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PDP-7 HYBRID COMPUTER PROGRAM
RECTANGULAR INTEGRATION SUBROUTINE

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From	To	By	Initials

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INTRODUCTION

The hybrid subroutine library contains three subroutines to be used in performing a rectangular integration, RINT\$, CNP\$, and ICL\$. Subroutine RINT\$ is used to perform the calculation of the integral and can be used in either synchronous or asynchronous mode. The purpose of CNP\$ is for calculation Δt , the time between integral calculations, for an asynchronous integration. Subroutine ICL\$ is for initialization of the real-time clock and also contains the save and restore portions of the clock service subroutine.

DISCUSSION

I. FUNCTION

- A. CNP\$: Calculate the number of clock pulses since the last calculation.
- B. RINT\$: Calculate the integral of an arbitrary input variable. The method of integration is rectangular.
- C. ICL\$: Initialize real-time clock and provide the user with a clock interrupt N_1 times per second.

II. CALLING SEQUENCE

- A. CNP\$: JMS CNP\$
 $\emptyset$ /last clock value
 DAC NP /RTN.PT., AC = number of
 /clock pulses since last
 /calculation

The programmer must provide one or two clocks for an asynchronous integration, \$CL1 and \$CL2. If only asynchronous operations are to take place, use:

```
41/      ISZ $CL1
50/      ISZ $CL1
```

If both synchronous (eg: time delay TD1\$) and asynchronous functions are to be performed, use:

```
41/      ISZ $CL1
50/      JMS CLSRV
```

For the latter case, the clock service subroutine CLSRV must calculate \$CL2 such that the sum of \$CL1 and \$CL2 gives the same result at the first method. ie:

```
LAC NCLOCK /reset hardware clock
CMA      /-NCLOCK
IAC      /-NCLOCK + 1
DAC $CL1
LAC NCLOCK /calculate software clock
ADD $CL2
DAC $CL2
```

When clock initialize subroutine ICL\$ is used, the absolute assignments in locations 41 and 50 may be disregarded and calculation of \$CL1, \$CL2

B. RINT\$

```

LAW .
JMP RINT$
LAC $MODE /INTEGRATOR MODE
LAC NP /PULSES SINCE LAST CALCULATION
LAC YØ /INITIAL CONDITION
LAC X /INPUT
LRSS or LLSS /RESCALE INPUT
ADD Y /OUTPUT
Ø /REMAINDER
DAC Y /OUTPUT

ETC. /ANY NUMBER OF INTEGRATIONS CAN BE
ETC. /NESTED IN A SINGLE CALLING SEQUENCE

NOP /TO RETURN TO CALLING PROGRAM, USE
JMP .+1 /NOP AND JMP .+1 FOLLOWING
CONTINUE /LAST INTEGRATION SEQUENCE

```

The mode variable should have a value of Ø to 4 according to the following table:

<u>MODE</u>	<u>VALUE</u>
Pot Set	0
Hold	1
Stand By	2
I C	3
Compute	4

Subroutine AMODE\$ in the hybrid subroutine library will calculate \$MODE according to the table. Location NP should contain the number of clock pulses since the last calculation. For a synchronous integration, NP would be a constant, but for asynchronous, it would vary and can be calculated by subroutine CNP\$. The frequency of the clock, 60 or 5000, should be stored in location \$FC. The time scale should be stored in location \$TS.

The shift instruction in the calling sequence (LLSS or LRSS) is used to rescale the input variable. This instruction effectively changes the gain of the integrator to

$$\begin{array}{ll}
 2^{+K} & \text{if LLSS K is used} \\
 \text{or } 2^{-K} & \text{if LRSS K is used.}
 \end{array}$$

External amplitude scaling should be used to compensate for this integrator gain change.

```

C.  ICL$:  JMS ICL$
           TS          /TIMESCALE
           FC          /CLOCK FREQUENCY
           NI(COMP)    /ITT/SEC
           NI(IC)      /ITT/SEC
           TAG1 or 0   /USER CLOCK SERVICE
           TAG2 or 0   /USER CLOCK SERVICE
           TAG3 or 0   /USER CLOCK SERVICE
                   /ZERO IF NO USER ACTION

           TIME,      0   /CONTAINS TIME SINCE
                   /ENTERING COMPUTE
                   /MODE
           . . . . . /RETURN

