TOKAPOLE MONITOR SYSTEM

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Introduction

For many years a Radio Shack Model I, Level II, 16 K TRS-80 with a Connecticut Microcomputer Model AIM16, 8 bit, 16 channel, 100 μsec A-to-D converter has been used to monitor standard machine and discharge parameters on Tokapole II. The system has slowly evolved over the years, but has remained relatively unchanged for the past year. It is appropriate, therefore, to document the system in its present form for those who need to understand how it works. The documentation here applies to the 26 Jan 83 version of the software and is subject to change if improvements are made. A compiled version of the program is also available, dated 28 Jan 83, and differs only in minor details such as timing loops. It runs at about five times the speed of the BASIC version.

Loading Instructions (BASIC version)

1)Make sure the computer and video display are ON. The computer is turned on by a push-button on the rear of the keyboard next to the three plugs that attach to the cassette and video display. The computer is ON when the red LED on the keyboard is illuminated. The computer powers up with the question MEM SIZE?__. You can cause the computer to initialize itself and ask the MEM SIZE question from BASIC by typing:

SYSTEM <ENTER>

/∅ <ENTER>

(<ENTER> means press the white ENTER key.) The MEM SIZE question allows you to reserve memory for use of machine language programs. Although the TOKAPOLE MONITOR program requires 767 bytes of reserved memory

(MEM SIZE = 32000), this is done automatically by the program, and therefore one need only press <ENTER> in response to this question. The computer should respond with

READY

>_

to indicate that it will now accept BASIC commands.

2)Place the cassette tape labeled TOKAPOLE MONITOR in the recorder and rewind. Press the PLAY button on the recorder and type CLOAD <ENTER>. Within about 5 seconds a pair of flashing astericks will appear in the upper right corner of the screen indicating that the program is loading. If the astericks fail to appear or do not blink, the volume is probably set wrong on the recorder, or the plugs are not inserted, or the tape is defective. A backup version of the program is located a little further along (counter setting 050) on the same tape. When loading is complete (after about 1-1/2 minutes), the recorder will stop. Rewind the tape and put it away. It is no longer needed. Type RUN <ENTER> to cause the program to run. It will identify itself and request a baseline shot (a machine shot without plasma). Before it runs, it performs a memory check to see if the correct number of bytes was loaded and gives an error message, MEMORY CHECK ERROR ON LOAD, if it detects a problem. If this happens, start over. A BASIC listing of the program is included in Appendix A.

Loading Instructions (Compiled version)

1)Make sure the computer and video display are ON and enter BASIC as described in 1) above.

2)Place the cassette tape labeled TOKMON in the recorder and rewind. Press the PLAY button on the recorder and type

SYSTEM <ENTER>

TOKMON <ENTER>

The astericks in the upper right corner will flash, but more slowly than with the BASIC version. When the tape stops (after about 3-1/3 minutes), rewind and put it away. Then type

/ <ENTER>

RUN <ENTER>

The program will identify itself and run as before, except at five times the speed.

3)If you interrupt the program by pressing the <BREAK> key, you normally cannot continue by typing CONT <ENTER> as with a BASIC program. You will have to type RUN <ENTER>, and all previous data will be lost. You can LIST the program, but you won´t see anything very interesting. You cannot EDIT or add anything to the program. Attempting to do so will likely necessitate reloading the program from scratch.

Running the Program

The program is intended to run unattended. The default option is for the program to display plasma current (I_P), ion saturation current density (J_{SAT}), toroidal field (B_T), poloidal gap voltage (V_{PG}), hoop current (I_H), and the time derivative of the plasma current (dI_P/dt) for the first 10 msec after the poloidal field is fired. It does this immediately after the shot and then rearms itself and waits for the next shot as indicated by a single illuminated pixel in the upper right corner of the video display. When it receives a trigger, a second adjacent pixel will illuminate. Other command sequences can be programmed by pressing the P key. Most of these are obvious or can be learned by trial and error. A command sequence is a series of letters and numbers indicating the sequence in which the various

commands are performed. A single digit between 1 and 9 will cause a delay of the corresponding number of seconds. For example, the command sequence 5I5J5L5A <ENTER> will cause the default data table, the plasma current graph, the ion saturation current graph, the amp-seconds for the previous shots, and the table of additional derived data to be displayed in sequence with a five second delay between each. For longer delays one can use, for example, 999 which will cause a 27 second delay.

Otherwise, the only attention the program requires is to take a new baseline when requested. The program determines this by comparing the measured plasma current at 20 msec (which it assumes should be zero) with the baseline signal. If the difference exceeds 9 kA, all successive shots will request a baseline, and the data should be interpreted with caution until a new baseline is taken. When the measured plasma current at 20 msec is not zero, the computer assumes that the error is due to a change in hoop temperature and adjusts the displayed currents accordingly, so that the current indicated by the computer will always read within 1 kA of zero at 20 msec. The computer recognizes a baseline if the sum of the ion saturation current density at 2.5, 5.0, and 7.5 msec is less than 50 mA/cm^2. During a run, the plasma current baseline will slowly drift downward as the hoops heat up, changing their resistance, but the computer will correct for this up to a point. The seriousness of this effect will depend on the poloidal field strength and the recycle time. It is also generally impossible to get a good baseline at normal poloidal field strengths without using the core cocking circuit because the iron core saturates before 20 msec at a slightly different time with and without the plasma. When making careful measurements, it is advisable to retake a baseline whenever

any of the capacitor bank voltages is altered even though the computer's criterion for needing a baseline may not be met.

What the Program Does

When the program is ready to receive data (pixel in the upper right corner illuminated), the V_{PG} channel is being interrogated every 100 μsec by a machine language software loop (see Appendix B). Whenever the highest order bit becomes a one (>127), the five channels (I_P, J_{SAT}, B_T, V_{PG}, and I_H) are read in sequence at a rate of 100 μsec each for a total time of 20 msec, thereby generating 200 values which are stored in a two-dimensional array with dimensions X(5,40). The baseline is similarly stored in an array XB(5,40). The value of a quantity I is determined at time step J from

$$S(I,J) = SC(I)*\left(X(I,J) - XB(I,J)\right)$$

where SC(I) is a scale factor for that particular channel to make the units come out as follows:

quantity	scale factor	units
I_P	SC(1)=1	kA
J_{SAT}	SC(2)=10	mA/cm^2
B_T	SC(3)=200	gauss
V_{PG}	SC(4)=0.5	volts
I_H	SC(5)=2	kA

The scale factor can also be thought of as the smallest measurable increment of the corresponding quantity. Actually, in order to determine the quantities at a given time (such as 4 msec), the values are interpolated from the one just below and just above the desired time. The first measurement of I_P occurs at t=0.1 msec, the first measurement of J_{SAT} occurs at t=0.2 msec, etc. The second measurement of I_P occurs at t=0.6 msec, etc. Note that the trigger scheme introduces a 100 μsec jitter into the timing,

and that there is a threshold trigger level, but neither of these has ever been a serious problem. A sixth channel, neutral pressure, is read from the fast ion gauge just after the 20 msec point and compared with a baseline pressure just before the A-to-D is rearmed. This reading has not proved very reliable or useful because the I_P channel is often saturated at that time, resulting in erroneous pressure readings.

Whenever the absolute value of the measured plasma current at 20 msec exceeds 1 kA, the computer assumes the plasma current baseline has drifted due to a change in hoop resistance and adjusts the measured current by subtracting from it a quantity,

$$\Delta I_P(t) = I_P(20) \int_0^t I_H dt \ / \int_0^{20} I_H dt \qquad (1)$$

where t is in milliseconds. The justification for this correction is given by Eq. (12). Although the computer will continue to track a drift in resistance indefinitely, whenever the unadjusted current at 20 msec, $|I_P(20)|$ exceeds 9 kA, a baseline is requested.

The program calculates the amp-seconds (a figure of merit for the discharge) by numerically integrating the plasma current:

$$AS = \int_0^{20} I_P dt \qquad (2)$$

where I_P is in kA and t is in milliseconds. If the plasma current is negative, it is set to zero in the above integral to reduce the effect of an erroneous baseline. Whenever a baseline is needed, the amp-seconds is not calculated but rather set to zero to avoid meaningless readings.

