학과(공학석사). 1993년 서울대학교 제어계측공학과(공학박사). 1993년~1998년 LG전자, 1998년~2000년 Innopoa, Inc., 2000년~2003년 8x8, Inc., 2003년~2008년 Ximeta, Inc., 2008년~현재 삼성전기 기술총괄 UM 솔루션랩 상무. 관심분야는 아날로그 및 디지털, 디지털 집적회로 설계.