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A Radiation Sensor Interface System for Mobile Application

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1. Introduction

Nuclear energy is widely used to improve the quality of life for humankind in many fields. In particular, nuclear power plants are the basis of modern industry because they can operate with higher efficiency than other existing power plants. On the other hand, failure to safely dispose of radioactive can lead to the most threatening incidents to humans. In the past, accidents from the Chernobyl disaster to the Fukushima nuclear plant accident were a disaster for humans in itself, and even later to secondary damage such as radiation exposure [1]. Even agricultural products exposed to radiation are at risk of being consumed regardless of the area where the accident occurred. Therefore, not only the areas previously classified as radioactive hazard areas, but also individuals in everyday life need to carry a radiation detector. However, the conventional portable radiation detector has a disadvantage that it is cumbersome for the individual to carry because it takes up too much volume. The reason for the large volume of the conventional radiation detector is that the driving voltage of the radiation detection sensor is high, and a large volume of batteries providing high voltage is inevitably used. Therefore, this study proposes a configuration of a radiation sensor interface integrated circuit system for a portable radiation detector and analyzes its performance. This paper consists of 3 sections. Section 1 discusses the need for this study, and Section 2 analyzes and proposes radiation sensor interface systems, and Section 3 will discuss the implementation results.

2. Proposed System

This section will discuss the construction of the portable radiation sensor interface system discussed in section 1. First, we will discuss the overall system configuration in section 2.1, and in section 2.2 we will discuss the configuration of battery-based power management circuits, the core of mobile systems. Section 2.3 will discuss the construction of the sensor interface circuit for processing the radiation signal detected by the configured sensor.

2.1 Overall System Implementation

In order to construct a mobile radiography system, three sub-blocks must be configured. As shown in Fig. 1, it consists of the silicon photo-multiplier (SiPM), the sensor interface circuits that process the signals generated from the SiPM, and the power management circuits that convert the Li-ion battery voltage into voltages suitable for the previous two sub-blocks. SiPM is the most widely used radiation detector and consists of a diode applied with reverse high voltage (25 ~ 80 V). When the radiation wave is injected to the SiPM from the outside, charges proportional to the energy of the wave are generated, and the sensor interface circuits amplify and quantize it to produce a digital output. The key feature of the proposed system is that it must be able to operate in conjunction with the elements mounted on the mobile phone. In general, the Li-ion battery used in the mobile phone has a nominal voltage of 3.6 V, so the power management circuits efficiently supply the voltages required for the respective sub-blocks. The radiation information sensed by the sensor interface circuits is processed by the mobile application processor, and it is possible to transmit the radiation detection to the user.

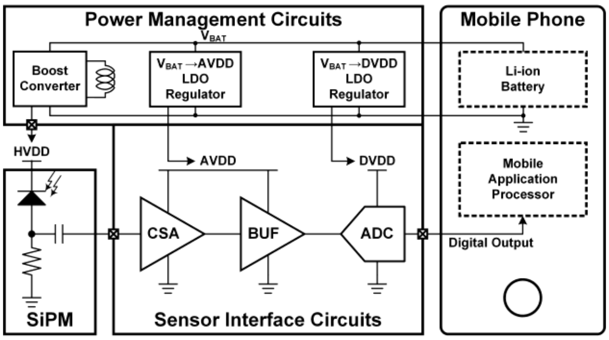

Fig. 1. Overall architecture of mobile radiation sensor interface system.

2.2 Power Management Circuits for Battery-based System

In the past studies, the implementation of a mobile radiation system was not possible because the SiPM required a high voltage (25 ~ 80 V). In particular, since

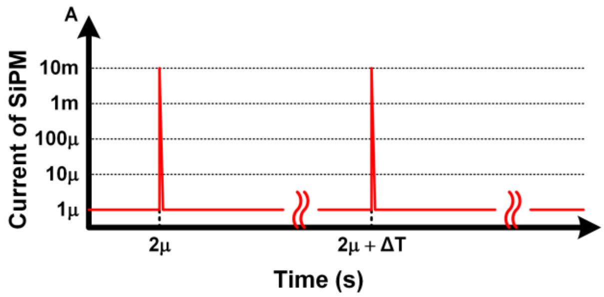

Fig. 2. Load transient characteristics of SiPM

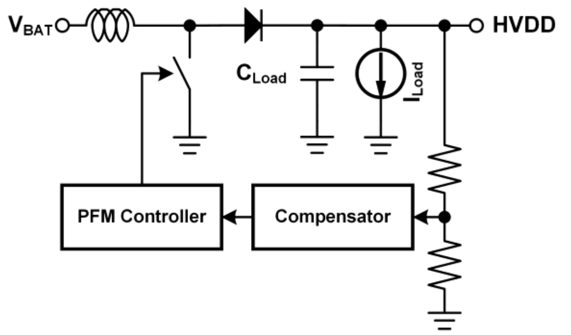

Fig. 3. Pulse frequency modulated (PFM) DC-DC boost converter for biasing of SiPM.