From the measured quantities, several additional derived data can be displayed (using the A command). An effective minor radius of the plasma (in cm) is calculated from

$$a = 17.4 \; |I_P/I_H|^{1/4} \qquad (3)$$

This radius is meant to be the radius of a circle of the same cross-sectional area as that enclosed by the square-shaped plasma inside the separatrix. This quantity is only approximate because of a number of assumptions, the most serious of which is that the entire measured current flows in a circularly symmetric fashion within a circle of radius a centered on the geometric axis of the machine. It also assumes a degenerate octupole field in the absence of plasma, such that in the vicinity of the field nulls the octupole field varies like r^3.

The average safety factor $\langle q \rangle$ is determined by assuming that the plasma current density is uniform over the cross-section of a circle of radius a centered on the axis. The current density is then independent of radius, and $\langle q \rangle$ is constant out to a radius at which the octupole field starts to compare with the plasma field (near the separatrix). Near the axis the $\langle q \rangle$ is given by

$$\langle q \rangle = 10^{-4} \; a^2 B_T / I_P \qquad (4)$$

Calculation of the loop voltage V_ℓ is considerably more difficult. To begin with, we mean by loop voltage only the resistive part of the voltage applied to the plasma, i.e.: the voltage that would be measured by a single turn loop of wire that goes once around the machine toroidally at the magnetic axis. Other tokamaks measure loop voltage by a toroidal loop at

the plasma edge, and hence there is a contribution to the measured signal from the time derivative of the poloidal magnetic flux in the plasma. The loop voltage can be expressed in terms of the measured quantities (I_P, V_{PG}, and I_H) using the circuit model of PLP 777:

$$V_\ell = \alpha V_{Pg} + (1-\alpha)R_H I_H - \alpha(1-\alpha)L_H \frac{dI_P}{dt} - \frac{d}{dt}(L_P I_P) \qquad (5)$$

where α=private flux/common flux in the absence of a plasma (typically 0.5), R_H is the hoop resistance, L_H is the hoop inductance, and L_P is the plasma inductance. This equation differs from Eq. (7) of PLP 756 in that the sign of the $L_H dI_P/dt$ term is opposite. The reason is that the plasma inductance is here defined so as to include the image currents of the plasma in the hoops, i.e.: the hoops represent a conducting boundary which alters the plasma inductance. In PLP 756, the plasma inductance is calculated as if the hoops were absent. This difference is of little consequence, however, since the plasma inductance L_P cannot be measured directly, but rather the quantity $L_P+\alpha(1-\alpha)L_H$ (as defined above) is measured as described in PLP 756 to have a value of ~0.7 μH. The term $I_P dL_P dt$ cannot be easily measured and undoubtedly gives rise to some high frequency structure on the loop voltage, but is is thought to be unimportant for the low frequency components of V_ℓ. Actually, the method of determining the plasma inductance by experimentally measuring $dV_\ell/d\dot{I}_P$ takes into account that portion of the $I_P dL_P/dt$ that results from a simple expansion or contraction of the plasma radius a in response to a change in I_P. Current profile changes are not modelled properly, however. The quantities α and R_H can be estimated theoretically, but since they change in time due to soak-in, a better representation was obtained by Sprott and Shepard by measuring the loop voltage directly as

described in PLP 756 in the absence of plasma and then fitting the results to a function of the form

$$V_\ell = \frac{1}{2}(1+At)V_{PG} + B(1+Ct)I_H \tag{6}$$

where A, B, and C are constants. Such a method gives a first-order correction to the time dependence of α and R_H as well as the initial value of R_H. The data (45 points) were taken at 2 msec intervals up to 20 msec for a crowbarred, damped poloidal field waveform for a variety of poloidal bank and power crowbar settings. Similarly, the effect of $\dot{I}_P$ on the loop voltage was determined by measuring the loop voltage difference ΔV_ℓ with and without a plasma using a probe on axis as described above. The data (20 points) were taken at 0.5 msec intervals for several 4 msec discharges with peak current of ~ 25 kA at 1.5 msec and fitted to a curve of the form $\Delta V_\ell = -Aa^B\dot{I}_P$ over the range $7<a<11$ cm. The fit was not excellent but gave A=2.3 and B=-0.5. This method undoubtedly hides a multitude of sins, and it should be redone more carefully. Nevertheless, the values obtained give

$$V_\ell = \frac{1}{2}(1+t/75)V_{PG} + 0.0045(1-t/37)I_H - 2.3\dot{I}_P/\sqrt{a} \tag{7}$$

where t is the time in msec after the start of the poloidal voltage pulse, and the currents are measured in kiloamps. Calculation of the time derivative of the plasma current $\dot{I}_P$ poses some special problems. The plasma current trace is not perfectly smooth, and the differentiated value of the wiggles can overwhelm the low frequency signal that is thought to be of primary interest. After much experimentation a method was settled upon in which a parobola is fit to the four I_P points nearest the time of interest

(spanning a 1.5 msec interval), and the derivative at the desired point is determined analytically from the parabola. The round-off error in the A-to-D converter gives an rms error in the loop voltage measurement of ±0.5 volts which is considerable since our standard discharges have V_ℓ in the range of 2-3 volts. The errors in V_ℓ are probably the weakest link in the calculation of all subsequent quantities.

The ohmic input power is simply calculated from

$$P_{OH} = I_P V_\ell \tag{8}$$

In addition to the errors in V_ℓ previously discussed, the ohmic input power is subject to assumptions about the plasma current profile, namely that the underestimate of P_{OH} for current flowing near the hoops where V_ℓ is small is just compensated by the overestimate of P_{OH} for current flowing near the wall where V_ℓ is large.

The electron temperature (in eV) is calculated from I_P and V_ℓ assuming Spitzer resistivity with $Z_{eff}=1$ and assuming the current is distributed uniformly over a circular cross-section of radius a:

$$T_e = 376(|I_P/V_\ell|/a^2)^{2/3} \tag{9}$$

The actual peak electron temperature is probably larger by a factor of ~2-3 because Z_{eff} is greater than 1 and the current is presumably somewhat peaked near the axis.

The average electron density is determined from the ion saturation current density J_{SAT} and the conductivity electron temperature using the usual Langmuir probe relation $J_{SAT} \propto n\sqrt{T_e}$ for $T_e > T_i$. However, the coefficient was adjusted so that the density determined in this fashion

agrees with the line-averaged density (averaged along the entire path between the interferometer horns) using a 72 GHz microwave interferometer for a standard discharge:

$$\langle n\rangle = \frac{0.05 J_{SAT}}{\sqrt{T_e}(1-e^{-45/T_e})} \qquad (10)$$

J_{SAT} is in mA/cm^2 and $\langle n\rangle$ is in 10^{12} cm^{-3}. The factor $1-e^{-45/T_e}$ is included to account for the fact that only 45 V bias is used on the probe, and thus not all electrons are repelled when the temperature is high. This voltage is provided by a power supply but should be checked occasionally. The actual peak density depends on the profile and is probably ~2-3 times the value indicated here. The Langmuir probe is located on the octupole separatrix in the lower outer bridge and uses as a reference a large electrode which extends across the plasma nearly to the hoop in the upper outer bridge at the same (330 degree) toroidal azimuth.

Finally, the electron energy confinement time is calculated from

$$\tau = \frac{0.144\langle n\rangle T_e}{P_{OH}} \qquad (11)$$

where τ is in msec and the other units are as before (10^{12} cm^{-3}, eV, and kW). This confinement time assumes a quasi-steady state, i.e.: τ is much less than the time scale for change in either plasma energy or ohmic input power. In the above formula, the total machine volume inside ψ_{crit} is used (5×10^5 cm^3), and thus it represents an overall machine confinement time rather than a confinement time for the central current channel. As such, it

is probably an overestimate since the volume-averaged T_e is probably less than that calculated from the conductivity which assumes the current flows only within a radius a, unless Z_{eff} is high enough to compensate for this effect. To get an estimate of the confinement of the central current channel, one should use a smaller volume ($\sim 1\times10^5$ cm^{-3}). However, since $\langle n\rangle T_e$ is low by a factor of ~4-9, the errors offset, and the calculated τ is probably a reasonable estimate for the confinement of the central current channel to within about a factor of two. It is interesting to note as pointed out by Prager that the method used to calculate τ involves multiplying the measured density by $I_H^{1/3} I_P^{-2/3} V_\ell^{-5/3}$, and thus the confinement time is most sensitive to the loop voltage and very little else. This is unfortunate since the error in V_ℓ exceeds that of any other quantity.