```

This calling sequence should be used in the initialization portion of the main program. Locations \$TS and \$FC (time scale and clock frequency) are set by the values TS and FC in the calling sequence. The compute mode N_I applies to both compute and hold modes while IC mode N_I applies to IC, Standby, and Potset modes. The symbolic locations TAG1, TAG2, and TAG3 are user locations where control should be transferred for Compute; IC-Standby-Potset; and Hold, respectively. (Note: TAG1, TAG2, and TAG3 could all be the same location. Anyone of them may be zero to indicate "no user action".)

The user's portion of the clock service subroutine must be terminated by

```
JMP RCL$
```

which will restore the instruction mode (MICL OR MIST), the step counter, the MQ, the link, the accumulator, and program counter to whatever condition existed before interrupt occurred.

Location TIME will contain the time (voltage scaled) since the analog computer entered compute mode. (Note: The user must call subroutine AMODE\$ somewhere in his main program loop.) This location could be used as input to a function

generator to generate a known time function. If the depressing of the compute switch is not the time desired for reference, the following sequence could be used:

At reference time to use:

```
LAC  TIME
DAC  T0#      t0 = TIME
```

At some point in the main program loop, use:

```
LAC  TIME
SUB  T0      t = TIME - t0
DAC  T#
```

III. REQUIREMENTS

A. MEMORY:

1. CNP\$: 19 (decimal) locations
2. RINT\$: 91 (decimal) locations
3. ICL\$: 165 (decimal) locations

B. DEVICES:

1. EAE
2. Modified Instruction
3. Real-Time Clock

C. EXECUTION TIME

1. CNP\$: 47 μ sec typical, 67 μ sec maximum
2. RINT\$: (57 + 66N) μ sec where N is the number of integrations nested in the calling sequence.
3. ICL\$ Clock
Service Routine: 135 μ sec plus time in user service routine

IV. EXAMPLE

Obtain the solution to the differential equation:

$$\frac{dy}{dt} + 3y = x ; y(0) = 0$$

or
$$\frac{dy}{dt} = x - 3y ; y(0) = 0$$

Obtain x at mux channel zero and output y at DAC channel
zero.

```

100/BGN,    CAF
            LAC 4000    /A-D OVERLOAD
            ASC
            JMS ICL$
            1          /TIME SCALE = 1
            5000'      /CLOCK FREQUENCY = 5000 HZ
            10'        /CALCULATE TIME EVERY .1 SEC
            10'
            0          /NO USER SERVICE
            0          /IE: ALL ASYNCHRONOUS
            0          /INTEGRATION.
            0
            EPI
            MIST
LOOP,       JMS AMODE$  /GET ANALOG MODE
            LAW 0
            JMS ADC$    /CONVERT A TO D
            LAW 0
            JMS ADC$    /CONVERT A TO D
            LAW 0
            DAC X#
            LAC Y
A,          JMS $MPCL$  /CALCULATE -A*Y
            -300.      /-100.*A
            ADD X
            DAC DYDT#   /DERAVITE OF Y
            JMS CNP$    /CALCULATE NP
            0
            DAC NP#

            LAW .
            JMP RINT$
            LAC $MODE   /MODE
            LAC NP      /PPI

            LAC YI      /I.C.
            LAC DYDT    /INPUT
            LLSS 0      /SHIFT
            ADD Y#      /OUTPUT
            0           /REMAINDER
            DAC Y       /OUTPUT

            NOP         /RETURN
            JMP .+1

            LAC Y       /OUTPUT Y ON D-A
            DA0         /CHANNEL ZERO
            JMP LOOP
YI,         0.00

