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A MULTIDECADE NUCLEAR REACTOR
SIMULATION USING HYBRID COMPUTER
AUTOMATIC RESCALING TECHNIQUES

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A MULTIDECADE NUCLEAR REACTOR SIMULATION
USING
HYBRID COMPUTER AUTOMATIC RESCALING TECHNIQUES

By

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Control and Instrumentation Department
Systems and Electronics Division

August 1969

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ABSTRACT

A method of applying "floating point" techniques to an analog problem was used to simulate a nuclear reactor from startup level to full power. A hybrid computer was used to execute the problem, the digital computer being used to store and operate on the exponents of the variables, while the analog was used to operate on the mantissas. The method is an extension of the point storage (or analog memory) rescaling technique, and is applicable to a wide-range of multidecade problems.

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INTRODUCTION

The point storage (analog memory) method of analog rescaling has been studied for some time as a possible method of handling multidecade simulations. ⁽¹⁾ However, all-analog point storage, requiring an additional integrator or sample-and-hold amplifier for each variable to be rescaled, is extremely wasteful of analog equipment. Also, interactions between portions of the problem with different scale factors are difficult, and rescaling from higher decades to lower ones becomes a complex process. Therefore, a hybrid automatic rescaling technique which reduces these problems to a level acceptable for general usage was developed.

The nuclear reactor simulated was the Plutonium Recycle Critical Facility as described in Reference (1). However, a more complex temperature feedback loop and a simple flow circuit were added to the simulation to better test the capabilities of the rescaling technique.

CONCLUSION

A practical method of hybrid rescaling using the basic philosophy of analog point storage was developed. Rescaling of both increasing and decreasing variable magnitudes is effectively handled. The technique allows multi-level scaling within a problem, and is accurate but conservative of both digital computer storage and execution time.

The rescaling techniques developed for this problem have direct application not only to other nuclear reactor problems but to any problem involving a wide-range of variable values.

Obvious applications would be in aerospace problems, fluid flow problems, or wide-range spectral problems. For the SIMPL-1 hybrid user⁽³⁾, the only programming required is to format the necessary tables, and to program the required director segments for his desired sequence of operations. All of the hybrid sub-routines should be suitable as written. The digital computer user would have to adapt the present programs to sample and change memory locations rather than amplifiers and pots. However, the basic philosophy of the rescaling techniques is still valid. The rescaling technique could be of particular benefit to users of small fixed point digital machines since it provides accurate scaling of difficult problem variables without sacrificing the speed or memory required by FORTRAN type floating point programs.

SUMMARY

The analog point storage rescaling technique has been expanded and altered to operate effectively on a hybrid computer. The equipment requirements and complexities of the all-analog method have been considerably reduced by using hybrid programming. The equipment advantage is realized by using the digital computer to replace analog elements for the purposes of storage, logic, manipulation of exponents, and control, while sacrificing very little digital computer memory or time to provide these functions. Programming of other digital functions is not complicated by the addition of the rescaling program. The address and mode control of the analog computer must be relinquished to the digital computer for automatic operation.

The operation employs analog interrupts to inform the digital computer that rescaling is needed. The digital computer samples the amplifier outputs and sets digital coefficient units (DCU's) or servo pots to the required initial conditions. Interaction between differently scaled problem parts, also handled by DCU's or servo pots, allows rescaling in both directions as well as

allowing many different variable scales within one problem. Effectively, a "floating point" simulation is produced by employing the digital computer to store the variable scaling, and to change the necessary coefficients when a change in exponent takes place.

When operating in an interrupt mode, digital computation is required only when the problem is placed in "HOLD". Thus, no digital time is stolen from the problem due to the addition of the rescaling program. Memory requirements are also relatively minor, occupying only 382 locations, including the pot and DCU setting subroutines. This number can be reduced to about 250 locations if hardware interrupts are available. The size, of course, varies with the complexity of the problem and the length of the amplifier and pot tables. Analog equipment is limited to two comparators, two sense lines, and one control line for each monitored variable, an analog-to-digital convertor (ADC) line from the address selector, and the necessary coefficient devices for initial conditions and variables. Individual integrator mode control is helpful but not necessary.