A-to-D Converter

The A-to-D converter is a Model AIM16, available for about $300 from Connecticut Microcomputer, Inc., 150 Pocono Road, Brookfield, CT 06804. Excerpts from the Data Sheet are included in Appendix C. It has the virtue of being the first such unit made for the TRS-80 with specifications adequate for the present purpose. Better units are now available but at higher cost. The unit has 16 multiplexed inputs with a maximum conversion time of 100 μsec per channel. Each channel has 8-bit accuracy (0-255) and responds to positive voltages in the range 0-5.12 volts (20 mvolt resolution). The absolute maximum error is 10 mvolts + 0.7%. In order to achieve reasonable time resolution (500 μsec), only channels 1-5 are used for the high speed recording of data. The remaining channels are available for monitoring other slowly varying quantities, but only channel 6 is being used at present (to monitor neutral pressure). The unit has two significant limitations: 1)It does not have a sample-and-hold circuit and thus will

produce erroneous results if the input voltage varies significantly over the 100 μsec conversion interval. 2)Saturation of any channel in either direction (V_{in} <0 or >5.12 volts) will produce erroneous readings in all the other channels during the time the channel is saturated.

The A-to-D converter was repackaged in a shielded rack panel with a filtered internal power supply (+5.12 volts), BNC input connectors, and 1 MΩ potentiometer gain adjustments on each channel. In addition, input filtering was provided to protect the AIM16 from noise, damage due to overvoltage, and rapidly changing input signals. The filtering typically limits the input response time to >24 μsec (<6.6 kHz) on most channels. The input resistance of each channel is 1 MΩ, and a 10 kΩ input resistor protects the A-to-D from damage by overvoltage for any reasonable input signal. Some channels are provided with a dc offset to allow a negative voltage swing at the input. Although channel ϕ is designated as a trigger channel, the software actually uses channel 4 (V_{PG}). The trigger channel can be changed by POKEing an integer corresponding to the desired channel number (0-15) into memory location 32011 after the program is running (BASIC version only). A schematic of the input circuitry for the A-to-D converter is included in Appendix D.

Current Monitor Circuit

The A-to-D circuit requires inputs proportional to plasma current and hoop current to operate properly. Unfortunately, there is no simple, non-perturbing method for generating such signals. Rather, one has to take the available signals (poloidal gap voltage V_{PG} and primary current I_{PR} in the iron core) and deduce the plasma and hoop currents based upon some reasonable model of the plasma current profile. Several PLP's have been written on this subject (712, 756, 777), and the emphasis here will

therefore be on the circuitry used to generate the signals rather than the justification of the model. Simply stated, the model assumes that the plasma current profile is such that in some appropriate flux space average, the current can be treated as if it were all concentrated at the geometric axis (or octupole null). Then the circuit model of PLP 777 gives

$$I_P = \frac{N}{\alpha} I_{PR} - \frac{1}{\alpha L_H} \int V_{PG}dt + \frac{1}{\alpha L_H} \int I_H R_H dt \tag{12}$$

and

$$I_H = NI_{PR} - I_P \tag{13}$$

where N is the poloidal field turns ratio (typically 40). An analog computer circuit was constructed to calculate I_P and I_H. The circuit as shown in Appendix E uses 10 type 741 operational amplifiers and generates a number of other useful quantities:

$\Phi = \int V_{PG}dt$ (poloidal flux: 0.1 webers/volt)

$AS = \int I_P dt$ (amp-seconds: 1000/volt)

$\dot{I}_P = dI_P/dt$ (time derivative of I_P: 10 kA/msec/volt)

Actually, for calculating plasma current, the circuit solves the equation:

$$I_P = AV_{PG} + BI_{PR} - 9.1 \int V_{PG}dt + C \int I_H dt$$
$$-D \int \left[\int I_{PR}dt\right]dt \tag{14}$$

in which A, B, C, and D are constants adjustable from the front panel and labeled "EARLY", "MID", "LATE", and "VERY LATE" respectively. The first term (A) is typically small and corrects for stray capacitance not included

in the circuit model. The last term (D) compensates for magnetic field soak-in ($\dot{R}_H$, $\dot{\alpha}$, and $\dot{L}_H$) as well as the magnetizing inductance of the iron core and other effects which become important only after a long time. Note that one of the coefficients (9.1) is fixed by the circuit (corresponding to an initial hoop inductance of L_H=0.22 μH and α=0.5), such that the calibration of the plasma current is ensured once the other coefficients are adjusted to give I_P=0 at all times in the absence of a plasma. In practice, one adjusts the circuit so as to give as nearly a flat baseline as possible when the fields are pulsed in the absence of a plasma. The plasma current is filtered by an active RC low pass filter with a cutoff frequency of 1.6 kHz (100 μsec response time) to reduce high frequency noise. The circuit has only two inputs, V_{PG} and I_{PR}. These inputs enter the circuit through LC low-pass filters with a cutoff frequency of 160 kHz. The poloidal gap voltage is measured by a single loop of wire around the iron core. The primary current is determined by measuring the voltage across a 10^{-3} Ω resistor (1 kA/volt) in series with the primary through a special, low-frequency, 1:2 turns ratio isolation transformer (Jensen Model JE-11S-L) to eliminate ground loops. The transformer is terminated in 150 Ω through a 1 MH inductor to compensate for the inductance of the current shunt, to produce a 2:1 voltage reduction, and to increase the volt-second limit of the transformer. All grounds are referenced to the panel of the current monitor circuit, and the computer gets its ground through the signal cables that connect to the A-to-D converter. The computer rack should float if these cables are disconnected.

In order to account for the time-varying hoop resistance, a modification was made to the circuit in Appendix E using the results of a calculation by Kerst of the voltage at the surface of a Tokapole hoop versus

time in the presence of a current step. The actual current waveform can be decomposed into an infinite sum of such current steps. The calculation treats the hoop as a uniform cylinder with a constant poloidal field at its surface. The result is a time varying resistance given by

$$R_H(t) = R(o)\left[1 + \sum_{i=1}^{\infty} e^{-t/\tau_i}\right] \qquad (15)$$

where in cgs units

$$\tau_i \cong \frac{4r_o^2}{\pi(i+0.24)^2 10^9 \rho} \qquad (16)$$

In Eq. (16), r_o is the radius (2.5 cm) and ρ is the resistivity (2.2 μΩ-cm) of the hoops. The first 20 values of τ_i are tabulated in Appendix F along with a schematic of an RC network whose reciprocal (I/V) approximates this function and replaces the 100 kΩ resistor between the output of op amp 7 and the input of op amp 5 in Appendix E. Actually, the ratio of voltage to current is not purely resistive in either the hoops or in the circuit model since part of the voltage at the hoop surface is due to the time varying magnetic flux inside the hoops. In other words, the product of voltage and current does not give the instantaneous ohmic power dissipated by the hoops as was the case in Spencer's calculation (PLP 771). Thus the time dependent hoop resistance automatically accounts for that portion of the variation of the hoop inductance, $L_H(t)$, that is due to flux soaking into the hoops. When the current monitor circuit was modified in this way, the result was a considerably flatter baseline and a plasma current trace whose initial peak is suppressed and moved considerably later in time.