```


V. THEORY

A rectangular integration is accomplished by the use of:

$$Y_{n+1} = X_n \Delta t \quad (1)$$

where $X = \frac{dy}{dt} \quad (2)$

let N_p = Number of clock pulses per calculation of Y

F_c = Frequency of clock (pulses per second)

T_s = Time Scale (10 for ten times real-time)

then:

$$\Delta t = \frac{N_p T_s}{F_c} \quad (3)$$

and $Y_{n+1} = Y_n + \frac{N_p T_s}{F_c} X_n \quad (4)$

$$= Y_n + \alpha X_n$$

where $\alpha = \frac{N_p T_s}{F_c} \quad (5)$

In order that maximum precision be retained, a normalized value of alpha is used such that

$$\beta = 2^J \quad (6)$$

and $\beta \approx 2^{17}$

After multiplication of x by β , βX is divided by 2^J through the use of a right shift instruction to form Δy plus a remainder. The remainder, from the calculation of Δy , is accumulated from one sample time to the next so that there will be no dead band associated with the integration.

VIII. MISCELLANEOUS (Error Analysis)First Order Differential Equation

When using a numerical integration method in solving differential equation, the analyst should be aware of the errors that can be present in his answers. The purpose of the analysis that follows is to develop some basic statements about simplified integration error and to make comparisons that may indicate a performance factor for several methods. The intent is not a rigorous development of output waveforms, but an analysis from which "order of magnitude" comparisons can be made.

The first numerical integration error to be discussed is that due to computation phase lag (time delay). This error becomes more noticable as feedbacks are added to a set of differential equations or as the existing feedback gains are increased. In order to obtain a general "feel" for the error introduced in a differential equation solution, consider the first order linear differential equation:

$$\frac{dy}{dt} = -ay \quad (7)$$

The analytical solution to (7) is

$$y(t) = y(0)e^{-at} \quad (8)$$

If we use rectangular numerical integration to obtain a solution,

$$X_n = \left. \frac{dy}{dt} \right|_{t_n} = -ay_n$$

$$\begin{aligned}
 Y_{n+1} &= Y_n + hX_n \\
 Y_{n+1} &= Y_n - ahY_n \\
 Y_{n+1} &= Y_n (1-ah)
 \end{aligned} \tag{9}$$

where $h = t =$ time between calculations.

From Equation (9),

$$\frac{Y_{n+1}}{Y_n} = 1 - ah \tag{10}$$

Note that, for any value of n , the ratio Y_{n+1}/Y_n is a constant $(1 - ah)$ less than unity. Thus, the waveform we obtain is also a decaying exponential but with an effective time constant slightly less than that for the analytical solution. We can check the error in (10) above by evaluating Y_{n+1}/Y_n for the exact solution:

$$\begin{aligned}
 Y_{n+1} &= Y(t_{n+1}) \\
 &= Y_{(0)} e^{-at_{n+1}} \\
 &= Y_{(0)} e^{-at_n - ah} \\
 &= Y_{(0)} e^{-at_n} e^{-ah} \\
 &= Y_n e^{-ah}
 \end{aligned}$$

from which

$$\frac{Y_{n+1}}{Y_n} = e^{-ah} \tag{11}$$

The normalized error in one calculation of Y_n is

$$E = \frac{Y_{n+1}}{Y_n} - e^{-ah} \quad (12)$$

For the rectangular integration method,

$$\begin{aligned} E_{\text{RECT}} &= 1 - ah - (1 - ah + \frac{a^2 h^2}{2} + \dots) \\ E_{\text{RECT}} &\approx \frac{-a^2 h^2}{2} \end{aligned} \quad (13)$$

Thus, the error for the rectangular integration method is proportional to $-(\Delta t)^2$.