The main limitations of the rescaling concept are that bipolar variables are difficult to handle since they must go through zero and also require a different sign initial condition, and the setting of coefficient devices during the "HOLD" period results in a discontinuity in the output. However, if sufficient DCU's are available (so that no servo pots need be set), the hold time is reduced to a few milliseconds and rescaling is essentially instantaneous. The necessary techniques are easily applied to any all-digital or hybrid problem where many decades of variable values are of interest. The actual programs discussed in this report are of particular benefit to the hybrid user, but could be modified for all digital operation.

DISCUSSIONTHE ANALOG CIRCUIT

The analog circuit (Figure 1), although basically as described in Reference (1), uses specialized AD-4 programming techniques. Modifications in the temperature circuit and the addition of a simple flow circuit are the other notable exceptions.

The system equations are as follows:

$$\frac{dn}{dt} = \frac{(\delta K - B)}{\ell^*} n + \sum_{i=1}^6 \lambda_i C_i + S$$

$$\frac{dC_i}{dt} = \frac{B_i}{\ell^*} n - \lambda_i C_i$$

$$\delta K = K_{\text{eff}} - 1 - \delta K_f$$

$$\delta K_f = D(T_f - 70)$$

$$\frac{dT_f}{dt} = A_1 n - A_2(T_f - T_p)$$

$$\frac{dT_p}{dt} = A_2(T_f - T_p) - A_3(T_p - 70)F$$

$$\frac{dF}{dt} = 1 - A_4 F$$

- where
- n = neutron flux, neutrons/cm²-sec
 - B = total delayed neutron fraction
 - ℓ^* = average neutron lifetime, sec
 - S = source strength, neutrons/cm²-sec
 - K_{eff} = neutron multiplication factor
 - δK = K - excess
 - F = coolant flow, lb/sec
 - δK_p = fuel temperature reactivity effect
 - B_i = delayed neutron fraction for i th group
 - λ_i = decay constant for i th group

C_i = concentration of i th group

D = fuel temperature coefficient, $\delta K/^\circ F$

T_f = fuel temperature, $^\circ F$

T_p = coolant temperature, $^\circ F$

A_1 = constant, $\text{cm}^2\text{-}^\circ F/\text{neutron}$

A_2 = constant, sec^{-1}

A_3 = constant, lb^{-1}

A_4 = constant, sec^{-1}

I = arbitrary input, lb/sec^2

Values of the constants are:

$$\ell^* = 7 \times 10^{-4} \text{ sec}$$

$$B = 6.014 \times 10^{-3}$$

$$S = 5 \times 10^4 \text{ n}/\text{cm}^2\text{-sec}$$

$$D = 0.655 \times 10^{-5}/^\circ F$$

$$A_1 = 0.985 \times 10^{-12}/^\circ F\text{-cm}^2/\text{n}$$

i	λ_i	B_i
1	7.7	14.5×10^{-5}
2	2.2	87.2×10^{-5}
3	0.465	245.0×10^{-5}
4	0.400	15.7×10^{-5}
5	0.170	114.0×10^{-5}
6	0.0458	125.0×10^{-5}

The remaining constants were arbitrarily chosen so that, at 100% flow and 5×10^{13} n/cm²-sec neutron flux, core temperature would be 800 °F and coolant temperature would be 400 °F.

Two variables, flow and neutron flux, were chosen to rescale. Nine decades of neutron flux and two of flow were decided upon. To prevent overloading the slow delay group integrator, both neutron flux and the slow decay group must decay to less than 9 V before a low level rescale can occur. High level rescale occurs when neutron flux reaches 100 V. Flow is rescaled at the same limits. The temperature circuit is not rescaled but is affected by both of the rescaled variables. Proper system operation is indicated by consistent temperature behavior regardless of the number of rescales having occurred.

The analog computer was an Applied Dynamics AD-4. Six DCU's and five servo pots required setting during the rescaling program (see Figure 1). The six DCU's and two servo pots were used for integrator initial conditions, and the remaining three servo pots were used for multiplication of differently scaled variables. Since the sense and control line system had not yet been implemented on the AD-4, the digital computer was signaled via voltages on ADC's. The comparators on the monitored variables were used to switch these voltages. Individual integrator control was available and was used to place the proper integrators in initial condition. Otherwise, the analog computer operated in the standard manner.

