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# DESIGN OF A FPGA-BASED DIGITAL REACTIVITY METER FOR DALAT NUCLEAR RESEARCH REACTOR

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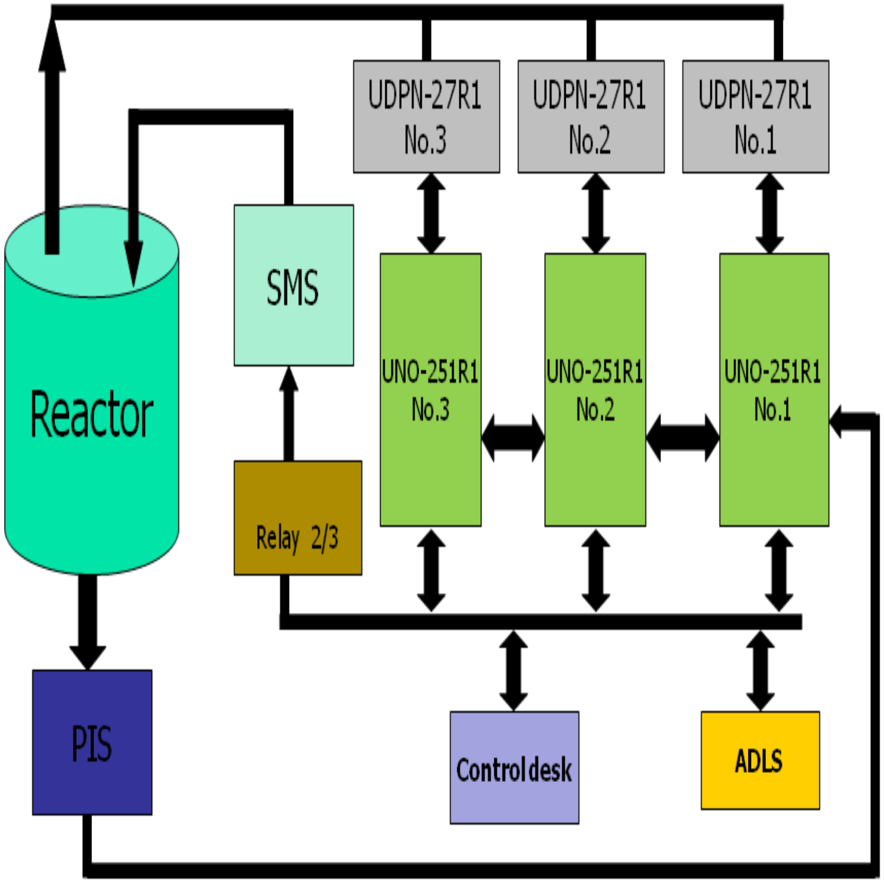
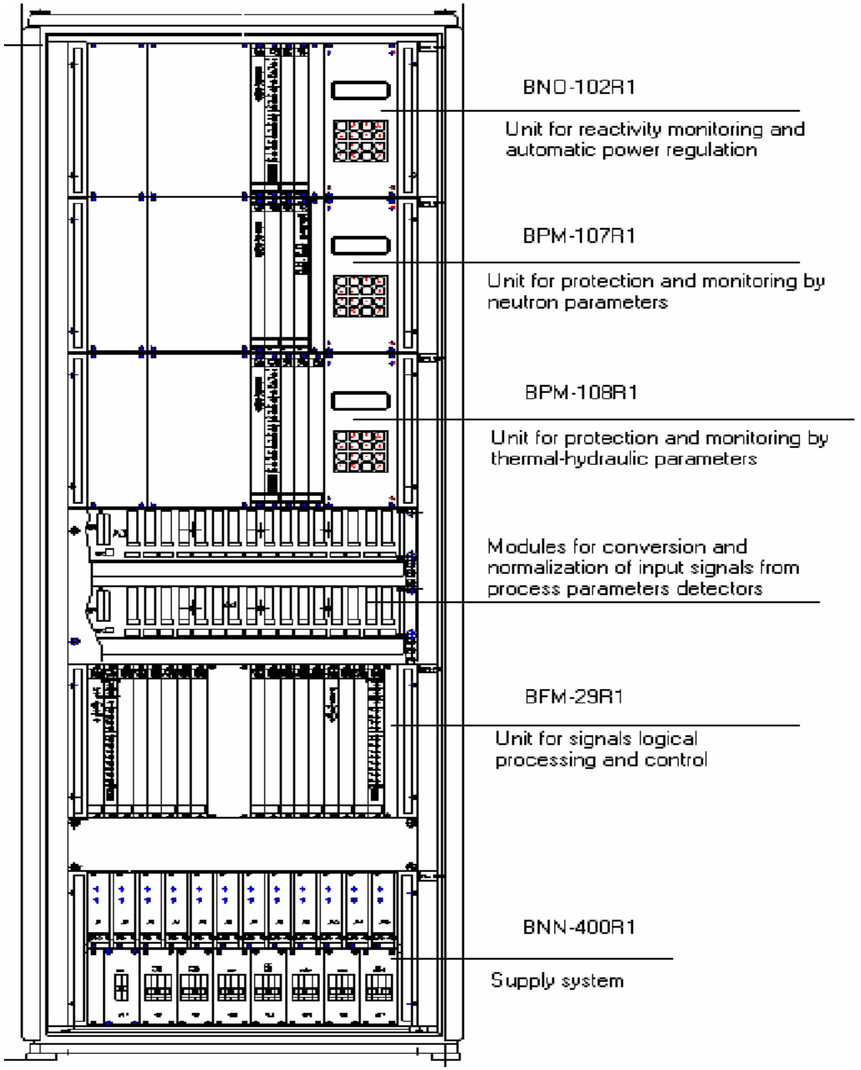
# I. INTRODUCTION