Similar analysis for a trapezoidal integration yields:

$$\begin{aligned} Y_{n+1} &= Y_n + \frac{h}{2} (X_{n-1} + X_n) \\ &= Y_n - \frac{h}{2} a (Y_{n-1} + Y_n) \\ &= Y_n (1 - \frac{ah}{2}) - \frac{ah}{2} Y_{n-1} \\ \frac{Y_{n+1}}{Y_n} &= (1 - \frac{ah}{2}) - \frac{ah}{2} \frac{Y_{n-1}}{Y_n} \end{aligned}$$

Since $Y(t)$ is approximately a decaying exponential,

$$\frac{Y_{n-1}}{Y_n} \approx \frac{Y_n}{Y_{n+1}}$$

and letting $\gamma = \frac{Y_{n+1}}{Y_n}$

$$\gamma^2 - (1 - \frac{ah}{2})\gamma + \frac{ah}{2} = 0$$

solving the above equation for γ ,

$$\gamma = 1 - ah - \frac{1}{2}a^2h^2 + \dots$$

Thus

$$E_{\text{TRAP}} \approx -a^2h^2 \quad (14)$$

This analysis when applied to the first order predictor corrector method:

$$Y_{n+1}^P = Y_n + \frac{h}{2} (3X_n - X_{n-1})$$

$$Y_{n+1}^C = Y_n + \frac{h}{2} (X_n + X_{n-1})$$

$$\text{yields: } E_{\text{PC1}} \approx -\frac{1}{12} a^3h^3 \quad (15)$$

A similar analysis for the second order predictor corrector (Milne's method) can be made.

$$Y_{n+1}^P = Y_{n-3} + \frac{4h}{3} (2X_n - X_{n-1} + 2X_{n-2})$$

$$Y_{n+1}^C = Y_{n-1} + \frac{h}{3} (X_{n-1} + 4X_n + X_{n+1})$$

The result is:

$$E_{\text{MILNE}} \approx -\frac{1}{90} a^5h^5 \quad (16)$$

The error equations (13), (14), (15), and (16) can be expressed in terms of an equivalent computation dead-time or phase shift. Consider the following equation as shown in the figure.

$$\frac{dy}{dt} = -ay(t+\tau)$$

The solution to this equation is

$$Y(t) = Y(0)e^{-bt}$$

Where b is given by the solution to the implicit function:

$$ae^{-b\tau} = b$$

$$\text{or} \quad b \approx a(1-a\tau)$$

The error, expressed in terms of the delay time τ , is then

$$\begin{aligned} E &= \gamma - e^{-ah} = e^{-bh} - e^{-ah} \\ &= e^{-ah}(e^{a^2\tau h} - 1) \\ E &\approx a^2\tau h \end{aligned} \tag{17}$$

Thus, each of the error equations can be rewritten as an effective computation delay time as follows:

$$\tau_{\text{RECT}} = -\frac{h}{2} \tag{18}$$

$$\tau_{\text{TRAP}} = -h \tag{19}$$

$$\tau_{\text{PCI}} = -\left(\frac{ah}{12}\right)h \tag{20}$$

$$\tau_{\text{MILNE}} = -\left(\frac{a^3h^3}{90}\right)h \tag{21}$$

The above equations show the relative increase in accuracy of the more complex methods and a figure of merit can be defined as $f = \tau/h$ which is the effective delay time to sampling interval ratio.

$$f_{\text{RECT}}^1 = 1 \frac{1}{2} \tag{22}$$

$$f_{\text{TRAP}}^1 = -1 \tag{23}$$

$$f_{\text{PCI}}^1 = -\frac{1}{12}(ah) \tag{24}$$

$$f_{\text{MILNE}}^1 = -\frac{1}{90}(a^3h^3) \tag{25}$$

The super script 1 indicates that the factor, f , is for a first order differential equation. Example: If the sampling time interval were chosen so as to iterate ten times per time constant of the exponential solution:

$$ah = .1$$

$$f_{\text{RECT}} = -1/2 = -.5$$

$$f_{\text{TRAP}} = -1 = -1.0$$

$$f_{\text{PCI}} = -1/120 = -.008$$

$$f_{\text{MILNE}} = -1/90000 = -.00001$$

Analysis of Numerical Oscillator

The latter analysis dealt with the error introduced in a first order linear differential equation solution by computation phase shift. The following analysis will illustrate the effect of phase shift in the computation loop of a second order differential equation. Since phase shift is directly related to the integration method, a relative comparison can be established. Consider the oscillator shown in the figure:

ω_o = Natural frequency if $\tau = 0$

τ = Computation delay time of the total loop

The output from the oscillator will be approximately a sine wave with varying amplitude. The analysis considers only the first derivatives of amplitude and assumes that frequency is constant. The output wave form and its derivatives are therefore:

$$\dot{Y}(t) = A(t)\sin\omega t \quad (26)$$

$$\dot{Y}(t) = A\sin\omega t + A\cos\omega t \quad (27)$$

$$\ddot{Y}(t) = 2A\omega\cos\omega t - A\omega^2\sin\omega t \quad (28)$$

The value of Y after time delay is:

$$Y(t+\tau) = A\cos\omega\tau\sin\omega t + A\sin\omega\tau\cos\omega t \quad (29)$$

The equation for the oscillator is

$$-\omega_o^2 y(t+\tau) = \ddot{y} \quad (30)$$

Substitution of equations (28) and (29) in (30) yields:

$$-\omega_o^2 A[\sin\omega\tau\cos\omega t + \cos\omega\tau\sin\omega t] = 2\dot{A}\omega\cos\omega t - A\omega^2\sin\omega t$$

dividing by $A\sin\omega t$,

$$-\omega_o^2 [\sin\omega\tau\cot\omega t + \cos\omega\tau] = 2\frac{\dot{A}}{A}\omega\cot\omega t - \omega^2 \quad (31)$$

Separating the constant and variable parts,

$$\omega^2 = \omega_o^2 \cos\omega\tau \quad (32)$$

$$\text{and} \quad \frac{\dot{A}}{A} = -\frac{\omega_o^2 \sin\omega\tau}{2\omega^2} \omega$$

Substitution of (32) in the latter,

$$\frac{\dot{A}}{A} = -\frac{\tan\omega\tau}{2} \omega \quad (33)$$

and integrating

$$A = A(0)e^{-\left(\frac{\tan\omega\tau}{2}\right)\omega t} \quad (34)$$

$$A \approx A(0)e^{-\left(\frac{\omega\tau}{2}\right)\omega t} \quad (35)$$

In equations (34) and (35) $\omega\tau$ is the phase angle introduced by the computation delay time and ωt is the total angular displacement of the oscillator wave form. Thus:

$$A \approx A_o e^{-\phi\pi N} \quad (36)$$

where:

A_o = Amplitude at $t = 0$

ϕ = Phase shift = $\omega\tau$

N = Number of cycles of the output wave form since $t = 0$

Another way to express the growth or decay of the envelope is to let m = the number of iterations per cycle of the oscillator wave form.

$$m = \frac{1}{fh} \quad (37)$$

thus,

$$A = A_o e^{-2\pi^2 \frac{\tau}{h} \frac{N}{m}} \quad (38)$$

Therefore; the rate of distortion in the output envelope is decreased by increasing the iteration rate, m ; and is decreased by reduction of $(\frac{\tau}{h})$ which is directly related to the integration method.

VI. Block Diagram. (RINT\$)

RECTANGULAR INTEGRATION RINTS

/LIBRARY SUBROUTINE

/LHG 2-10-62

/RINTS CAN BE USED SYNC OR ASYNC

/IN EITHER CASE, NP (CLOCK PULSES SINCE LAST CALCULATION)