APPENDICES

A. BASIC Listing of Tokapole Monitor Program

B. AIM16 Machine Language Routine

C. AIM16 Data Sheet Excerpts

D. Schematic of A-to-D Input Circuit

E. Schematic of Tokapole Current Monitor Circuit

F. Schematic of Circuit to Model Hoop Resistance

APPENDIX A

BASIC Listing of Tokapole Monitor Program

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10 POKE16561,254:POKE16562,124:CLEAR:RESTORE:CLS:PRINTTAB(11)"TO
KAPOLE MONITOR PROGRAM / JCS / 26 JAN 83":CLEAR600:DEFINTA-R,T-Z
:DIMX(5,40),XB(5,40),GR(40),AS(127),S(13,10):M=MEM
20 IFM<>6769PRINT"MEMORY CHECK ERROR ON LOAD":PRINT"MEM =";M;"(S
HOULD BE 6769)":PRINT"TRY RELOADING CASSETTE":ENDELSEPOKE16526,1
:POKE16527,125:FORI=32001TO32145:READX:POKEI,X:NEXT
30 DATA62,1,50,44,126,62,192,211,223,62,4,211,223,58,1,56,33,2,5
6,182,33,4,56,182,33,16,56,182,33,64,56,182,192,62,255,211,223,2
19,223,203,127,40,222,14,206,33,45,126,22,1,122,211,223,20
40 DATA122,254,6,32,2,22,1,6,6,16,254,62,255,211,223,219,223,119
,122,211,223,35,13,32,230,62,0,50,44,126,42,42,126,1,45,126,30,4
1,22,5,54,0,35,54,0,35,10,119,35,54,0,3,21,32,246,35,29,32
50 DATA235,221,42,42,126,253,42,40,126,14,246,6,2,175,221,126,0,
253,158,0,221,119,0,221,35,253,35,16,241,13,32,235,201:PP=223:OU
TPP,128:FORI=1TO5:OUTPP,I:OUTPP,192:XB(I,0)=INP(PP):FORJ=1TO40:X
B(I,J)=XB(I,0):NEXTJ,I:FS=10:PRINT
60 SC(1)=1:SC(2)=10:SC(3)=200:SC(4)=0.5:SC(5)=2
70 IFBM=0PRINT" ***** TAKE A BASELINE SHOT";
80 SET(125,0):OUTPP,128:OUTPP,6:OUTPP,192:PB=INP(PP):POKE32299,I
NT(VARPTR(X(0,0))/256):POKE32298,VARPTR(X(0,0))-256*INT(VARPTR(X
(0,0))/256):POKE32297,INT(VARPTR(XB(0,0))/256):POKE32296,VARPTR(
XB(0,0))-256*INT(VARPTR(XB(0,0))/256):X=USR(0)
90 OUTPP,128:OUTPP,6:OUTPP,192:PR=INP(PP):SET(127,0):IFPEEK(3230
0)THEN270ELSEBL=X(2,5)+X(2,10)+X(2,15):IFBL>5THENBL=1:GOTO110ELS
EBL=0:BM=1:FORI=1TO2:FORJ=0TO40:XB(I,J)=XB(I,J)+X(I,J):NEXT:NEXT
:FORI=3TO5:OUTPP,I:OUTPP,192:XB(I,0)=INP(PP)
100 FORJ=1TO40:XB(I,J)=XB(I,0):NEXT:NEXT
110 QI=0:IFBL>0THENNS=NS+1
120 CLS:IFBL=0THENPRINT"BASELINE"ELSEPRINT"SHOT NUMBER:";NS:IFAB
S(X(1,40))>9THENBM=0
130 IFABS(X(1,40))>1THENIH=0:FORJ=0TO40:IH=IH+X(5,J):NEXT:IFIHTH
ENIT=0:FORJ=0TO40:IT=IT+X(5,J):X(1,J)=X(1,J)-X(1,40)*IT/IH:NEXT
140 IM=X(1,0):AS=0:FORJ=0TO40:AS=AS+X(1,J):IFX(1,J)>=IMTHENIM=X(
1,J):JM=J
150 IFX(1,J)<0THENAS=AS-X(1,J)
160 NEXT
170 AS=AS*BM*BL:TM=5*JM+1:IFJM>0ANDJM<40THENS0=X(1,JM-1):S2=X(1,
JM+1):IF2*IM<>S0+S2THENTM=TM-2.5*(S2-S0)/(S2-2*IM+S0):IM=IM-0.10
0*(S2-S0)*(S2-S0)/(S2-2*IM+S0)
180 IFIMPRINT"MAX IP =";SC(1)*IM;"KA AT";TM/10;"MSEC"ELSEPRINT"M
AX IP = 0"
190 PRINT"AMP SECONDS =";SC(1)*AS/2:PRINT"PRES =";4*(PR-PB);"E-5
 TORR":PRINT"TIME     IP     JSAT     BT     VPG     IHOOP     DIP
/DT":FORJ=1TO10:J1=FS*J/5:S(0,J)=FS*J/10:PRINTS(0,J);:FORI=1TO5:
XP(I)=((5-I)*X(I,J1)+I*X(I,J1-1))/5
200 X1=BL*X(I,J1)+XB(I,J1):X2=BL*X(I,J1-1)+XB(I,J1-1):IFX1<=0ORX
2<=0PRINTTAB(8*I);"SAT-";:GOTO210ELSEIFX1>=255ORX2>=255PRINTTAB(
8*I);"SAT+";:GOTO210ELSES(I,J)=SC(I)*XP(I):PRINTTAB(8*I);S(I,J);
```

BASIC Listing of Tokapole Monitor Program

```
10 POKE16541,254:POKE16543,124:CLEAR:RESTORE:CLS:PRINTTAB(11)"TO
KAPOL [illegible]
[illegible] 40),YB(5,40),DR(40),[illegible] :M=MEM
20 IF[illegible]PRINT"MEMORY CHECK ERROR ON LOAD":PRINT"MEM =";M;"(S
HOULD BE 67689)":PRINT"TRY RELOADING CASSETTE":END:ELSEPOKE16526,1
:POKE16527,125:FORI=32061TO32195:READX:POKEI,X:NEXT
30 DATA62,1,50,44,124,62,195,211,223,62,4,211,220,58,1,54,33,2,5
[illegible] 54,182,[illegible] 195,199,62,255,211,26[illegible]
[illegible] 22,211,223,20
[illegible] DATA152,254,[illegible] 211,223,219,223,119
,122,211,223,35,13,32,230,62,0,50,44,126,42,42,126,1,45,126,30,9
1,22,5,54,0,35,54,0,35,10,119,35,54,0,3,21,32,246,35,29,32
[illegible] DATA225,201,42,42,124,253,42,40,126,14,246,6,7,175,221,[illegible]
[illegible] 2,235,201:PP [illegible]
[illegible] 05:OUTPP,[illegible] OUTP[illegible] XP[illegible]=INP(PP):FORJ=[illegible]
[illegible]=XB[illegible]NEXTI,1:FS=10:PRINT
60 SC(1)=1:SC(2)=10:SC(3)=200:SC(4)=0.5:SC(5)=2
70 IFEM=0PRINT" ***** TAKE A BASELINE SHOT";
80 SET(125,0):OUTPP,128:OUTPP,6:OUTPP,192:PB=INP(PP):PRINT[illegible]
[illegible]
[illegible]
[illegible]
90 OUTPP,128:OUTPP,6:OUTPP,192:PR=INP(PP):SET(127,0):IFPEEK(3230
0)THEN270ELSEBL=X(2,5)+X(2,10)+X(2,15):IFBL>5THENBL=1:GOTO110ELS
EBL=0:BM=1[illegible]
[illegible]
120 CLS:IFEL=0THENPRINT"BASELINE"ELSEPRINT"SHOT NUMBER";NS:IFAB
S(X(1,40))>9THENBN=6
130 IFABS(X(1,40))>[illegible]THENTH=0:FORJ=0TO40:TH=TH+X(5,J):NEXT:IFTHTH
[illegible]
[illegible] INTH=NTH=X
[illegible]
150 IFX(1,J)<0THENAS=AS-X(1,J)
160 NEXT
170 AS=AS*BM*BL:TM=5*JM+1:IFJM>0ANDJM<40THENS0=X(1,JM-1)*S2=X(1
[illegible] 0)/(S2-2*IN+S0):IP=1:[illegible]
[illegible]
[illegible]PRINT"MAX IP[illegible]SC(2)*IN;"KA AT";TM/10;"MSEC"ELSEPRINT"M
AX IP = 0"
190 PRINT"AMP SECONDS =";SC(1)*AS/2:PRINT"PRES =";4*(PR-PB);"E-5
 TORR":PRINT"TIME      IP      ISAT     FT      VPG     TWOOP    DIP
[illegible]PRINTS(0.[illegible]FORI=1TO5:
[illegible] (1)*X(I,J1-1))/5
[illegible] X2=BL*X(I,J1-1)+XB(I,J1-1):IFX1<=0ORX
2<=0PRINTTAB(8*I);"SAT-";:GOTO210ELSEIFX1>=255ORX2>=255PRINTTAB(
8*I);"SAT+";:GOTO210ELSES(I,J)=SC(I)*XP(I):PRINTTAB(8*I);S(I,J);
```