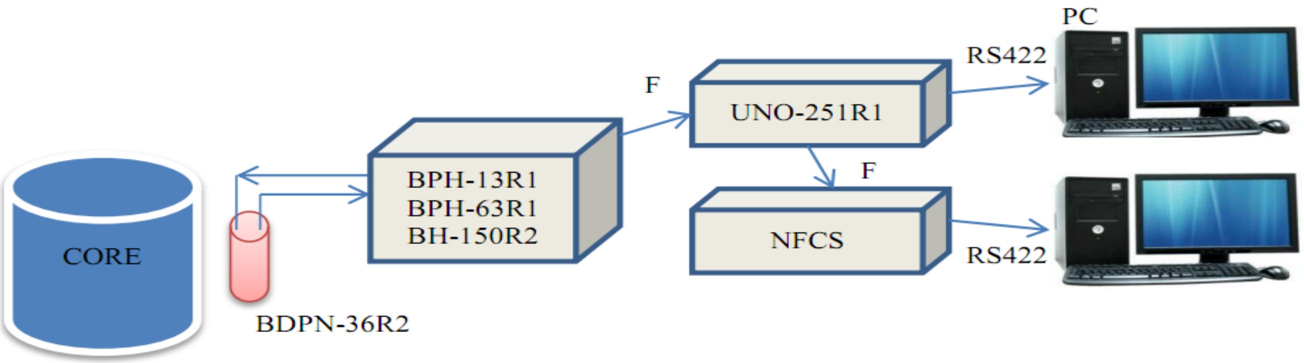
- Reactor Control system



- ASUZ-14R



# I. INTRODUCTION



$$P_{SR} = K_{SR} \times F_{SR} \times 10^{-6} \qquad (1)$$

Psr ($10^{-6}$ to $10^{-1}$ % Pnominal, Pnominal = 500 kWt));

Reactivity is an important parameter that indicates a departure of a reactor power from critical, to calculate whether the neutron density in a reactor will remain constant or change. The reactor is in critical state or operates at the steady power level when $k_{eff} = 1.0$.