/MUST BE PROVIDED BY THE CALLING PROGRAM

/ALSO, A MODE VARIABLE MUST BE PROVIDED

/ACCORDING TO THE STANDARDS OF \$MODE

/AVERAGE COMPUTE MODE TIME = (57 + 71*N) MICRO SEC

/WHERE N = NUMBER OF INTEGRATIONS IN CALLING SEQUENCE

/RE-ENTER; INTER PROG MUST RESTORE L, AC, MQ, SC

/AND LOCATIONS GIVEN BEFORE RINTS

/CALLING SEQUENCE:

```

/      LAW .
/      JMP RINTS
/      LAC $MODE      /OR LAC MODE TO SET INTEGRATOR MODE
/      LAC NP          /NUMBER OF CLOCK PULSES SINCE LAST CALC.
/
/      LAC Y0          /INITIAL CONDX
/      LAC X            /INPUT
/      LRSS OR LLSS     /INPUT GAIN OF 2**K.
/      ADD Y            /OUTPUT
/      0                /REMAINDER
/      DAC Y            /OUTPUT
/
/      ETC.             /ANY NUMBER OF INTEGRATIONS CAN BE
/      ETC.             /NESTED IN A SINGLE CALLING SEQUENCE.
/
/      NOP              /TO RETURN TO CALLING PROGRAM, USE NOP
/      JMP . 1           /AND JMP .+1 FOLLOWING LAST INTEGRATION
/      CONTINUE

```

```

OCTAL      $INTI      Y      /LOCATIONS TO BE
           BETA      SHFT    /SAVED BY INTER PROG
           -4

```

```

RINTS,      ADD (DAC-LAW+1
           DAC $INTI      /DAC (JMS PT + 1), $INTI IS AUTO INDEX
           XCT I $INTI    /GET MODE OF INTEGRATOR
           ADD (XCT TBL
           DAC . 1
Y,          XX            /CLL IF COMPUTE
           XCT I $INTI    /GET NP (NO. OF CLOCK PULSES SINCE LAST COMP)
           MUL            /MULT BY TS/FC
FCI,        0             /FCI=(2↑K)*TS/FC (K=22+N-M)
           NORM          /AC=(2↑(K+L))*TS*NP/FC = (2↑(K+L))*ALPHA
           DAC BETA
           LACS          /34+L+22
           SNA           /IF NP=0, LACS WILL GET 0
           LAC (44
           ADD FCN       /LRSS K+L
           DAC SHFT

```

/RINTS PAGE 2

/COMPUTE MODE

```

COMPT,      ISZ $INTI    /IGNORE INIT CONDX
            XCT I $INTI  /LAC X (INPUT) OR JMP BACK
            MULS        /MULT BY BETA=(2↑J)*ALPHA (J=K+L)
BETA,       3           /A,M = (2↑J)*DELTA Y
SHFT,      XX          /LRSS J-22; A=DELTA Y; M=(2↑22)*REM; L=SIGN
            XCT I $INTI  /SHIFT INST. RE-SCALE INPUT BY 2**K
            XCT I $INTI  /ADD Y(I-1); AC=Y(I)
            DAC Y        /SAVE OUTPUT FOR INCREMENT OR DECREMENT
            LACS        /((2↑22)*REM
            LRS I       /((2↑21)*REM
            CLL         /L=0 IF ABS(SUM(REM)) < 1
            ADD I $INTI  /ACCUMULATE REMAINDERS
            XCT $INTI    /DAC REM
            SML         /L=1 IF ABS(SUM(REM)) >OR= 1
            JMP OUT      /NO REM OVFLOW
            XOR (400000 /INVERTS BIT 0 IF SUM(REM)
            XCT $INTI    /DAC REM; XOR (400000 ABOVE SAME AS +OR- 2↑21
            SPA!CLA!IAC!CLL /+1 FOR POS SUM(REM)
            LAM-1        /-1 FOR NEG SUM(REM)
            ADD Y        /INCREMENT OR DECREMENT Y
            XCT I $INTI  /DAC Y
            JMP COMPT

```

```

OUT,        LAC Y
            XCT I $INTI  /DAC Y
            JMP COMPT

```

/DISPATCH TABLE FOR MODES

```

TBL,        JMP ICX      /POT SET
            JMP HLD      /HOLD
            JMP ICX      /STAND-BY
            JMP ICX      /I C
            CLL          /COMPUTE

```

/HOLD MODE

```

HLD,        ISZ $INTI    /IGNORE NP
            ISZ $INTI    /IGNORE I C
            XCT I $INTI  /LAC X OR JMP BACK
            LAC $INTI
            ADD (5
            DAC $INTI
            JMP HLD 2

