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Circuit Designs for Measuring Reactor Period, Peak Power, and Pulse Fluence on TRIGA and Other Pulse Reactors

Robert D. Meyer, Frank V. Thomé, Robert L. Williams

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115
and Livermore, California 94550 for the United States Energy Research
and Development Administration under Contract AT(29-1)-789

Printed August 1977

Sandia Laboratories

SF 2900 Q(7-73)

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Printed in the United States of America

Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy \$3.50; Microfiche \$3.00

400

CIRCUIT DESIGNS FOR MEASURING REACTOR PERIOD,
PEAK POWER, AND PULSE FLUENCE ON
TRIGA AND OTHER PULSE REACTORS

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ABSTRACT

Inexpensive circuits for use in evaluating reactor periods, peak power, and pulse fluence (NVT), are presented. Besides being low in cost, these circuits are easily assembled and calibrated, and operate with a high degree of accuracy. The positive period measuring system has been used in evaluating reactivity additions as small as 5 cents (with an accuracy of ± 0.1 cent) and as large as \$4.50 (accuracy ± 2 cents). Reactor peak power is measured digitally with a system accuracy of $\pm 0.1\%$ of a 10 volt input (± 10 mV). The NVT circuit measures over a 2-1/2 decade range, has 3-place resolution, and an accuracy of better than 1%.

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ACKNOWLEDGMENT

The author wishes to thank H. L. Kefauver, 5423, for his assistance in the design of the logic circuitry which controls the display in the peak power detector. He also built the first working circuit and developed the method for calibrating the peak detector.

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CIRCUIT DESIGNS FOR MEASURING REACTOR PERIOD, PEAK POWER, AND PULSE FLUENCE ON TRIGA AND OTHER PULSE REACTORS

Introduction

Reactor pulse evaluation circuits are not readily available as off-the-shelf instrumentation. Circuits were designed specifically for the Annular Core Pulse Reactor (ACPR)¹ but are applicable to all TRIGA pulse reactors and other types of pulse reactors. Of particular interest in evaluating a single reactor pulse is the prompt reactor period or e-folding time, the peak reactor power that the reactor achieves, and the resultant pulse fluence (NVT or neutrons/cm²) delivered to an experiment.

The Annular Core Pulse Reactor is a TRIGA-type reactor using cylindrical uranium-zirconium hydride fuel-moderator elements. Some of the significant features are its large dry central cavity, close fuel element spacing producing an undermoderated core and a "harder" neutron energy spectrum, and its high pulse capability. The maximum pulse capability is produced by a reactivity addition of $\$4.50$ delivering a total fluence of about 3.6×10^{15} neutrons/cm² to the central cavity, a pulse width at half maximum (PWHM) of 4.5 ms, minimum prompt period of 1.280 ms, and a peak reactor power of 15,000 MW.

Circuit Descriptions and Calibration

Reactor Period Measuring System

As may be seen in Figures 1 and 2, a current signal originating from a neutron detector is conditioned to provide a linear voltage output of 0 to 5 volts (or 0 to 10 V) for each range (a decade) of reactor power. The power level range is selected before the pulse to provide a "window" of power level in which to sample for a minimum prompt period. The larger the expected pulse size the higher the sample range. This voltage signal is applied to the Callex Voltsensor which is the heart of the system. Adjusting the low and high setpoint potentiometers on the Voltsensor for a factor of "e" (2.718) in voltage separation, will cause an incoming signal to be converted to independent output trigger signals that start and stop a time interval counter. The time reads directly in reactor period and is easily convertible to reactivity.

¹L. L. Bonzon, F. M. Morris, and F. V. Thomé, "Annular Core Pulse Reactor (ACPR): Experimenters' Manual," SLA-73-1017, Sandia Laboratories, October 1974.

Figure 1. Present ACPR Reactor Period Measuring System

Figure 2. Proposed ACPR Reactor Period Measuring System

Two identical systems were employed in a recent ACPR recalibration where the period measuring systems were used in determining fuel element worths and in calibrating the transient bank from 0¢ through prompt critical to \$4.50. The system provided reproducible results and had an accuracy of about ± 0.1 ¢ for 5-cent reactivity additions and ± 2 ¢ for \$4.50 pulses.