If $k_{eff} < 1.0$, the reactor is subcritical or operates at the power level is falling.

If $k_{eff} > 1.0$, the reactor is supercritical or the power level is rising. Reactivity is given by equation (2) [1, 4] as:

$$\rho = (k_{eff} - 1)/ k_{eff} \qquad (2)$$

where, $\rho$ is reactivity and $k_{eff}$ is effective multiplication factor of the reactor.

# II. ALGORITHM OF REACTIVITY CALCULATION

The time behavior of the reactor power level in a nuclear reactor by changes $k_{eff}$ can be expressed by the point kinetics equations are shown in equations (3) and (4) [1, 4, 5] as:

$$\frac{dP(t)}{dt} = \frac{\rho(t)-\beta}{\Lambda} P(t) + \sum_{i=1}^{6} \lambda_i C_i(t) \qquad (3)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} P(t) - \lambda_i C_i(t) \; for \; i = 1,2,\dots,6. \qquad (4)$$

where,

- P(t) is the reactor power at time t,
- ρ(t) = [k(t)-1]/k(t) is the reactor reactivity at time t,
- Ci(t) is the concentration of the i-th group delayed neutron precursors, λi is the decay constant of the i-th group;
- βi is the fraction of the delayed neutron for the i-th group;
- Λ = l/k is the mean neutron generation time.
- Note that a neutron source was ignored in equation (3).

# II. ALGORITHM OF REACTIVITY CALCULATION(tt)

- Solution of the equations (3) and (4) we have equation (5).

- The equation (5) is used to develop the algorithm for the reactivity calculation of the designed digital reactivity meter module for the DNRR.

- $$\rho_n = \frac{\beta_{eff}}{1+l\tau} + \frac{l\tau}{1+l\tau} - \frac{1}{P_m(1+l\tau)} \sum_{i=1}^{6} \lambda_i \beta_i S_{im} \qquad (5)$$

- where,

- $$\tau = \frac{P_m - P_{m-1}}{P_m \Delta t} \qquad (6)$$

- $$S_{im} = S_{im-1} e^{-\lambda_i \Delta t} + \frac{1}{\lambda_i}\left(1 - e^{-\lambda_i \Delta t}\right)\left[P_{m-1} - \frac{P_m - P_{m-1}}{\lambda_i \Delta t}\right] + \frac{P_m - P_{m-1}}{\lambda_i} \qquad (7)$$

- where,

- $P_m = P(t)$, $P_{m-1} = P(t-\Delta t)$,
- $\Delta t$ is the sampling rate (in seconds),
- $\beta_{eff}$ is the delayed neutron fraction of DNRR = $7.464.10^{-3}$,
- and $S_{im}$ is the reactor power history.

$\beta_{ieff}$

# II. ALGORITHM OF REACTIVITY CALCULATION (tt)

- The initial value $S_{i0}$ that is the mean power level of the reactor at critical state, is given by equation (8):