THE DIGITAL PROGRAM

The four basic parts to the digital rescaling program (Figure 2) and their respective functions can be described as follows:

- The first part is an initialization routine which sets all coefficient devices to the proper initial conditions for the problem start and allows reinitialization of the problem after a run.

FIGURE 2. Digital Flowchart

- The second part would ordinarily detect the need for variable rescaling by sense line interrupt. However, since the sense lines were not fully implemented, ADC's were sampled for a switch in voltage instead.
- Part three compares the exponent count for the various parts of the circuit and sets the necessary coefficient devices to the proper values for the current exponents.
- Part four samples the integrator outputs associated with a certain variable and sets the corresponding coefficient devices to 10 times or one-tenth the output value depending on the direction of rescaling.

The following information must be provided for each variable. The program must have:

- A table of integrator addresses, their corresponding pots or DCU's, and their initial condition values.
- A table of coefficient devices whose settings increase as the scaling becomes greater, and their corresponding maximum values.
- A table of coefficient devices whose settings decrease as the scaling becomes greater, and their corresponding maximum values.

Listings of the digital programs are presented in the Appendix, while operation of the program is described under each of the following headings.

Part 1

When initialized, the program first loads the integrator initial conditions, and the corresponding coefficient device addresses. A decision is made as to whether the device is a pot or DCU and the proper subroutine is entered to set the device. Then all exponent counts are initialized to zero. The tables of pot and DCU settings whose values are greatest when the exponent is zero are set directly. The maximum value of

those settings which increase as the exponent increases, are divided by the maximum number of decades for that variable and the device is set as above.

Part 2

The computer enters a loop awaiting the need to rescale. A series of ADC's are sampled for a change in sign from 50 V negative to 50 V positive when rescaling is required. The particular ADC that changes sign indicates which variable needs service and the direction of rescale required. In the ideal case, the loop would be the user's main program which would be interrupted by a sense line signal. The service routine would determine, from a reading of the sense line register, the variable to be rescaled.

Part 3

When rescaling is required, the digital computer places the entire problem in "HOLD" and then determines which variable needs rescaling and whether it is a high or low level interrupt. The exponent count for that variable is incremented or decremented by one, depending on the direction of rescale. The two tables of coefficient devices and values are sent to a subroutine which multiplies the maximum values by $10^{-\text{exp}}$ if their values decrease as the exponent increases, and by $10^{\text{exp}-\text{maxexp}}$ if their values are to increase with increasing exponent. Thus, for a problem scaled for five (0 through 4) decades of operation and operating at the third decade, the value of the decreasing device would be $\text{VALUE } A_{\text{max}} \times 10^{-3}$ and the value of increasing the device would be $\text{VALUE } B_{\text{max}} \times 10^{(3-4)}$ or $\text{VALUE } B_{\text{max}} \times 10^{-1}$. This method helps to minimize errors by insuring that the tabular values are always divided, rather than multiplied, by the exponent factor. In addition to these functions, Part 3 must monitor the exponent counts so that the program does not attempt to rescale beyond the intended limits of the problem.

Part 4

The table of integrators associated with the required variable is sent to another subroutine which addresses the amplifier, pauses for a specified delay so that the Address Selector Output (ASO) can stabilize, and then reads the value through an ADC. This method requires only one ADC for all integrators and gives the digital computer access to the ASO if required in other parts of the program. The amplifier output is multiplied or divided by 10 and set into the respective initial condition device. A signal is then sent to the analog to place the selected integrators in initial condition, and a pause is initiated until the values have stabilized. The analog problem is then placed in "OPERATE" so that execution resumes.

The digital computer used was a Digital Equipment Corporation PDP-9. It has multilevel interrupt capability, hardware multiply and divide, one microsecond cycle time, and 24 channels of analog-to-digital and digital-to-analog conversion provided by Adage equipment. Both mode and address control of the analog computer are maintained by the PDP-9.

RESULTS

The results from the rescaling program have been quite favorable. The unscaled integrator outputs appear consistent with rescaled ones and, despite the need to set pots in the "HOLD" period, do not suffer any great discontinuity although small steps may be seen in the output (see sample output displayed in Figures 3 through 5). The most difficult portion of the problem is in the intermediate range when neither the source nor temperature feedback is large enough to insure stable steady-state values. However, this would be true in any reactor simulation and is not a basic fault of the rescaling program.