Several techniques are available for measuring reactor period. The most desirable is a system like that shown in Figure 2 but with three additional period indications covering four decades of reactor power. A single detector system will suffice for all four decades where the current-to-voltage converter or log amplifier determines the power level range(s). More than one channel and one range of period information is required to adequately determine stable periods in the supercritical but sub-prompt-critical region and to evaluate the area of minimum prompt period for large pulses. Reactor periods in the sub-prompt-critical region are influenced by the prompt neutron fraction and by reactor heating. Periods, therefore, must be evaluated in the "stable" region where the period is slower than that immediately following the reactivity addition, but faster than that prior to the onset of fuel heating. Super-prompt-critical periods on TRIGA reactors, and other variable heat capacity reactors, present other problems in measurement since the minimum period occurs at different power levels dependent on the pulse size. The four periods measured over the four-decade range allow for proper evaluation of the data and provide important information concerning the fuel heating and the negative reactivity feedback. It also can aid in determining whether all available reactivity is inserted for a given pulse.

The cost of a two-channel (four decades per channel) system is not prohibitive since the largest portion of the cost is for the detectors and any period system requires this purchase. Table I (costs) illustrates that each complete channel can be built for about \$2000. The table also provides important specifications on the Callex Voltsensor.

Calibration -- Calibration of the Callex Voltsensor is the only section of the system that requires some caution. The objective is to set the low and high trip points a factor of e apart (e.g., at 1 V and 2.718 V). The high and low setpoints (pots 1 and 2), as seen in Figure 3, produce a voltage signal at their respective connectors that is indicative of the voltage trip points. A digital voltmeter capable of measuring voltage to four significant figures is necessary to get the required period resolution. These measured voltage polarities are opposite that of the actual trip point polarity. Measured voltages at these high and low set connectors is not necessarily the true voltage trip point and should be checked by very accurately applying a known increasing voltage and observing the proper Voltsensor output trip. Several iterations and the readjusting of pots 1 and 2 may be necessary to establish the true trip settings. Read and record the settings with the input disconnected because applied voltages slightly affect the low and high setpoints as measured at the set connector. A periodic check of these set voltages is all that is necessary to assure proper tripping. When ordering the Callex Model 256 Mounting Kit, specify the voltage trip range (e.g., 0 to +5.0 volts) and the factory installs the proper size resistors. Refer to Sandia Dwg T40887 in the Appendix of this report for details on connecting the Callex system.

TABLE I

ACPR Reactor Period Measuring System Specifications and Costs

Calex Specifications:

Volsensor Model 552-01	
Trip Point Range	: -14 V to +14 V for ± 15 V Supply
Resolution	: "Infinite" Depends on Pot & Resistance
Repeat & Sens.	: Better than 0.5 mV
Trip Point Stabil.	: < 0.1 mV/ $^{\circ}$ C
Hysteresis	: < 1 mV
Output	: 80% of B^+ Unreg. Supply (+20.8 V @ 50 mA): For 0 V input; Low Out +20 V, Hi Out 0 V
Input Z	: > 50 k Ω
Input Overload	: ± 200 V
Operating Time	: < 10 μ s
Output Rise & Fall	: < 2 μ s
Power Require.	: ± 15 Vdc @ 14 mA; ± 25 Vdc @ 21 mA Plus Load

Power Supply Model 222	
Input Volt	: 115 Vac 50-400 HZ Fused 0.25 A
Output	: ± 15 Vdc @ 60 mA Reg.; ± 26 Vdc @ 100 mA Unreg.
Load Reg.	: 0.05% No Load to Full Load
Ripple & Noise	: < 1 mV RMS
Temp. Coeff.	: 0.01%/ $^{\circ}$ C

Component Costs:

	Trigger System	Present 1-Decade Condition & Measuring	Proposed 4-Decade Condition & Measuring
Volsensor 552-01	84	84	84
Sensor Mount 256	18	18	18
Power Supply 222	48	48	48
CIC WL 8105		~800	~800
Cadmium Detector		~300	~300
Picoammeter		1500	
Timer-Counter		2150	
Amplifiers			~250
Logic CKTS. & OSC.			~ 80
Digital Counter			~400
Totals	\$150	\$4900	\$1980

Reactor Peak Power Detector

Reactor peak power information is useful in evaluating a reactor pulse. From peak power information the PWHM and peak flux (NV) can be inferred. The most critical aspect of an inference from peak power information is that of the detector location. The detector must be insensitive to experiment interactions and core flux profile shifts due to control and/or transient rod unbalances.