$$S_{i0} = \frac{P_0}{\lambda_i} \qquad (8)$$

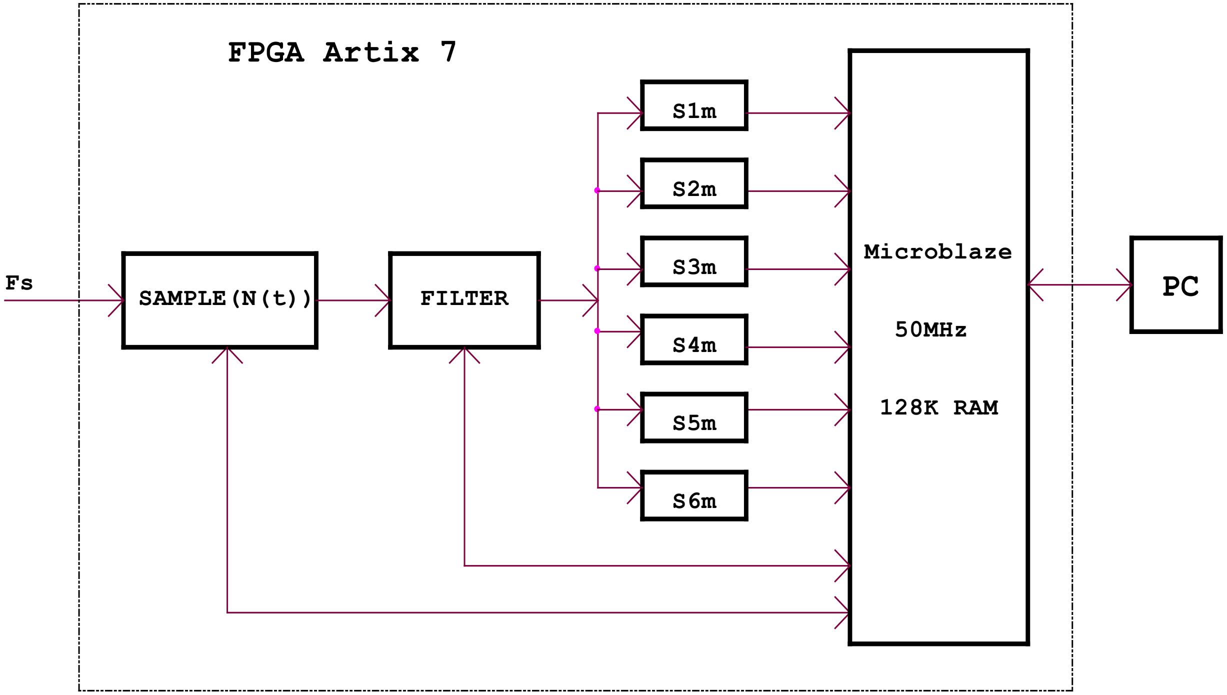
- An initial reactivity is equal zero. Kinetic parameters , , and of the DNRR are shown in Table 1.

Table 1: Kinetic parameters of the DNRR [6]

| Group | Effective yield $\beta_i$ | % of delayed neutrons $a_i=\beta_i/\beta$ | Decay constant $\lambda_i$ |
|---|---|---|---|
| 1 | 2.626E-04 | 3.518 | 1.334E-02 |
| 2 | 1.351E-03 | 18.10 | 3.273E-02 |
| 3 | 1.301E-03 | 17.44 | 1.208E-01 |
| 4 | 2.867E-03 | 38.41 | 3.028E-01 |
| 5 | 1.186E-03 | 15.90 | 8.499E-01 |
| 6 | 4.959E-04 | 6.644 | 2.854E+00 |
| βeff | 7.464E-03 | | |
| 1 | 8.044E-05 | | |

# II. ALGORITHM OF REACTIVITY CALCULATION (tt)

- Functions of each unit in the diagram of Fig. 1 are summarized as: Fs is the output pulse frequency from the pulse amplifier, which is proportional to the reactor power; SAMPLE (N(t)) is for sampling pulse frequency Fs; FILTER is for filtering sampled pulses by using moving average technique; $S_{1m}$ to $S_{6m}$ are reactor power history for six groups of delayed neutrons; Microblaze is a microcontroller with 50-MHz on-board clock and 128 kbytes RAM for reactivity calculation; and PC is a computer for recording reactivity.

