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Modeling and Simulation of the Radiation Signal Filtering Circuits for BCMS

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1. Introduction

There is a boron concentration measuring system (BCMS) between the radiation monitoring systems for nuclear power plants. This system has a function of measuring the boron concentration indirectly through a BF_3 detector. The detector in the sample tank for the system measures the neutrons generated by a source which has a clearance from the detector. Since boron has a broad absorption cross section against the neutrons, the higher boron concentration in the reactor coolant is, the fewer neutrons are measured.

Some plants replaced old systems with advanced ones containing new signal filtering circuits as their processing units are obsolete, and these systems are operating successfully since the post-maintenance test was performed through functional procedures. But, the theoretical access and its verification through a program simulation were not implemented, therefore this study was performed additionally to support and explain the signal process operation of the installed filtering circuits.

2. Modeling of Radiation Filtering Circuits

2.1 Pulse Pile-up and Undershoot

Generally, the time constant of the preamplifier is much larger than the charge collection time of the detector. The time required for the signal pulse to reach its peak value is determined by the charge collection time of the detector. Since the radiation energy magnitude which the detector measures is typically variable and random, the preamplifier output also has generally variable patterns. But, although the signals with constant magnitudes enter into the preamplifier circuit, its outputs are different from the levels of original signals because the rising portion of a pulse is piled up on the previous pulse's tale which is decaying exponentially. This makes the magnitude of following pulse bigger as much as that of the previous pulse's tale.

Therefore, the long decay time should be shortened through a pulse filtering amplifier. Otherwise, this results in the acceptable pulse number and the distortion of a measured energy level. To prevent this problem, a derivative circuit is connected to the preamplifier to separate the overlapped pulses. But, this causes the signal undershoot. In the high count rate case, pulses are piled up on these undershoots. The measured energy magnitude of these pulses are obviously lower than their original energy levels, and this results in the broaden energy spectrum. The following figure shows the effect of a real pile-up case in the new BCMS measurement circuit and improved signals through the filtering circuit.

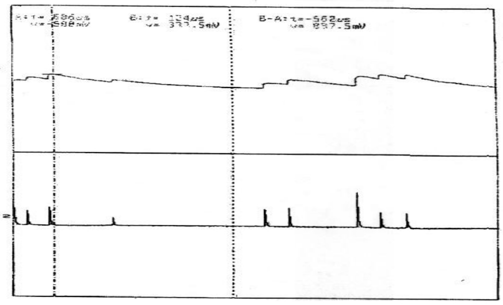

Figure 1. BCMS signal outputs from the filtering circuit

2.2 Modeling of the Filtering Circuits

The modeling of the radiation signal filtering circuit on the S-domain is as follows. The radiation signal from the detector is a response to the current pulse into the paralleled RC circuit, where the current collection time of the detector is extremely short and the time constant of the RC circuit is relatively long. Therefore, the preamplifier signal can be modeled as the exponential function decaying with the time constant RC (*T*).

$$e_1(t) = \mathrm{Emax} \times e^{-\frac{t}{T}}, \quad E_1(s) = \mathrm{Emax} \times \frac{1}{s+\frac{1}{T}}$$

When a preamplifier signal passes the derivative circuit with the time constant *To*, the original signal is changed into the composed signal which contains one signal decaying with the short time constant *To* and the large peak voltage and the other signal decaying from the negative region to the baseline with the short time constant *T* and the small peak voltage.

$$E_2(s) = \mathrm{Emax} \times \frac{1}{s+\frac{1}{T}} \times \frac{s}{s+\frac{1}{To}}, \quad To = RoCo$$

$$\therefore\ e_2(t) = \frac{Emax}{T-To}\left[T \times e^{-\frac{t}{To}} - To \times e^{-\frac{t}{T}}\right]$$

Consequently, after use of the derivative circuit, the pulse width becomes narrowed to solve the pile-up problem, but the undershoot below the baseline still exists. To remove the adverse effect from this undershoot, a feedback resistor, Rpz, is added to the original derivative circuit. If the preamplifier signal passes the new derivative circuit, the final output will be the below terms.

$$E(s) = E_{max} \frac{1}{s+\frac{1}{T}} \times \frac{s+\frac{1}{R_{pz}C_o}}{s+\frac{R_o+R_{pz}}{R_oR_{pz}C_o}}$$

If Rpz is adjusted so that the denominator of the preamplifier transfer function can be the same as the numerator of the new derivative circuit, the final output signal is changed into the fitted exponential signal decaying to the baseline without the undershoot.

$$\therefore E(s) = E_{max} \frac{1}{s+\frac{R_o+R_{pz}}{R_oR_{pz}C_o}}$$

3. The Circuit Simulation

3.1 Pulse Separation and Undershoot Compensation

The MATLAB (Matrix Laboratory) simulation has been performed to show that the overlapped preamplifier signals are separated by the derivative circuit respectively and the undershoots are recovered by the compensation circuit.