FIGURE 3. Response to Step Reactivity and Motor Speed Inputs Producing 7 and 50% Flow Followed by Power Shutdown

FIGURE 4. Response to Step Reactivity Input in No-Flow Condition.

FIGURE 5. Response to Flow Shutdown Showing Continuity of Temperature and Power Response.

Period measurements taken in this range were as accurate and repeatable as could be determined from recording equipment.

The hybrid rescaling technique provides accurate variables that do not lose sensitivity as they go up in decades. However, display does pose a problem. The strip chart recorder is not ideal for display purposes, since full scale discontinuities appear in the rescaled variable every time a rescale occurs. This response becomes somewhat confusing for a variable with a range of many decades. In this particular simulation, a decade counter was added to the output to help keep track of neutron flux. An alphanumeric scope display would be ideal for the rescale problem, since it could give both graphical and numerical output.

REFERENCES

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2. Glasstone. Principles of Nuclear Reactor Engineering. D. Van Nostrand Company, Inc., Princeton, N. J., 1955.
3. R. D. Benham. SIMPL-1: Simulation Implementing Machine Programming Language, BNWL-878. Battelle-Northwest, Richland, Washington, October 1968.

APPENDIX

RESCALE SUBPROGRAMS

1. TEST PROGRAM (269 locations)
 - a. Initializes teletype, pot and DCU settings, exponent count, and control lines
 - b. Awaits rescaling interrupt
 - c. Contains lists of amplifiers, pots, and settings
 - d. Directs computer to proper subroutines when rescaling is required
 - e. Multiplies settings by the proper exponent factor
2. RESCALE PROGRAM (38 locations)
 - a. Addresses amplifiers
 - b. Delays until ASO stabilizes
 - c. Samples amplifier output through ASO
 - d. Multiplies or divides by 10
 - e. Exits to device setting subroutine
3. RESET PROGRAM (26 locations)
 - a. Determines whether device is pot or DCU
 - b. Enters proper device setting subroutine
4. POT (31 locations)
 - a. Multiplies value by correct scale factor
 - b. Limits so that $0.0 \leq \text{value} \leq 1.5$
 - c. Addresses correct pot
 - d. Sets the pot
5. DCU (18 locations)
 - a. Multiplies value by correct scale factor
 - b. Limits so that $0.0 \leq \text{value} \leq 3.2767$
 - c. Addresses correct DCU
 - d. Sets the DCU

RESCALE SUBPROGRAMS

```

                                .GLOBL RESET, RESCAL
                                .IODEV 3
000000 R          BGN          .INTT 3.1, BGN

```

TELETYPE INITIALIZATION

```

000000 R 001003 A GEN*      CAL+1*1000 3&777
000001 R 000001 A GEN*      I
000002 R 000000 R GEN*      BGN
000003 R 000000 A GEN*      0

```

PROBLEM INITIALIZATION

```

000004 R 701101 A          MXRN
000005 R 702104 A          ASCF
000006 R 702001 A          HYSF
000007 R 600173 R          JMP TYP
000010 R 200403 R          LAC (10
000011 R 100205 R          JMS MULT
000012 R 000141 R          .DSA POTUP1
000013 R 200404 R          LAC (1
000014 R 100205 R          JMS MULT
000015 R 000144 R          .DSA POTUP2
000016 R 750000 A          CLA
000017 R 100205 R          JMS MULT
000020 R 000147 R          .DSA PTDWN1
000021 R 750000 A          CLA
000022 R 100205 R          JMS MULT
000023 R 000170 R          .DSA PTDWN2
000024 R 767777 A          LAW -.5
000025 R 712002 A          DA4
000026 R 702022 A          DA1
000027 R 702042 A          DA2
000030 R 140372 R          DZM CNT1#
000031 R 140373 R          DZM CNT2#
000032 R 200405 R          LAC (.5
000033 R 040376 R          DAC DASPOT
000034 R 750004 A          LAS
000035 R 701401 A          AADR
000036 R 600240 R          JMP TEST