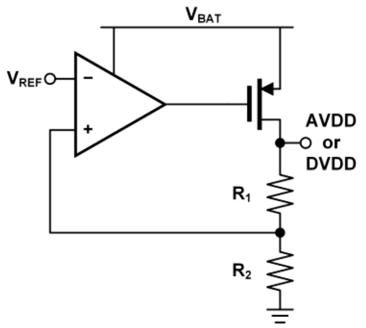

Fig. 4. Low dropout (LDO) linear regulator for driving general analog and digital circuits

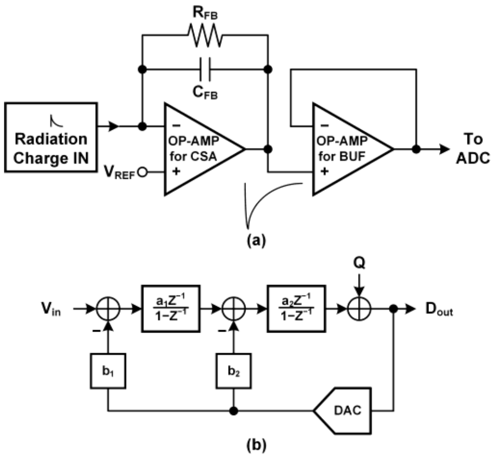

Fig. 5. Circuit diagram for sensor interface circuits (a) charge sensitive amplifier (CSA) with buffer, (b) discrete time 2nd order delta sigma modulator.

the SiPM has a characteristic that the charge efficiency increases as the driving voltage increases, it is necessary to implement a stable high voltage generator to obtain reliable signal information. The commercial radiation detection systems in the past have used bulky batteries for this reason. Another reason why the implementation of mobile radiation detection systems has been difficult is that the characteristics of the current consumed by the SiPM are different from the load of general system. As shown in Fig. 2, when the radiation particles are irradiated on the SiPM, charges in proportion to the energy of the particles are generated in the diode to which the reverse bias is applied. The ΔT means the period in which radiation particles are injected. However, since a very low current flows most of the time when no radiation particles are injected, it can be seen that the current changes in a very wide range. Therefore, there is a need for a driving circuit capable of operating at maximum efficiency in such load characteristics. In other words, there is a need for a DC-DC boost converter that always operates at high efficiency even with wide load changes.

In consideration of the load characteristics of the SiPM, a boost converter that can generate and drive a voltage of 25 ~ 30 V is applied in the proposed radiation detection system [2]. As shown in Fig. 3, the basic boost converter topology is used as it is, but a control circuit with pulse frequency modulation (PFM) method is configured to switch quickly to the original driving voltage at the moment of load transient caused by radiation particles. On the contrary, when the radiation particles are not normally input, the switching speed is decreased to minimize the power consumed by the boost converter itself. The general pulse width modulation (PWM) scheme, which always operates at the same switching frequency and controls only the pulse width, dissipates the same power over the entire load range, making it unsuitable in such situations where the load changes notably.

The remainder of the power management circuit part is the generation of AVDD and DVDD for sensor interface circuits. The sensor interface circuits discussed in the next sub-section must accurately amplify the charge generated by the SiPM and convert it to digital, requiring stable voltage generation even at low efficiency. Therefore, as shown in Fig. 4, a conventional low dropout (LDO) linear regulator must be designed for AVDD and DVDD respectively.

2.3 Sensor Interface Circuits for Radiation Detection

Fig. 5 shows the implementation of the basic radiation sensor interface circuit. Since a typical radiation detector has high parasitic capacitance, the charge generated in the SiPM is lost to the detector itself. Therefore, as shown in Fig. 1, the decoupling capacitor should be used as a large value to configure as much charge as possible into the sensor interface circuit. Additionally, high sensitivity charge sensitive amplifier (CSA) is applied to amplify the radiation charge with a high efficiency (Fig. 5 (a)) [3]. Radiation charges amplified to voltage through the CSA must be converted to digital. The 2nd order discrete time delta sigma modulator (DTDSM) of Fig. 5 (b) was placed after the CSA to accurately detect peak values of rapidly generated radiation pulses [4].

3. Conclusions

In this study, we proposed a radiation detection system that can be combined with a mobile phone to easily detect the danger of radiation. The proposed radiation detection system has the ability to drive the high bias voltage of commercial SiPM, which can be applied to mobile applications. The proposed circuits can be implemented as real integrated circuits, and they are expected to be applicable to real mobile applications if the miniaturization is made at low cost.

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