```

/RINT\$ PAGE 3

/I C MODE

```

ICX,      LAC $TS      /TIME SCALE
          NORMS!CLQ    /(2↑(N+1))*TSCALE
          RCR          /(2↑N)*TS
          DAC TS#
          LACS         /34+N+1
          ADD (LRSS-22-34-1      /LRSS N-22
          DAC FCN#
          LAC $FC       /CLOCK FREQUENCY
          NORMS!CLQ    /(2↑N)*FCLOCK
          DAC NFC
          LACS         /34+N
          CMA          /-34-N
          ADD FCN       /LRSS N-N-22-34
          DAC FCN
          LAC TS
          DIV!CLQ
NFC,      Z            /(2↑N)*FC
          LAC          /(2↑(22+N-N))*TS/FC
          DAC FCI

          ISZ $INTI     /IGNORE NP

ICX1,     XCT I $INTI  /GET INIT CONDX
          LMQ          /SAVE Y3
          XCT I $INTI  /LAC X OR JMP BACK
          ISZ $INTI    /IGNORE SHIFT INST
          ISZ $INTI    /IGNORE ADD Y
          DZM I $INTI  /ZERO REMAINDER
          LAC          /Y3
          XCT I $INTI  /DAC Y
          JMP ICX1

```

LIBERM RINT\$

START

```

CALCULATE NUMBER OF CLOCK PULSES  CNP$
/LIBRARY SUBROUTINE
/LHG 2-19-63
/SUBROUTINE CNP$ CAN BE USED TO CALCULATE NP
/FOR AN ASYNC INTEGRATION WHERE NP IS NOT CONSTANT
/TWO CLOCKS MUST BE PROVIDED:  SCL1  SCL2
/ONE OR THE OTHER CAN BE THE HARDWARE CLOCK
/IE:      41/          ISZ SCL1
/          52/          ISZ SCL1
/OR ONE CAN BE HARDWARE AND THE OTHER SOFTWARE
/IE:      41/          ISZ SCL1
/          52/          JMS CLSRV  /CLOCK SERVICE ROUTINE
/FOR THE LATTER CASE, THE CLOCK SERVICE ROUTINE MUST
/CLACULATE SCL2 ON EACH INTERRUPT
/SUCH THAT THE SUM OF SCL1 AND SCL2 GIVES THE SAME RESULT
/AS THE FIRST METHOD
/IE:      LAC NCLOCK  /RESET HARDWARE CLOCK
/          CMA        /-NCLOCK
/          IAC        /-NCLOCK + 1
/          DAC SCL1
/          LAC NCLOCK  /RESET S.W. CLOCK, NO. PULSES PER INTERRUPT
/          ADD SCL2
/          DAC SCL2    /SCL2 INCREMENTED BY PPI
/TIME = 47 MICRO-SEC. TYPICAL; 67 MICRO-SEC. MAXIMUM
/RE-ENTER

```

/CALLING SEQUENCE:

```

/          JMS CNP$
/          0          /HOLDS LAST CLOCK VALUE
/          .....    /RETURN POINT, AC = NP

```

```

OCTAL      CNP$      NP      -2

```

```

CNP$,      0
            LAC SCL1    /FORM SUM OF CLOCKS
            ADD SCL2
            LMR
            SUB SCL1
            SUB SCL2    /CHECK VALUE CALCULATED. 0 IF OKAY
            SZA
            JMP CNP$ 1  /POSSIBLY A WRONG VALUE, RE-CALCULATE
            LACQ        /CORRECT CLOCK VALUE
            SUB I CNP$   /CLOCK - LAST CLOCK
            DAC NP#
            LACQ
            DAC I CNP$   /SET LAST CLOCK VALUE
            LAC NP
            ISZ CNP$
            JMP I CNP$

```

LIBRM CNP\$

START

REAL TIME CLOCKS SCL1, SCL2
/LIBRARY ENTRY
/L'3 2-19-68

SCL1, 0

SCL2, 0

LIBFRM SCL1, SCL2

START

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