```

DIRECTOR SEGMENT
FOR HIGH NEUTRON FLUX INTERRUPT

00037	R	000000	A	ONESET	0
00040	R	200372	R		LAC CNT1
00041	R	740001	A		CMA
00042	R	340403	R		TAD (10
00043	R	100205	R		JMS MULT
00044	R	000141	R		.DSA POTUP1
00045	R	200372	R		LAC CNT1
00046	R	340404	R		TAD (1
00047	R	040372	R		DAC CNT1
00050	R	300406	R		ADD (TABL
00051	R	040400	R		DAC TEMP#
00052	R	220400	R		LAC* TEMP
00053	R	040376	R		DAC DASPOT#
00054	R	620037	R		JMP* ONESET

SOURCE TABLE

00055	R	010000	A	TABL	.5
00056	R	000632	A		.05
00057	R	000051	A		.005
00060	R	000004	A		.0005
00061	R	000001	A		.0001
00062	R	000000	A		.0
00063	R	000000	A		.0
00064	R	000000	A		.0
00065	R	000000	A		.0
00066	R	000000	A		.0
00067	R	000000	A	TWOST	0

DIRECTOR SEGMENT
FOR LOW NEUTRON FLUX INTERRUPT

00070	R	200372	R		LAC CNT1
00071	R	340407	R		TAD (-1
00072	R	040372	R		DAC CNT1
00073	R	740001	A		CMA
00074	R	340410	R		TAD (11
00075	R	100205	R		JMS MULT
00076	R	000141	R		.DSA POTUP1
00077	R	200372	R		LAC CNT1
00100	R	300406	R		ADD (TABL
00101	R	040400	R		DAC TEMP
00102	R	220400	R		LAC* TEMP
00103	R	040376	R		DAC DASPOT
00104	R	620067	R		JMP* TWOST

DIRECTOR SEGMENT FOR HIGH FLOW INTERRUPT

00105	R	000000	A	THRST	0
00106	R	200405	R		LAC (.5
00107	R	712002	A		DA4
00110	R	200373	R		LAC CNT2
00111	R	740001	A		CMA
00112	R	340404	R		TAD (1
00113	R	100205	R		JMS MULT
00114	R	000144	R		.DSA POTUP2
00115	R	200373	R		LAC CNT2
00116	R	340404	R		TAD (1
00117	R	040373	R		DAC CNT2
00120	R	100205	R		JMS MULT
00121	R	000170	R		.DSA PTDWN2
00122	R	620105	R		JMP* THRST

DIRECTOR SEGMENT FOR LOW FLOW INTERRUPT

00123	R	000000	A	FORST	0
00124	R	767777	A		LAW -.5
00125	R	712002	A		DA4
00126	R	200373	R		LAC CNT2
00127	R	340407	R		TAD (-1
00130	R	040373	R		DAC CNT2
00131	R	740001	A		CMA
00132	R	340412	R		TAD (2
00133	R	100205	R		JMS MULT
00134	R	000144	R		.DSA POTUP2
00135	R	200373	R		LAC CNT2
00136	R	100205	R		JMS MULT
00137	R	000170	R		.DSA PTDWN2
00140	R	620123	R		JMP* FORST

POT and DCU TABLES

00141	R	000255	A	POTUP1	255;	.985
00142	R	017605	A			
00143	R	740040	A		HLT	
00144	R	000246	A	POTUP2	246;	1.5
00145	R	030000	A			
00146	R	740040	A		HLT	
00147	R	000305	A	PTDWN1	305;	.2
00150	R	003146	A			
00151	R	000303	A		303;	.2
00152	R	003146	A			

POT and DCU TABLES (contd)

00153	R	000304	A		304;	.35
00154	R	005463	A			
00155	R	000301	A		301;	.2
00156	R	003146	A			
00157	R	000302	A		302;	.28
00160	R	004366	A			
00161	R	000300	A		300;	.15
00162	R	002315	A			
00163	R	000311	A		311;	.37
00164	R	005727	A			
00165	R	000242	A		242;	.1
00166	R	001463	A			
00167	R	740040	A		HLT	
00170	R	000235	A	PTDWN2	235;	1.0
00171	R	020000	A			
00172	R	740040	A		HLT	

Rings bell if analog computer
is not in "hybrid" mode.