Figure 3. ACPR Reactor Period Measuring Voltage Sensor

Figure 4 illustrates a circuit design capable of detecting peak powers and holding that information on a digital panel meter until manually reset. The circuit does not show a specific input signal but should adapt to most TRIGA consoles with a reactor pulse capability or any conditioned signal between 0 and +10 volts. Central to the design is a Burr-Brown peak detector and a digital panel meter with a capability to hold a displayed reading on command. The remainder of the circuitry consists of logic to control the different modes of operation. Burr-Brown's peak detector is of the R-C memory type with a very low "droop rate" (specifications state droop at ± 5 mV/s, but it measures at about 2 mV/s). It is this low droop rate, plus its capability to slew at a fast rate, provide a "status" signal of a peak event, and accurately transfer the input signal to the output, that makes such a detector ideal for reactor pulse application.

The peak detector is controlled by using compatible integrated circuitry. The logic mode (peak detect or reset) is controlled through a Local/Remote selector switch. This switch, in the LOCAL position, permits resetting of the peak detector with a pushbutton switch and contact-bounce-elimination circuit and, on release of the button, returns the system to the peak detect mode. The system then awaits an incident pulse to evaluate. Noise on the input line can cause the

Digital power-level indication is displayed on the Non-Linear Systems, Inc. Model PM-4. Its ± 10 V four-digit display provides more than enough resolution, while its "hold" feature provides a means for maintaining the displayed signal by shorting 2 terminals. To hold the display at the proper time, a signal from the peak detector "Status" terminal is fed to a monostable multivibrator; this multivibrator is used to invert the signal slopes for use in the timer. The One Shot Timer is also a monostable multivibrator, but its purpose is to adjust the time from peak detect to meter hold. This is important because the digital meter must have time to condition, settle, and display the signal which takes about 2 seconds. During this 2 seconds the peak detector output has "drooped" 4 to 10 mV. The remaining circuitry is for driving and resetting the relay.

Table II illustrates some of the systems primary component capabilities and limitations. The cost estimate is for a do-it-yourself fabrication and is very inexpensive compared to available general-purpose, peak-reading voltmeters.

Calibration -- Calibration of the peak detector system consists of applying precisely 9 kV at the input connector with the continuous/peak detect selector in the CONTINUOUS position, then adjusting the R-1 potentiometer inside the meter until the display reads 9000. The R-2 resistor (see Dwg. T40885 in the Appendix) can be changed to provide a time other than 3 seconds by selecting a resistor that produces a delay, within limits, of 1 second per megohm of resistance. This change may be desirable for a meter other than the PM-4. There are no other calibrations necessary to place this system into operation. Careful attention to the instructions provided with the Burr-Brown peak detector and the PM-4 digital meter is important for wiring information, and for multiple channel applications.

Reactor Pulse Fluence Detector

Pulse fluence (NVT) is one of the most important parameters that can be provided an experimenter. To be able to measure accurately the NVT for various conditions of pulse width and pulse tail energy contribution aids in understanding experiment and reactor phenomena.

Shown in Figure 5 is a circuit which is very simple in construction and low in cost. The key to the system is the self-powered rhodium detector. Rhodium detectors use natural rhodium (over 99% Rh 103) which has a very high thermal neutron absorption cross section. Rhodium 103 plus a neutron produces Rh 104 and decays by a beta emission with a 42 second half-life. It is this negatively charged beta particle that produces the desired signal current. During a reactor pulse, electrons are produced in the detector materials from the gamma photons (Compton effect), but this prompt gamma effect is undesirable for use in evaluating the neutron pulse fluence on a slow-moving strip chart recorder or peak reading voltmeter as described in the last section. The desirable kind of signal from a detector is representative of the neutrons the rhodium sees during and shortly after the pulse (pulse tail). Indicated in Figure 5 is the type of signal seen in different parts of the circuit with various time scales.

The objectives in altering the signal from the rhodium detector to produce an accurate NVT signal are:

1. To produce a peak output which is proportional to NVT and accurately measurable on the console strip chart recorder
2. To place the peak output late enough in time to allow for accumulation of neutrons from tail energy (2 seconds after the pulse) and to evaluate a multiple-pulse operation with time between pulses of about 1 second.