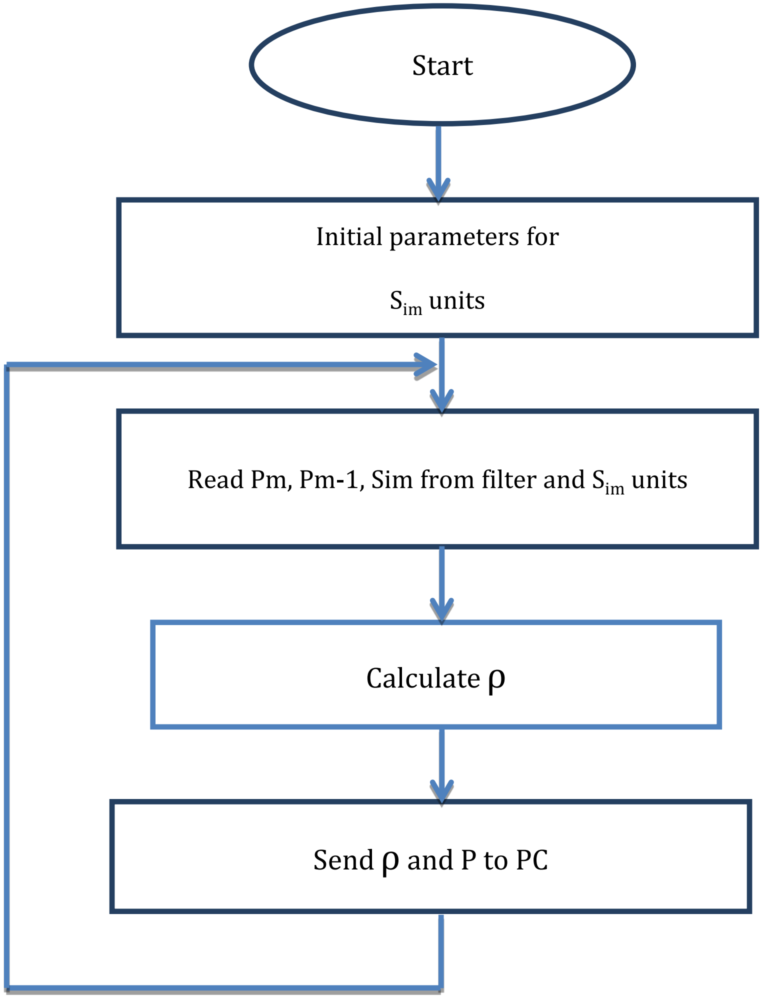


# II. ALGORITHM OF REACTIVITY CALCULATION (tt)

- The output frequency from a pulse amplifier is sampled and filtered by hardware on FPGA Artix-7.
- In which, the current reactor powers of $P_m$ and $P_{m-1}$ as the reactor power history are determined, and $S_0$ and $S_{im}$ ($S_{1m}$ .... $S_{6m}$) are also calculated using Eq. (8) and Eq. (7), respectively.
- The Microblaze calculates the reactor reactivity by Eq. (5) and sends its value to the on-board display LCD and to the PC for recording.

# II. ALGORITHM OF REACTIVITY CALCULATION (tt)

- Flow chart of reactivity calculation in FPGA Artix-7 with embedded Microblaze.