```
210 NEXT:J2=J1+1:IFJ2=41THENJ2=40
220 J0=J1-2:IFJ0<0THENJ0=0
230 S(13,J)=SC(1)*(8*X(1,J2)+2*X(1,J1)-8*X(1,J1-1)-2*X(1,J0))/10
:PRINTTAB(48)S(13,J):NEXT:IFBL=0THEN260ELSENT=127:IFNS<128THENNT
=NS
240 IFNS>127FORI=1TO127:AS(I-1)=AS(I):NEXT
250 AS(NT)=AS
260 IFCS$<>""THENGOSUB530:IFQQ$<>""THEN280
270 QQ$=INKEY$:IFQQ$=""THEN70
280 IFQQ$="0"THENPRINT" ***** COMPUTER ON STANDBY---PRESS 1 TO C
ONTINUE TAKING DATA";
290 IFQQ$="0"THENIFINKEY$<>"1"THEN290ELSECLS:GOTO70ELSEIFQQ$="1"
THEN70ELSECLS:PRINTAS/2;"AS";:IFQQ$="I"THENPRINT,"PLASMA CURRENT
 VS TIME";:IG=1:GOTO350ELSEIFQQ$="J"THENPRINT,"ION SATURATION CU
RRENT VS TIME";:IG=2:GOTO350
300 IFQQ$="B"THENPRINT,"TOROIDAL FIELD VS TIME";:IG=3:GOTO350ELS
EIFQQ$="V"THENPRINT,"POLOIDAL GAP VOLTAGE VS TIME";:IG=4:GOTO350
ELSEIFQQ$="H"THENPRINT,"HOOP CURRENT VS TIME";:IG=5:GOTO350ELSEI
FQQ$="C"THENCLS:GOSUB400:GOTO120ELSEIFQQ$="R"THEN120
310 IFQQ$="S"THENCLS:PRINT"CURRENT SHOT NUMBER =";NS:INPUT"NEW S
HOT NUMBER";NS:GOTO70ELSEIFQQ$="L"THENGOSUB410:GOTO260ELSEIFQQ$=
"E"THENGOSUB430:GOTO280ELSEIFQQ$="A"THENGOSUB450:GOTO260ELSEIFQQ
$="M"THENGOSUB550:GOTO280ELSECLS:PRINT"COMMANDS:";
320 PRINT,"0: STANDBY":PRINT,"1: CONTINUE":PRINT,"I: GRAPH PLASM
A CURRENT":PRINT,"J: GRAPH ION SATURATION CURRENT":PRINT,"B: GRA
PH TOROIDAL FIELD":PRINT,"V: GRAPH POLOIDAL GAP VOLTAGE":PRINT,"
H: GRAPH HOOP CURRENT":PRINT,"C: CHANGE TIME SCALE"
330 PRINT,"L: GRAPH A-S FOR LAST";NT;"SHOTS":PRINT,"R: RETURN TO
 INITIAL TABLE":PRINT,"S: CHANGE SHOT NUMBER COUNTER":PRINT,"E:
EXAMINE ANALOG INPUTS":PRINT,"A: DISPLAY DERIVED DATA":PRINT,"M:
 PRINT MESSAGE ON SCREEN"
340 PRINT,"P: PROGRAM COMMAND SEQUENCE":IFQQ$="P"THENCS$="":INPU
T"WHAT COMMAND SEQUENCE";CS$:GOTO70ELSE260
350 IFBL=1PRINTTAB(52);"SHOT";NS;ELSEPRINTTAB(52);"BASELINE";
360 Y1=0:Y2=0:FORJ=0TO40:GR(J)=X(IG,J):IFGR(J)>Y2THENY2=GR(J)
370 IFGR(J)<Y1THENY1=GR(J)
380 NEXT:IFY2=Y1PRINT:PRINT:PRINT" ***** NO DATA TO GRAPH":GOTO2
60ELSESY=34/(Y2-Y1):FORJ=0TO40:SET(3*J+5,44.5-SY*(GR(J)-Y1)):NEX
T:Y=44.5+SY*Y1:FORI=3TO125:SET(I,Y):NEXT:FORY=15553TO16257STEP64
:POKEY,170:NEXT
390 PRINT@961,"0      2      4      6      8     MSEC    12     14     1
6     18     20";:PRINT@80,"MAXIMUM VALUE:";SC(IG)*Y2;:GOTO260
400 FS=10:INPUT"HOW MANY MSEC FULL SCALE (DEFAULTS TO 10)";FS:IF
FS>20PRINT"MAXIMUM IS 20 MSEC":GOTO400ELSEIFFS<5PRINT"MINIMUM IS
 5 MSEC":GOTO400ELSECLS:RETURN
```

```
210 NEXT:J2=J1+1:IFJ2=41THENJ2=40
220 J0=J1-2:IFJ0<0THENJ0=0
230 S(13,J)=SC(1)*(2*Y(1,J2)+2*Y(1,J1)-2*Y(1,J1-1)-2*X(1,J0))/10
... ABS(S(13,J)) ... THEN240ELSEP=-127:IFP<1 THENP...
240 ... I=... TO127:A$(I)=A$(I):NEXT
250 A$(NT)=A$
260 IFCS$<>""THENGOSUB530:IFOO$<>""THEN280
270 OO$=INKEY$:IFOO$=""THEN270
280 ... PRINT" ***** COMPUTER ON STANDBY---PRESS ? TO ...
...
290 ... IFOO$="O"THEN ... "THEN290ELSECLS:GOTO70ELSEIFOO$="I"THEN70ELSECLS:PRINTTAB(7);"A$";:IFOO$="I"THENPRINT,"PLASMA CURRENT VS TIME";:IG=1:GOTO320ELSEIFOO$="J"THENPRINT,"ION SATURATION CURRENT VS TIME";:IG=2:GOTO350
... THENPRINT,"TOROIDAL FIELD VS TIME";:IG=3:GOTO350 ... PRINT,"POLOIDAL CAP VOLTAGE VS TIME";:IG=4:GOTO350ELSEIFOO$="H"THENPRINT,"HOOP CURRENT VS TIME";:IG=5:GOTO350ELSEIFOO$="C"THENCLS:GOSUB400:GOTO120ELSEIFOO$="R"THEN120
310 IFOO$="S"THENCLS:PRINT"CURRENT SHOT NUMBER =";NS:INPUT"NEW SHOT NUMBER";NS:GOTO70ELSEIFOO$="L"THENGOSUB410:GOTO240ELSEIFOO$=
... GOTO280 ... IFOO$="A"THENGOSUB450:GOTO240ELSEIFOO
... GOSUB ... ELSECLS:PRINT"COMMANDS:"
320 PRINT, ... PRINT,"1: CONTINUE":PRINT,"I: GRAPH PLASMA CURRENT":PRINT,"J: GRAPH ION SATURATION CURRENT":PRINT,"B: GRAPH TOROIDAL FIELD":PRINT,"V: GRAPH POLOIDAL CAP VOLTAGE":PRINT,"H: GRAPH HOOP CURRENT":PRINT,"C: CHANGE TIME SCALE"
... GRAPH ... OF LAST ... SHOTS":PRINT,"R: ... TO ... PRINT ... SHOT NUMBER COUNTER":PRINT,"L: ... LINE ANALOG INPUTS":PRINT,"A: DISPLAY DERIVED DATA":PRINT,"N: PRINT MESSAGE ON SCREEN"
340 PRINT,"P: PROGRAM COMMAND SEQUENCE":IFOO$="P"THENCS$="":INPUT"WHAT COMMAND SEQUENCE";CS$:GOTO70ELSE260
... PRINTTAB(52);"SHOT ";NS ... PRINTTAB(52);"BASELINE";
... Y2=0:FORJ=6TO40:IFCG(J)>Y2THENY2=CG(J)
... IFCG(J)<Y1THENY1=CG(J)
380 NEXT:IFY2=Y1PRINT:PRINT:PRINT" ***** NO DATA TO GRAPH":GOTO240ELSESY=34/(Y2-Y1):FORJ=6TO40:SET(2*J+5,44.5-SY*(CG(J)-Y1)):NEXT:Y=44.5+SY*Y1:FORI=5TO125:SET(I,Y):NEXT:FORY=15TO44STEP4
... SET ...
390 PRINT@962,"0 ... 6 ... MSEC ... 12 ... 14 ...
... 18 ... PRINT@20,"MAXIMUM VALUE:";SC(IG)*Y2;:GOTO240
400 FS=10:INPUT"HOW MANY MSEC FULL SCALE (DEFAULTS TO 10)";FS:IFFS>20PRINT"MAXIMUM IS 20 MSEC":GOTO400ELSEIFFS<5PRINT"MINIMUM IS 5 MSEC":GOTO400ELSECLS:RETURN
```