00173	R		TYP	.WRITE 3,2,MSG,35
00173	R	002003	A GEN*	CAL+2*1000 3&777
00174	R	000011	A GEN*	11
00175	R	000201	R GEN*	MSG
			GEN*	.DEC
00176	R	777735	A GEN*	-35
00177	R	740000	A	NOP
00200	R	600177	R	JMP .-1
00201	R	620002	A	MSG 620002
00202	R	000000	A	0
00203	R	034161	A	.ASCII <7><7><15>
00204	R	500200	A	

Divides pot settings
by proper number of decades.

00205	R	000000	A	MULT	0
00206	R	740001	A		CMA
00207	R	040375	R		DAC CTR#
00210	R	760103	A		LAW 103
00211	R	701402	A		AMOD
00212	R	220205	R		LAC* MULT
00213	R	440205	R		ISZ MULT
00214	R	040377	R		DAC SAVI#
00215	R	200375	R		LAC CTR
00216	R	040374	R		DAC CT#
00217	R	220377	R		LAC* SAVI

Divides pot settings
by proper number of decades (contd)

00220	R	540413	R	SAD (HLT
00221	R	620205	R	JMP* MULT
00222	R	040236	R	DAC .+14
00223	R	440377	R	ISZ SAVI
00224	R	220377	R	LAC* SAVI
00225	R	440377	R	ISZ SAVI
00226	R	440374	R	ISZ CT
00227	R	741000	A	SKP
00230	R	600235	R	JMP .+5
00231	R	744000	A	CLL
00232	R	657116	A	MULS-4
00233	R	003146	A	3146
00234	R	600226	R	JMP .-6
00235	R	120402	E	JMS* RESET
00236	R	000000	A	0
00237	R	600215	R	JMP MULT+10

RESCALE DETECTION AND ROUTING SEGMENT

00240	R	701222	A	TEST	MX1
00241	R	200376	R		LAC DASPOT
00242	R	702062	A		DA3
00243	R	744000	A		CLL
00244	R	200372	R		LAC CNT1
00245	R	657124	A		MULS-16
00246	R	031463	A		31463
00247	R	712042	A		DA6
00250	R	100317	R		JMS READN
00251	R	701242	A		MX2
00252	R	741100	A		SPA
00253	R	600261	R		JMP .+6
00254	R	100037	R		JMS ONESET
00255	R	750001	A		CLA!CMA
00256	R	120401	E		JMS* RESCAL
00257	R	000347	R		AMP1
00260	R	600327	R		JMP ONE
00261	R	100317	R		JMS READN
00262	R	701262	A		MX3
00263	R	741100	A		SPA
00264	R	600275	R		JMP .+11
00265	R	200372	R		LAC CNT1
00266	R	741200	A		SNA
00267	R	600275	R		JMP .+6
00270	R	100067	R		JMS TWOST

RESCALE DETECTION AND ROUTING SEGMENT (contd)

00271	R	750000	A	CLA
00272	R	120401	E	JMS* RESCAL
00273	R	000347	R	AMP1
00274	R	600327	R	JMP ONE
00275	R	100317	R	JMS READN
00276	R	711202	A	MX4
00277	R	741100	A	SPA
00300	R	600306	R	JMP .+6
00301	R	100105	R	JMS THRST
00302	R	750001	A	CLA!CMA
00303	R	120401	E	JMS* RESCAL
00304	R	000366	R	AMP2
00305	R	600331	R	JMP THREE
00306	R	100317	R	JMS READN
00307	R	701222	A	MX1
00310	R	741100	A	SPA
00311	R	600241	R	JMP TEST+1
00312	R	100123	R	JMS FORST
00313	R	750000	A	CLA
00314	R	120401	E	JMS* RESCAL
00315	R	000366	R	AMP2
00316	R	600331	R	JMP THREE

ADC WAIT SUBROUTINE

00317	R	000000	A	READN	0
00320	R	777777	A		LAW -1
00321	R	040326	R		DAC .+5
00322	R	440326	R		ISZ .+4
00323	R	600322	R		JMP .-1
00324	R	701312	A		ADRB
00325	R	620317	R		JMP* READN
00326	R	000000	A		0