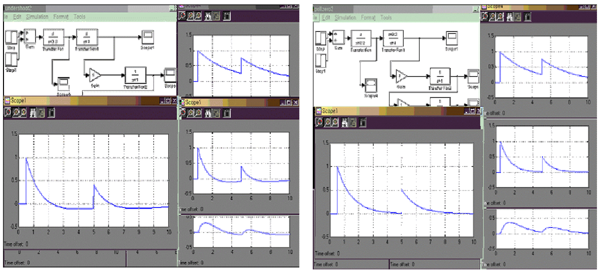

Figure 2. The MATLAB simulation results

The output of the original filtering circuit without the derivative circuit and undershoot compensation has been simulated through the PSPICE (PC Simulation Program with Integration Circuit Emphasis) program for the verification based on electrical components.

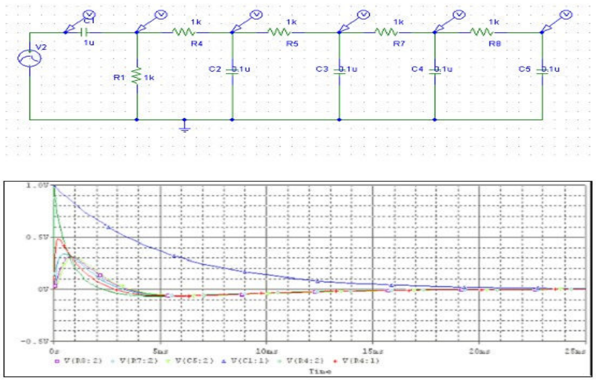

Figure 3. The PSPICE simulation results

3.2 BCMS Circuit Simulation

The BCMS circuit which includes an active type filter has been simulated. The active filter was used to acquire the higher pulse count rate and signal to noise ratio. The signal characteristics of the BCMS preamplifier followed the vendor manual. The range of output signal is 45mV～4.5V, and the time constant of the preamplifier is 100 ㎲. The raw peak voltage before the filtering stage is supposed as 500mV.

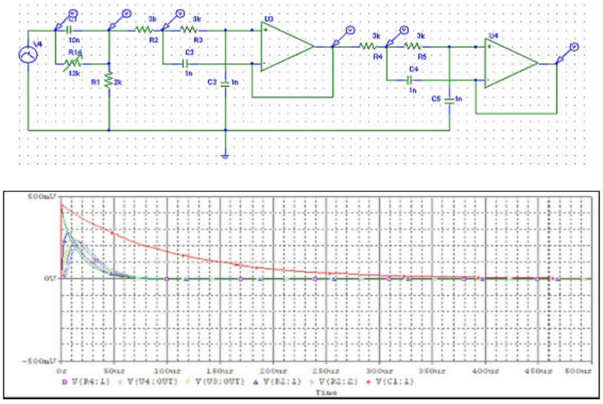

Figure 4. The PSPICE simulation for the BCMS circuit

4. Conclusion

The radiation signal filtering circuit for BCMS has been verified and explained through the system replacement experiences and the further simulations.

The preamplifier can be regarded as the equivalent circuit including the paralleled RC load which accumulates and consumes the charges from the detector, and it has a time constant much larger than the charge collection time of the detector. Therefore, the signal characteristic can be represented as the two stages, one with the very fast rising time and the other with the slow decay time. If the rising time is approximated to zero, the preamplifier output can be modeled as an exponential function decaying to the baseline with the time constant RC. According to the simulation results (the same in the real system), the preamplifier signal problems such as the pulse pile-up due to the large RC and the undershoot from the derivative function can be solved by the derivative filter with a feedback resistor.

This new signal processing unit for BCMS has been installed and operated successfully in Yonggwang, Kori, and Ulchin site. The modeling and simulation methods within this study could be used also for improvements of other applications such as other gamma ray monitors and on-line local radiation monitors, etc.

REFERENCES

[1] "Radiation Detection and Measurement," 3rd Edition, John Wiley & Sons, Inc. 2000.
[2] "Boron Concentration Monitoring System," Westinghouse, June 1985