TABLE II

ACPR Reactor Peak Power Detector System Specifications and Costs

Specifications:

<u>Peak Detector</u>		<u>- Output</u>	
Burr-Brown Mod. 4084/25		Analog	± 10 V ± 5 mA
		Impedance	0.05Ω
		Noise dc to 10 kHz	0.1 mV rms
		Digital	TTL/DTL Compatible
		<u>4-Digit Panel Meter</u>	
		Non-Linear Sys. Model PM-4	
<u>- Analog Inputs:</u>		<u>- Range</u> : ± 10 Volt	
Signal	± 10 V	<u>- Accuracy</u> : $\pm 0.02\%$ F.S. (2 mV)	
Maximum	± 15 V	<u>- Settle Time</u> : 2 seconds max.	
Input Bias I	600 nA	<u>- Speed</u> : 2 Readings/second	
Input Z	$50 M\Omega$	<u>Integ. Time</u> : 100 ms	
<u>- Digital Inputs</u>		<u>- Power</u> : +5 Vdc $\pm 5\%$ @ 160 mA	
Logic Level	Voltage	<u>- Size (in.)</u> : 15/16 H x 2-1/2 W x 3-1/4 D	
"1"	$+2.4 \text{ V} < e < +15 \text{ V}$	<u>- Temp. Coef.</u> : $\pm(0.005\% \text{ rdg} + 0.001\% \text{ F.S.})/^{\circ}\text{C}$	
"0"	$0 \text{ V} < e < +0.8 \text{ V}$	<u>- Input Z</u> : $1 M\Omega$	
<u>- Transfer Characteristics</u>		<u>- C.M.R.</u> : 80 dB min.	
Accuracy		<u>- Control Signal or Hold Line to Inhibit Readings</u>	
Voltage Gain	1.0 V/V	<u>- Decimal Location Control by Jumper</u>	
Gain Accuracy dc	± 1 mV		
dc to 100 Hz	± 2 mV		
Stability			
Droop (after detecting a peak or in hold 0° to 25°C)	± 5 mV/s		
Switching Performance			
Output Slew Rate	1 V/ μs		

Costs:

<u>Part No./Name</u>	<u>Manufacturer</u>	<u>Cost</u>
Peak Detector	Burr-Brown	145.00
P. D. Connector	Burr-Brown	10.00
D.P.M.-PM-4	Non-Linear Sys.	70.00
D.P.M. Connector	Non-Linear	5.00
MC 846P Gate	Motorola	.90
SN74121N M.V.	Texas Inst.	1.06
NE 555V Timer	Signetics	1.50
MC 848 P.F.F.	Motorola	(2) 2.50
MC 858P Gate	Motorola	.90
W118 Dip-5 Relay	Magnacraft	8.50
MC836P Inv.	Motorola	1.00
Sockets		(8) 4.00
MTIL-C06-1T	Tec Lite	5.75
± 15 V Pwr. Sup.		45.00
± 5 V Pwr. Sup.		45.00
Misc. Switches, Connec., & Panel		30.00
Total Cost		~\$410

Figure 5. ACPR Pulse Fluence (NVT) Measuring Circuit

3. To provide a peak amplitude that is usable for a shutdown signal soon after the pulse
4. To be accurate over the full range of ACPR pulsing (\$1 to \$4.50, or 5×10^{12} to 1.8×10^{15} NVT, neutron energies $E > 10$ keV)
5. To filter out the gamma-induced pulse,

Resistance is used to develop the voltage proportional to the neutron induced current, and a bypass capacitor is sized to pass the gamma pulse while it also acts to charge and produce a peak proportional to NVT. With the component sizes listed, the peak occurs about 15 seconds after the pulse. This satisfies objectives 1, 2, 3, and 5 above. Accuracy has been verified in over three years of operation throughout the entire range of pulse capability and by two complete ACPR recalibrations with new core configurations. Figure 6 illustrates the affect of capacitor size on the time to peak signal after a pulse, as well as the affects on the rhodium decay. The 50 μF capacitor was chosen as the best size to satisfy all the design objectives. A pulse of just slightly over \$1 produces a pulse width of ~ 800 ms at the base. The reactance the capacitor offers to this pulse is about 5 kΩ and is much less than the resistors sized to provide NVT output. Figure 7 was included to show that over a wide range of pulsing, \$2 to \$1.10, the NVT peak occurs about the same time

and the basic rhodium decay signal is unaffected. Also illustrated is an evaluation of the rhodium decay without any bypass capacitance to measure a normal decay. The half life for the detector was measured at 46.3 seconds. This does not coincide with the published half life, but reveals that the 50 μ F capacitor does not affect the decay scheme after the NVT peak:

Figure 6. NVT Peak Detector Response for Different Storage Capacitor Sizes

Figure 7. NVT Peak Detector Response for Different Pulse Sizes

The basic cost of the system is about \$600 for two rhodium detectors. Two detectors are necessary to average out the effects of tilting and to provide a larger output current. The ACPR detectors are located inside the fuel elements; this is not desirable because the high fuel temperatures reduce the detector resistance and useful lifetime. It is also not the optimum location for a large thermal neutron population since it is too close to the fuel.