INTEGRATOR MODE CONTROL

00327	R	200414	R	ONE	LAC (DA1
00330	R	741000	A		SKP
00331	R	200415	R	THREE	LAC (DA2
00332	R	040343	R		DAC IC+7
00333	R	040335	R		DAC IC+1
00334	R	200405	R	IC	LAC (.5
00335	R	740040	A		HLT
00336	R	760000	A		LAW

INTEGRATOR MODE CONTROL (contd)

00337	R	040371	R	DAC CNT#
00340	R	440371	R	ISZ CNT
00341	R	600340	R	JMP .-1
00342	R	767777	A	LAW -.5
00343	R	740040	A	HLT
00344	R	760102	A	LAW 102
00345	R	701402	A	AMOD
00346	R	600240	R	JMP TEST

AMPLIFIER TABLES

00347	R	000350	A	AMP1	350;	305
00350	R	000305	A			
00351	R	000340	A		340;	303
00352	R	000303	A			
00353	R	000351	A		351;	304
00354	R	000304	A			
00355	R	000320	A		320;	301
00356	R	000301	A			
00357	R	000321	A		321;	302
00360	R	000302	A			
00361	R	000311	A		311;	300
00362	R	000300	A			
00363	R	000310	A		310;	311
00364	R	000311	A			
00365	R	740040	A		HLT	
00366	R	000241	A	AMP2	241;	242
00367	R	000242	A			

00370	R	740040	A	HLT
		000000	A	.END
00401	R	000401	E *ETV	
00402	R	000402	E *ETV	
00403	R	000010	A *LIT	
00404	R	000001	A *LIT	
00405	R	010000	A *LIT	
00406	R	000055	R *LIT	
00407	R	777777	A *LIT	
00410	R	000011	A *LIT	
00411	R	000055	R *LIT	
00412	R	000002	A *LIT	
00413	R	740040	A *LIT	
00414	R	702022	A *LIT	
00415	R	702042	A *LIT	

NO ERROR LINES

				.TITLE RESCALE
				.GLOBL RESCAL, RESET
				SAVE=.; 0
000000	R	000000	A	
		000001	R	CNT=.; 0
000001	R	000000	A	
		000002	R	NUM1=.; 500000
000002	R	500000	A	
		000003	R	NUM2=.; 3146
000003	R	003146	A	

INITIALIZES SUBROUTINE

000004	R	000000	A	RESCAL	0
000005	R	740200	A		SZA
000006	R	600011	R		JMP .+3
000007	R	200002	R		LAC NUM1
000010	R	741000	A		SKP
000011	R	200003	R		LAC NUM2
000012	R	040036	R		DAC VAL1
000013	R	220004	R		LAC* RESCAL
000014	R	440004	R		ISZ RESCAL
000015	R	040000	R		DAC SAVE

ADDRESS AMPLIFIER

000016	R	220000	R	LOOPS	LAC* SAVE
000017	R	540046	R		SAD (HLT
000020	R	600042	R		JMP END
000021	R	701401	A		AADR
000022	R	440000	R		ISZ SAVE

DELAY

000023	R	774000	A		LAW -4000
000024	R	040001	R		DAC CNT
000025	R	440001	R		ISZ CNT
000026	R	600025	R		JMP .-1

SAMPLE AMPLIFIER OUTPUT

000027	R	701202	A		MX0
000030	R	220000	R		LAC* SAVE
000031	R	440000	R		ISZ SAVE
000032	R	040040	R		DAC .+6
000033	R	744000	A		CLL
000034	R	701312	A		ADRB

MULTIPLY BY 10 or .10

00035	R	657116	A		MULS-4
00036	R	000000	A	VALI	0

EXIT TO DEVISE ROUTINE

00037	R	120045	E		JMS* RESET
00040	R	000000	A		0
00041	R	600016	R		JMP LOOPS

EXIT

00042	R	750004	A	END	LAS
00043	R	701401	A		AADR
00044	R	620004	R		JMP* RESCAL

		000000	A		.END
00045	R	000045	E	*ETV	
00046	R	740040	A	*LIT	

NO ERROR LINES

.GLOBL RESET,DCU.,POT.