```
410 PRINT,"AMP SECONDS FOR LAST";NT;"SHOTS":Y2=0:FORI=0TONT:IFAS
(I)>Y2THENY2=AS(I)
420 NEXT:IFY2=0PRINT:PRINT" ***** NO DATA TO GRAPH":RETURNELSEPR
INT@960,STRING$(63,CHR$(176));:POKE16363,176:FORI=1TONT:SET(I,47
-41*AS(I)/Y2):NEXT:FORY=6TO46:SET(0,Y):NEXT:PRINT@80,"MAXIMUM VA
LUE";Y2*SC(1)/2;:RETURN
430 CLS:PRINT,"ANALOG INPUT FOR EACH CHANNEL":PRINT:OUTPP,128:FO
RI=0TO15:PRINTUSING"####";I;:NEXT:PRINT@396,"PRESS ANY KEY TO RE
SUME TOKAPOLE DATA"
440 PRINT@192,"";:FORI=0TO15:OUTPP,I:OUTPP,192:PRINTUSING"####";
INP(PP);:NEXT:QQ$=INKEY$:IFQQ$=""THEN440ELSERETURN
450 PRINT,"ADDITIONAL DERIVED DATA";:IFBL=1PRINTTAB(52);"SHOT";N
SELSEPRINTTAB(52);"BASELINE"
460 PRINT:PRINT"TIME     A       <Q>      VLOOP   POH     TE
<N>      TAU":FORJ=1TO10:IFS(5,J)THENS(6,J)=17.4*(ABS(S(1,J)/S(5,
J)))[.25ELSES(6,J)=0
470 IFS(1,J)THENS(7,J)=1E-4*S(6,J)*S(6,J)*S(3,J)/S(1,J)ELSES(7,J
)=0
480 S(8,J)=.5*(1+S(0,J)/75)*S(4,J)+.0045*(1-S(0,J)/37)*S(5,J):IF
S(6,J)THENS(8,J)=S(8,J)-2.3*S(13,J)/SQR(S(6,J))
490 S(9,J)=S(8,J)*S(1,J):IFS(8,J)*S(6,J)THENS(10,J)=376*(ABS(S(1
,J)/S(8,J)/S(6,J)/S(6,J)))[.6666667ELSES(10,J)=0
500 IFS(10,J)>0THENS(11,J)=.050*S(2,J)/SQR(S(10,J))/(1-EXP(-45/S
(10,J)))ELSES(11,J)=0
510 IFS(9,J)THENS(12,J)=.144*S(11,J)*S(10,J)/S(9,J)ELSES(12,J)=0
520 PRINTTAB(0)S(0,J);:FORI=6TO12:PRINTTAB(8*I-41)INT(100*S(I,J)
+.5)/100;:NEXT:PRINT:NEXT:PRINT"MSEC     CM                VOLTS
KW       EV       E12/CC  MSEC":RETURN
530 LS=LEN(CS$):QI=QI+1:IFQI<=LSTHENQQ$=MID$(CS$,QI,1)ELSEQQ$=""
540 FORI=0TO600*VAL(QQ$):NEXT:IFVAL(QQ$)THEN530ELSERETURN
550 CLS:INPUT"MESSAGE";M$:CLS:IFLEN(M$)<192THENMM$=STRING$(31,"
")+M$ELSEMM$=M$
560 FORI=1TOLEN(MM$):PRINT@448,CHR$(23);MID$(MM$,I,31);STRING$(3
1," "):FORJ=1TO50:NEXTJ,I:QQ$=INKEY$:IFQQ$=""THEN560ELSECLS:RETU
RN
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10 POKE16561,252:POKE16562,118:CLEAR:RESTORE:CLS:PRINTTAB(11)"TO
KAPOLE MONITOR PROGRAM / JCS / 28 JAN 83":CLEAR600:DEFINTA-R,T-Z
:DIMX(5,40),XB(5,40),GP(40),AS(127),S(13,10)
20 PRINTTAB(24)"COMPILED VERSION":POKE16526,1:POKE16527,125:FORI
=32001TO32145:READX:POKEI,X:NEXT
30 DATA62,1,50,44,126,62,192,211,223,62,4,211,223,58,1,56,33,2,5
6,182,33,4,56,182,33,16,56,182,33,64,56,182,192,62,255,211,223,2
19,223,203,127,40,222,14,206,33,45,126,22,1,122,211,223,20
40 DATA122,254,6,32,2,22,1,6,6,16,254,62,255,211,223,219,223,119
,122,211,223,35,13,32,230,62,0,50,44,126,42,42,126,1,45,126,30,4
1,22,5,54,0,35,54,0,35,10,119,35,54,0,3,21,32,246,35,29,32
50 DATA235,221,42,42,126,253,42,40,126,14,246,6,2,175,221,126,0,
253,158,0,221,119,0,221,35,253,35,16,241,13,32,235,201:PP=223:OU
TPP,128:FORI=1TO5:OUTPP,I:OUTPP,192:XB(I,0)=INP(PP):FORJ=1TO40:X
B(I,J)=XB(I,0):NEXTJ,I:FS=10:PRINT
60 SC(1)=1:SC(2)=10:SC(3)=200:SC(4)=0.5:SC(5)=2
70 IFBM=0PRINT" ***** TAKE A BASELINE SHOT";
80 SET(125,0):OUTPP,128:OUTPP,6:OUTPP,192:PB=INP(PP):POKE32299,I
NT(VARPTR(X(0,0))/256):POKE32298,VARPTR(X(0,0))-256*INT(VARPTR(X
(0,0))/256):POKE32297,INT(VARPTR(XB(0,0))/256):POKE32296,VARPTR(
XB(0,0))-256*INT(VARPTR(XB(0,0))/256):X=USR(0)
90 OUTPP,128:OUTPP,6:OUTPP,192:PR=INP(PP):SET(127,0):IFPEEK(3230
0)THEN270ELSEBL=X(2,5)+X(2,10)+X(2,15):IFBL>5THENBL=1:GOTO110ELS
EBL=0:BM=1:FORI=1TO2:FORJ=0TO40:XB(I,J)=XB(I,J)+X(I,J):NEXT:NEXT
:FORI=3TO5:OUTPP,I:OUTPP,192:XB(I,0)=INP(PP)
100 FORJ=1TO40:XB(I,J)=XB(I,0):NEXT:NEXT
110 QI=0:IFBL>0THENNS=NS+1
120 CLS:IFBL=0THENPRINT"BASELINE"ELSEPRINT"SHOT NUMBER:";NS:IFAB
S(X(1,40))>9THENBM=0
130 IFABS(X(1,40))>1THENIH=0:FORJ=0TO40:IH=IH+X(5,J):NEXT:IFIHTH
ENIT=0:FORJ=0TO40:IT=IT+X(5,J):X(1,J)=X(1,J)-X(1,40)*IT/IH:NEXT
140 IM=X(1,0):AS=0:FORJ=0TO40:AS=AS+X(1,J):IFX(1,J)>=IMTHENIM=X(
1,J):JM=J
150 IFX(1,J)<0THENAS=AS-X(1,J)
160 NEXT
170 AS=AS*BM*BL:TM=5*JM+1:IFJM>0ANDJM<40THENS0=X(1,JM-1):S2=X(1,
JM+1):IF2*IM<>S0+S2THENTM=TM-2.5*(S2-S0)/(S2-2*IM+S0):IM=IM-0.10
0*(S2-S0)*(S2-S0)/(S2-2*IM+S0)
180 IFIMPRINT"MAX IP =";SC(1)*IM;"KA AT";TM/10;"MSEC"ELSEPRINT"M
AX IP = 0"
190 PRINT"AMP SECONDS =";SC(1)*AS/2:PRINT"PRES =";4*(PR-PB);"E-5
 TORR":PRINT"TIME      IP      JSAT      BT      VPG     IHOOP    DIP
/DT":FORJ=1TO10:J1=FS*J/5:S(0,J)=FS*J/10:PRINTS(0,J);:FORI=1TO5:
XP(I)=((5-I)*X(I,J1)+I*X(I,J1-1))/5
200 X1=BL*X(I,J1)+XB(I,J1):X2=BL*X(I,J1-1)+XB(I,J1-1):IFX1<=0ORX
2<=0PRINTTAB(8*I);"SAT-";:GOTO210ELSEIFX1>=255ORX2>=255PRINTTAB(
8*I);"SAT+";:GOTO210ELSES(I,J)=SC(I)*XP(I):PRINTTAB(8*I);S(I,J);
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10 POKE16414,255:POKE16415,115:CLEAR:PRETOPE:CLS:PRINTTAB(11)"TO
[illegible] MONITOR PROGRAM [illegible]
[illegible] 1979 [illegible]
20 PRINT[illegible]:POKE16526,1:POKE16527,[illegible]:FORI
=[illegible]TO[illegible]:READY:POKEI,Y:NEXT
30 DATA[illegible],1,60,64,124,62,192,211,223,62,4,211,223,58,1,56,33,2,5
4,192,[illegible]
[illegible]
[illegible],229,11
[illegible],11,223,35,[illegible]
1,[illegible],5,54,0,35,54,0,35,10,119,35,54,0,2,21,32,246,35,29,32
50 DATA35,221,[illegible],124,253,42,40,124,14,246,6,2,175,221,126,0,
253,[illegible],0,221,[illegible],201:PE=223:OU
T[illegible]
F[illegible]
60 [illegible]=10:SC(3)=200:SC(4)=0.5:SC(5)=2
70 IFAM=0PRINT" ***** TAKE A BASELINE SHOT";
80 SET(125,0):OUTPP,128:OUTPP,6:OUTPP,192:PP=INP(PP):POKE32299,I
NT(UAPPTP(X(0,0))/256):POKE32298,UAPPT(X(0,0))-256*INT(UAPPTP(X
[illegible]:POKE32296,UAPP[illegible]
[illegible]
90 OUTPP,128:OUTPP,[illegible]:PE=INP(PP):SET(127,0):IFPEEK(3230
0)THEN[illegible]=X(2,5)+X(2,10)+X(2,15):IFBL>5THENBL=1:GOTO110ELS
EBL=0:BM=1:FORI=1TO2:FORJ=0TO40:XP(I,J)=XB(I,J)+X(I,J):NEXT:NEXT
[illegible]:OUTPP,I:OUTPP,192:XP(I,0)=INP(PP)
[illegible]
[illegible]
150 CLS:IFBL=0THEN[illegible]"BASELINE"ELSEPRINT"SHOT NUMBER";[illegible]
[illegible]X(1,40))>9THENBM=0
120 IFABS(X(1,40))>1THENIH=0:FORJ=0TO40:IH=IH+X(5,J):NEXT:IFIHTH
ENTT=0:FORJ=0TO40:TT=TT+X(5,J)*X(1,J)=X(1,J)-X(1,40)*TT/IH:NEXT
[illegible]
[illegible]
150 IFX(1,J)<0THENAS=AS-X(1,J)
160 NEXT
170 AS=AS*BM*BL:TM=5*JM+1:IFJM>0ANDJM<40THENS0=X(1,JM-1):S2=X(1,
JM+1):IFS2*TM>S0+S2THENTM=TM-2.5*(S2-S0)/(S2-2*TM+S0):IM=TM-0.10
[illegible]
180 IFIM[illegible]"MAX[illegible]AT[illegible]TM/10;"MSEC"ELSEPRINT"M
AX [illegible]
190 PRINT"AMP SECONDS =";SC(1)*AS/2:PRINT"PRES =";4*(PR-PE);"E-5
TORR":PRINT"TIME      IP      JSAT      ET      VPG      IHOOP      DIP
":[illegible]
[illegible]
200 [illegible]=BL*X(I,[illegible]):IFX1<=00[illegible]
[illegible]:GOTO210ELSEIFX1>=250RX2>=255PRINTTAB(
8*I);"SAT+";:GOTO210ELSES(I,J)=SC(I)*XP(I):PRINTTAB(8*I);S(I,J);
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210 NEXT:J2=J1+1:IFJ2=41THENJ2=40
220 J0=J1-2:IFJ0<0THENJ0=0
230 S(13,J)=SC(1)*(8*X(1,J2)+2*X(1,J1)-8*X(1,J1-1)-2*X(1,J0))/10
:PRINTTAB(48)S(13,J):NEXT:IFBL=0THEN260ELSENT=127:IFNS<128THENNT
=NS
240 IFNS>127FORI=1TO127:AS(I-1)=AS(I):NEXT
250 AS(NT)=AS
260 IFCS$<>""THENGOSUB530:IFQQ$<>""THEN280
270 QQ$=INKEY$:IFQQ$=""THEN70
280 IFQQ$="0"THENPRINT" ***** COMPUTER ON STANDBY---PRESS 1 TO C
ONTINUE TAKING DATA";
290 IFQQ$="0"THENIFINKEY$<>"1"THEN290ELSECLS:GOTO70ELSEIFQQ$="1"
THEN70ELSECLS:PRINTAS/2;"AS";:IFQQ$="I"THENPRINT,"PLASMA CURRENT
 VS TIME";:IG=1:GOTO350ELSEIFQQ$="J"THENPRINT,"ION SATURATION CU
RRENT VS TIME";:IG=2:GOTO350
300 IFQQ$="B"THENPRINT,"TOROIDAL FIELD VS TIME";:IG=3:GOTO350ELS
EIFQQ$="V"THENPRINT,"POLOIDAL GAP VOLTAGE VS TIME";:IG=4:GOTO350
ELSEIFQQ$="H"THENPRINT,"HOOP CURRENT VS TIME";:IG=5:GOTO350ELSEI
FQQ$="C"THENCLS:GOSUB400:GOTO120ELSEIFQQ$="R"THEN120
310 IFQQ$="S"THENCLS:PRINT"CURRENT SHOT NUMBER =";NS:INPUT"NEW S
HOT NUMBER";NS:GOTO70ELSEIFQQ$="L"THENGOSUB410:GOTO260ELSEIFQQ$=
"E"THENGOSUB430:GOTO280ELSEIFQQ$="A"THENGOSUB450:GOTO260ELSEIFQQ
$="M"THENGOSUB550:GOTO280ELSECLS:PRINT"COMMANDS:";
320 PRINT,"0: STANDBY":PRINT,"1: CONTINUE":PRINT,"I: GRAPH PLASM
A CURRENT":PRINT,"J: GRAPH ION SATURATION CURRENT":PRINT,"B: GRA
PH TOROIDAL FIELD":PRINT,"V: GRAPH POLOIDAL GAP VOLTAGE":PRINT,"
H: GRAPH HOOP CURRENT":PRINT,"C: CHANGE TIME SCALE"
330 PRINT,"L: GRAPH A-S FOR LAST";NT;"SHOTS":PRINT,"R: RETURN TO
 INITIAL TABLE":PRINT,"S: CHANGE SHOT NUMBER COUNTER":PRINT,"E:
EXAMINE ANALOG INPUTS":PRINT,"A: DISPLAY DERIVED DATA":PRINT,"M:
 PRINT MESSAGE ON SCREEN"
340 PRINT,"P: PROGRAM COMMAND SEQUENCE":IFQQ$="P"THENCS$="":INPU
T"WHAT COMMAND SEQUENCE";CS$:GOTO70ELSE260
350 IFBL=1PRINTTAB(52);"SHOT";NS;ELSEPRINTTAB(52);"BASELINE";
360 Y1=0:Y2=0:FORJ=0TO40:GR(J)=X(IG,J):IFGR(J)>Y2THENY2=GR(J)
370 IFGR(J)<Y1THENY1=GR(J)
380 NEXT:IFY2=Y1PRINT:PRINT:PRINT" ***** NO DATA TO GRAPH":GOTO2
60ELSESY=34/(Y2-Y1):FORJ=0TO40:SET(3*J+5,44.5-SY*(GR(J)-Y1)):NEX
T:Y=44.5+SY*Y1:FORI=3TO125:SET(I,Y):NEXT:FORY=15553TO16257STEP64
:POKEY,170:NEXT
390 PRINT@961,"0      2      4      6      8     MSEC    12     14     1
6     18     20";:PRINT@80,"MAXIMUM VALUE:";SC(IG)*Y2;:GOTO260
400 FS=10:INPUT"HOW MANY MSEC FULL SCALE (DEFAULTS TO 10)";FS:IF
FS>20PRINT"MAXIMUM IS 20 MSEC":GOTO400ELSEIFFS<5PRINT"MINIMUM IS
 5 MSEC":GOTO400ELSECLS:RETURN
```