Calibration -- In preparing to calibrate the system, the detector(s) should be placed next to the experiment irradiation space and, if two are used, so oriented that any tilting effects will average out in the detector output sum. The NVT to the experiment space is of primary importance, not the reactor energy release, but this system can also be used to establish the core energy release from a pulse since NVT is directly proportional to the pulse fluence; in such cases it is particularly important that two detectors be positioned so that the effects of flux tilting are averaged out.

To calibrate the output signal for console recorder accuracy, the potentiometers must first be set at some known resistance. Then a known pulse is produced. From the ratio of the known to the recorded NVT, the desired voltage on the recorder can be obtained, then the required resistance derived. The pots are set for this new value and another pulse test conducted to check the accuracy of the setting. Note that of the two pots, the 10 k Ω pot provides the needed 3-place resolution. (See Dwg. T40886 in the Appendix for other details.)

Summary

These circuit designs have been used to yield reliable information about ACPR operations for a significant period of time. After the initial calibration of the circuits, periodic checks have shown no need for subsequent changes. The systems were low in price and easy to assemble. The reactor period measuring system is useful in evaluating reactivity additions as small as a few cents and pulses as large as \$4.50. Reactor peak power detection has been found to be accurate to three significant figures and over the entire range of ACPR pulsing. The pulse fluence detector is simple, dependable, and accurate, with a broad operating range of 5×10^{12} to 1.0×10^{15} NVT ($E > 10$ keV).

APPENDIX

Sandia Drawings

DESIGN AGENCY	NO.	ISSUE	DESCRIPTION	REVISIONS	PREPARED BY	DATE	CHK	INCR
T40886-00C	A	J. ARAGON, 9652	F. THOME, 5421	2-20-76

RHODIUM SELF-POWERED DETECTORS
REUTER - STOKES
MODEL: RSN-202-LC
SENSITIVITY: 1.2×10^{-21} AMP/NV-CM
LENGTH: 49.17 CM (19.36 INCH)
RHODIUM 104 HALF LIFE 42 SEC.
RHODIUM DETECTOR MEASURED HALF LIFE 46 SEC
300 KW EQUILIBRIUM DETECTOR CURRENT
SUM OF 4941 & 4942 IS 1.37×10^{-7} AMP

CONSOLE RECORDER
WESTRONICS
MODEL: D1E (18 INCH SCALE)
RANGE: 0 TO 10 MV
INPUT Z: UNBAL. 50K ; BAL. INFIN.

ACPR PULSE FLUENCE (NVT) MEASURING CIRCUIT

AGENCY APPROVALS				1 SHEET		TITLE	
093	DATE	INITIALS	ISSUE	A		ACPR PULSE FLUENCE MEASURING CIRCUIT (NVT)	
5421				SHEET INDEX			
PART CLASSIFICATION				UNCLASSIFIED			
DOWD CLASSIFICATION LEVEL				C		14213	
9652				UNCLASSIFIED		DOWD NUMBER T40886	
SCALE				SHEET 1 OF 1			

NOTES:

1. ALL RESISTORS 100 PPM/°C.
2. LOW AND HIGH SET VOLTAGE AS MEASURED AT J-1 AND J-2 NOT ALWAYS TRUE TRIP VOLTAGES.
3. SETPOINTS ADJUSTED BY INSERTING A STABLE VOLTAGE AT INPUT THEN ADJUSTING THE RESPECTIVE SET POTENTIOMETER. CHECK THIS SETPOINT BY SLOWLY RAISING THE INPUT VOLTAGE UNTIL OUTPUT TRIP IS SEEN.

4. SETPOINTS VARY AS A FUNCTION OF SOURCE CONDITIONS SO ALWAYS SET TRIP POINTS WITH INPUT CIRCUITRY CONNECTED AS IT WILL BE IN THE OPERATING SYSTEM.

* CALEX-CALIFORNIA ELECTRONIC MFG. CO.,
P.O. BOX 555 ALAMO, CALIF.

ACPR REACTOR PERIOD
MEASURING VOLTAGE SENSOR

DESIGN AGENCY	REVISIONS
T40887-000	A
ARAGON, 9652/F. THOME, 5421	3-26-76

AGENCY APPROVALS	SHEET	FILE
DATE	ISSUE	INDEX
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OWD CLASSIFICATION LEVEL	UNCLASSIFIED	
9652		
CODE	14213	420887
SCALE		

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