Start

Initial parameters for

$S_{im}$ units

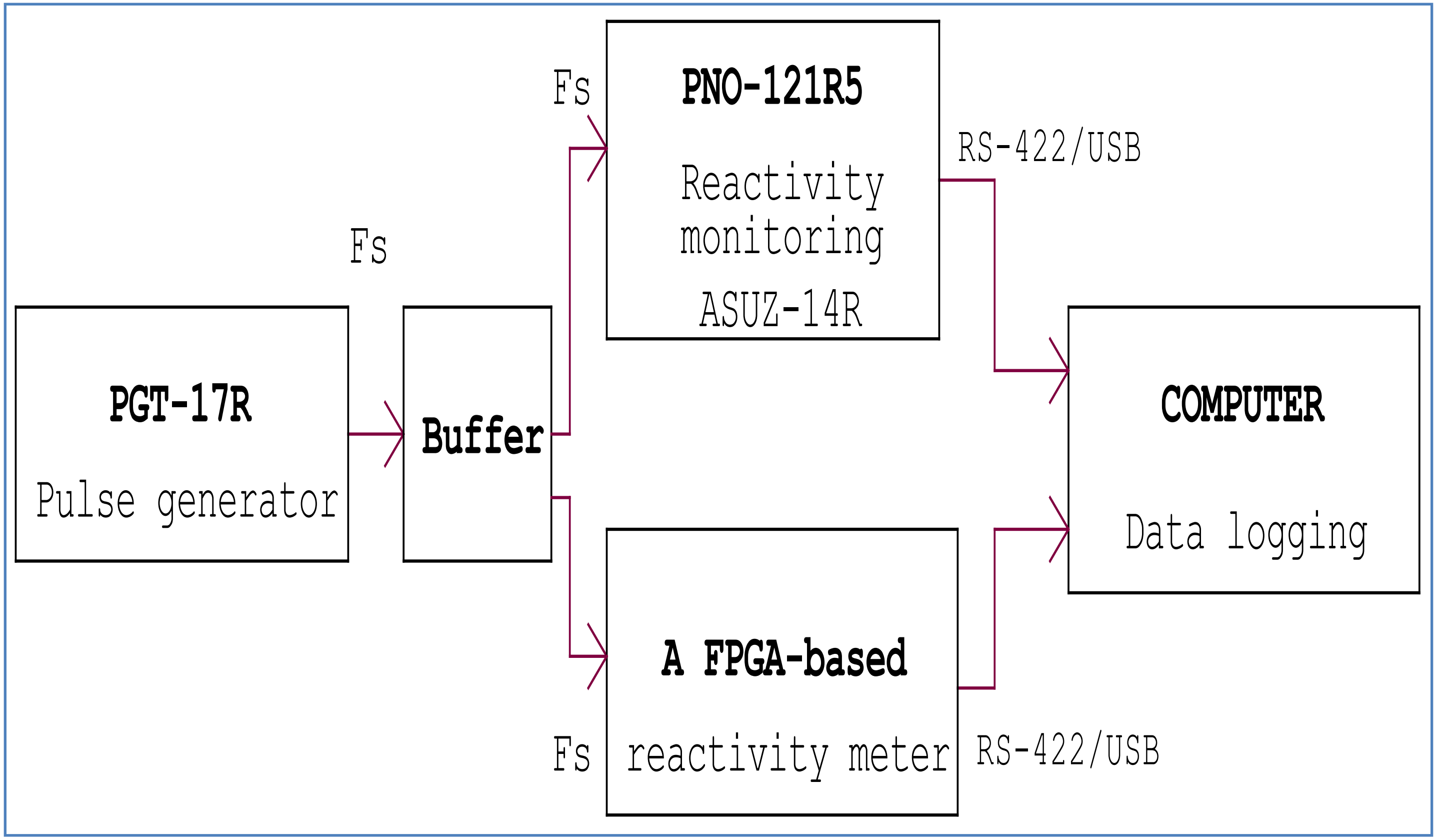
Read Pm, Pm-1, Sim from filter and $S_{im}$ units

Calculate $\rho$

Send $\rho$ and P to PC

# III. EXPERIMENTS, RESULTS AND DISCUSSION

- The designed reactivity meter module was tested for its comparison with the imported PNO-121R5 module using the pulse-generated simulator PGT-17R