DETERMINE if POT or DCU

00000	R	000000	A	RESET	Ø
00001	R	652000	A		LMQ
00002	R	220000	R		LAC* RESET
00003	R	500031	R		AND (370
00004	R	540032	R		SAD (300
00005	R	600016	R		JMP DCU

EXIT TO POT SUBROUTINE

		000006	R	POT=.;	LAW 3000
00006	R	763000	A		
00007	R	320000	R		ADD* RESET
00010	R	040014	R		DAC .+4
00011	R	440000	R		ISZ RESET
00012	R	641002	A		LACQ
00013	R	120030	E		JMS* POT.
00014	R	000000	A		Ø
00015	R	620000	R		JMP* RESET

EXIT TO DCU SUBROUTINE

		000016	R	DCU=.;	LAW 2000
00016	R	762000	A		
00017	R	320000	R		ADD* RESET
00020	R	040024	R		DAC .+4
00021	R	440000	R		ISZ RESET
00022	R	641002	A		LACQ
00023	R	120027	E		JMS* DCU.
00024	R	000000	A		Ø
00025	R	754002	A		CLA!STL

00026	R	620000	R		JMP* RESET
		000000	A		.END
00027	R	000027	E	*ETV	
00030	R	000030	E	*ETV	
00031	R	000370	A	*LIT	
00032	R	000300	A	*LIT	

NO ERROR LINES

.NV2

PERFORMS LIMITING AND SCALING

00000	R	000000	A	DCU.	0
00001	R	664000	A		GSM
00002	R	340021	R	.	TAD (-3.2767
00003	R	740102	A		SMA!CML
00004	R	750000	A		CLA
00005	R	340022	R		TAD (3.2767
00006	R	652000	A		LMQ
00007	R	220000	R		LAC* DCU.
00010	R	701401	A		AADR
00011	R	440000	R		ISZ DCU.
00012	R	641121	A		EAE+1121
00013	R	470400	A		470400
00014	R	741100	A		SPA
00015	R	420000	R		XCT* DCU.

SETS DCU

00016	R	440000	R		ISZ DCU.
00017	R	701606	A		DCUL!DCUS
00020	R	620000	R		JMP* DCU.
		000000	A	.GLOBL DCU.	.END
00021	R	713445	A	*LIT	
00022	R	064333	A	*LIT	

NO ERROR LINES

.GLOBL POT.
.NV2

PERFORMS LIMITING AND SCALING

00000	R	000000	A	POT.	Ø
00001	R	664000	A		GSM
00002	R	741400	A		SZL
00003	R	754000	A		CLA!CCL
00004	R	340036	R		TAD (-1.5
00005	R	744102	A		SMA!STL
00006	R	754000	A		CLA!CCL
00007	R	340037	R		TAD (1.5
00010	R	652000	A		LMQ
00011	R	220000	R		LAC* POT.
00012	R	440000	R		ISZ POT.
00013	R	701401	A		AADR
00014	R	777774	A		LAW -4
00015	R	040034	R		DAC CNT#
00016	R	641605	A		EAE+1605
00017	R	742010	A		RTL
00020	R	742010	A		RTL
00021	R	040035	R		DAC OUT#
00022	R	641122	A		EAE+1122
00023	R	000012	A		12
00024	R	240035	R		XOR OUT
00025	R	440034	R		ISZ CNT
00026	R	600017	R		JMP .-7

SETS POT

00027	R	702104	A	ASCF
00030	R	701506	A	701506
00031	R	701501	A	SVSF
00032	R	600031	R	JMP .-1
00033	R	620000	R	JMP* POT.

		000000	A	.END
00036	R	750000	A *LIT	
00037	R	030000	A *LIT	

NO ERROR LINES

STRING OF POTENTIOMETER SETTINGS

POT	SETTING
220	0.0950
221	0.9900
237	0.0700
243	0.0700
244	0.0100
245	1.2500
247	1.2500
250	0.6560
252	0.0700
254	1.2500
256	1.2500
264	0.0354
276	0.0859
277	1.4300
310	0.9900
312	1.0000
313	1.0000
314	0.0458
315	0.2200
316	0.0179
317	0.1246
320	0.0950
323	0.0220
324	0.4650
325	0.0458
326	0.3500
327	0.0465
332	0.1700
334	0.0385
335	0.4000
336	0.0400
337	0.2242
344	0.1700
345	0.7700
346	0.1630
347	0.4142

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