```
410 PRINT,"AMP SECONDS FOR LAST";NT;"SHOTS":Y2=0:FORI=0TONT:IFAS
(I)>Y2THENY2=AS(I)
420 NEXT:IFY2=0PRINT:PRINT" ***** NO DATA TO GRAPH":RETURNELSEPR
INT@960,STRING$(63,CHR$(176));:POKE16363,176:FORI=1TONT:SET(I,47
-41*AS(I)/Y2):NEXT:FORY=6TO46:SET(0,Y):NEXT:PRINT@80,"MAXIMUM VA
LUE";Y2*SC(1)/2;:RETURN
430 CLS:PRINT,"ANALOG INPUT FOR EACH CHANNEL":PRINT:OUTPP,128:FO
RI=0TO15:PRINTUSING"####";I;:NEXT:PRINT@396,"PRESS ANY KEY TO RE
SUME TOKAPOLE DATA"
440 PRINT@192,"";:FORI=0TO15:OUTPP,I:OUTPP,192:PRINTUSING"####";
INP(PP);:NEXT:QQ$=INKEY$:IFQQ$=""THEN440ELSERETURN
450 PRINT,"ADDITIONAL DERIVED DATA";:IFBL=1PRINTTAB(52);"SHOT";N
SELSEPRINTTAB(52);"BASELINE"
460 PRINT:PRINT"TIME     A        <Q>      VLOOP    POH      TE
<N>      TAU":FORJ=1TO10:IFS(5,J)THENS(6,J)=17.4*(ABS(S(1,J)/S(5,
J)))[.25ELSES(6,J)=0
470 IFS(1,J)THENS(7,J)=1E-4*S(6,J)*S(6,J)*S(3,J)/S(1,J)ELSES(7,J
)=0
480 S(8,J)=.5*(1+S(0,J)/75)*S(4,J)+.0045*(1-S(0,J)/37)*S(5,J):IF
S(6,J)THENS(8,J)=S(8,J)-2.3*S(13,J)/SQR(S(6,J))
490 S(9,J)=S(8,J)*S(1,J):IFS(8,J)*S(6,J)THENS(10,J)=376*(ABS(S(1
,J)/S(8,J)/S(6,J)/S(6,J)))[.6666667ELSES(10,J)=0
500 IFS(10,J)>0THENS(11,J)=.050*S(2,J)/SQR(S(10,J))/(1-EXP(-45/S
(10,J)))ELSES(11,J)=0
510 IFS(9,J)THENS(12,J)=.144*S(11,J)*S(10,J)/S(9,J)ELSES(12,J)=0
520 PRINTTAB(0)S(0,J);:FORI=6TO12:PRINTTAB(8*I-41)INT(100*S(I,J)
+.5)/100;:NEXT:PRINT:NEXT:PRINT"MSEC     CM                VOLTS
KW       EV       E12/CC  MSEC":RETURN
530 LS=LEN(CS$):QI=QI+1:IFQI<=LSTHENQQ$=MID$(CS$,QI,1)ELSEQQ$=""
540 FORI=0TO4200*VAL(QQ$):NEXT:IFVAL(QQ$)THEN530ELSERETURN
550 CLS:INPUT"MESSAGE";M$:CLS:IFLEN(M$)<192THENMM$=STRING$(31,"
")+M$ELSEMM$=M$
560 FORI=1TOLEN(MM$):PRINT@448,CHR$(23);MID$(MM$,I,31);STRING$(3
1," "):FORJ=1TO350:NEXTJ,I:QQ$=INKEY$:IFQQ$=""THEN560ELSECLS:RET
URN
```

TOKAPOKE MONITOR -- AIM16 ROUTINE

APPENDIX B

AIM16 Machine Language Routine