**PGT-17R**

Pulse generator

Fs

**Buffer**

Fs

**PNO-121R5**

Reactivity monitoring

ASUZ-14R

RS-422/USB

Fs

**A FPGA-based**

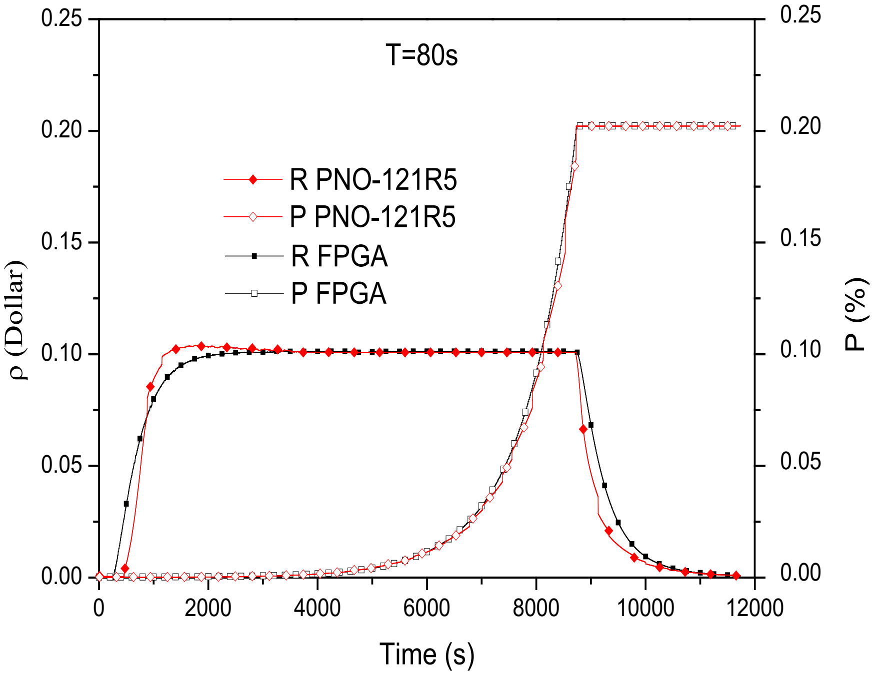
reactivity meter

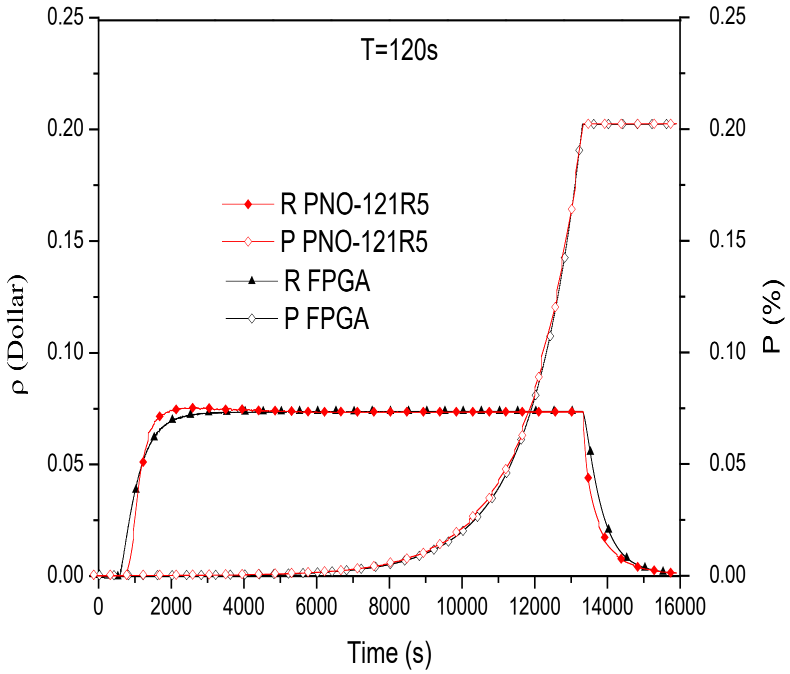
RS-422/USB

**COMPUTER**

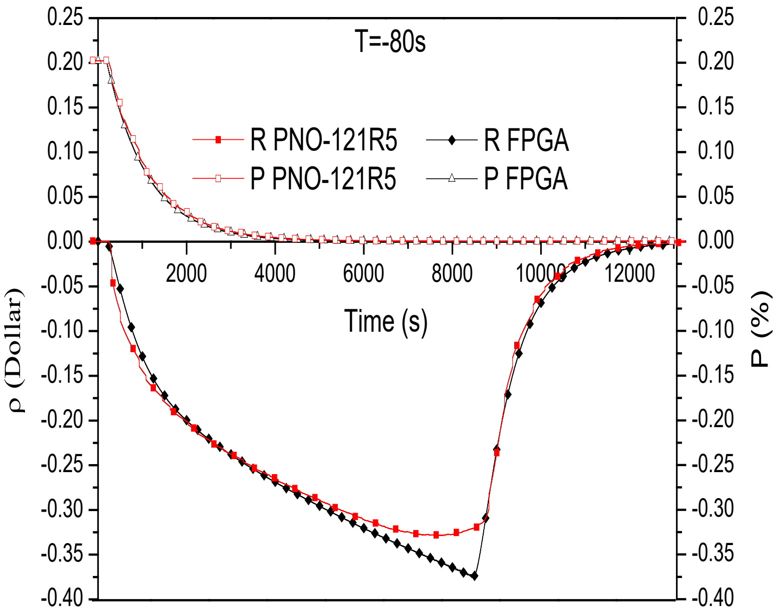
Data logging

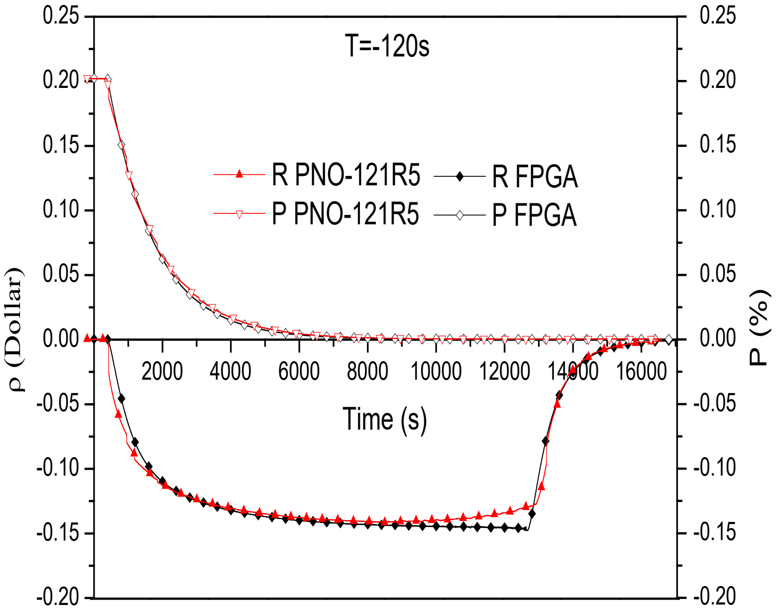
# III. EXPERIMENTS, RESULTS AND DISCUSSION (tt)





# III. EXPERIMENTS, RESULTS AND DISCUSSION (tt)





# III. EXPERIMENTS, RESULTS AND DISCUSSION (tt)

- Figure 4 shows the measured reactivity with the reactor power changes from 4.10$^{-5}$ % to 2.10$^{-1}$% at T = 80s, -80s, 120s and -120s. The results obtained by the designed module and the PNO-121R5 module are equivalent with the discrepancy about 10%. Some experimental results are equivalent as shown in Table 2.

| **T = 120s** | | |
|---|---|---|
| **$\rho/\beta_{eff}$ calculated by using inverse hour [7]** | $\rho/\beta_{eff}$ by module PNO-121R5 | $\rho/\beta_{eff}$ by FPGA-based module using Eq. (5) |
| **0.0777 ($)** | 0.0766 ($) | 0.0779 ($) |

# IV. CONCLUSION

- A digital reactivity meter module was designed and constructed. The output pulses of the amplifier, which are proportional to the reactor power, are sampled and filtered by hardware in FPGA.

- The tasks for the solution of the point reactor kinetics equations to calculate reactivity are performed in parallel on the FPGA hardware and embedded Microblaze.

- The experimental results of measured reactivity by the FPGA-based module that was compared with that by the PNO-121R5 show that the designed reactivity meter module can be used to measure and monitor the reactivity of the DNRR.

- The obtained results are only the first step for next experiments to the measurement of effective reactivity of the control rods including compensation rods and automatic regulation rod of at the DNRR basing on the rod drop method.

# VI. REFERENCES

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# Thank you for your attention!