```
7D01                      ORG     32001
7D01 3E01                 LD      A,1
7D03 322C7E               LD      (32300),A;STORE 1 IN 32300
7D06 3EC0                 LD      A,192
7D08 D3DF                 OUT     (223),A ;INITIALIZE SYSTEM
7D0A 3E00         NOSIG   LD      A,0
7D0C D3DF                 OUT     (223),A ;SELECT TRIGGER CHANNNEL
7D0E 3A0138               LD      A,(3801H);STROBE KEYBOARD
7D11 210238               LD      HL,3802H
7D14 B6                   OR      (HL)
7D15 210438               LD      HL,3804H
7D18 B6                   OR      (HL)
7D19 211038               LD      HL,3810H
7D1C B6                   OR      (HL)
7D1D 214038               LD      HL,3840H
7D20 B6                   OR      (HL)    ;SET FLAG IF KEY PRESSED
7D21 C0                   RET     NZ      ;RETURN IF KEY PRESSED
7D22 3EFF                 LD      A,255
7D24 D3DF                 OUT     (223),A ;ENABLE TRIGGER
7D26 DBDF                 IN      A,(223) ;READ TRIGGER SIGNAL
7D28 CB7F                 BIT     7,A     ;TEST HIGH ORDER BIT
7D2A 28DE                 JR      Z,NOSIG ;RETURN IF TRIGGER < 128
7D2C 0ECE                 LD      C,206   ;NUMBER OF POINTS
7D2E 212D7E               LD      HL,32301;BEGINNING MEMORY ADDRESS
7D31 1601                 LD      D,1
7D33 7A                   LD      A,D
7D34 D3DF                 OUT     (223),A ;SELECT CHANNEL 1
7D36 14           CONT    INC     D       ;INCREMENT CHANNEL NUMBER
7D37 7A                   LD      A,D
7D38 FE06                 CP      6       ;HIGHEST CHANNEL # EXCEDED?
7D3A 2002                 JR      NZ,MORE ;GOTO MORE IF D<>6
7D3C 1601                 LD      D,1     ;RESET TO FIRST CHANNEL
7D3E 0606         MORE    LD      B,6     ;DELAY BETWEEN POINTS
7D40 10FE         LOOP    DJNZ    LOOP    ;LOOP UNTIL B=0
7D42 3EFF                 LD      A,255
7D44 D3DF                 OUT     (223),A ;ENABLE DATA
7D46 DBDF                 IN      A,(223) ;READ DATA
7D48 77                   LD      (HL),A  ;STORE DATA
7D49 7A                   LD      A,D
7D4A D3DF                 OUT     (223),A ;SELECT CHANNEL
7D4C 23                   INC     HL      ;INCREMENT MEMORY LOCATION
7D4D 0D                   DEC     C       ;DECREASE C BY 1
7D4E 20E6                 JR      NZ,CONT ;CONTINUE IF MORE DATA
7D50 3E00                 LD      A,0
7D52 322C7E               LD      (32300),A;STORE 0 IN 32300
7D55 2A2A7E               LD      HL,(32298);X BLOCK ADDRESS
7D58 012D7E               LD      BC,32301;DATA BLOCK ADDRESS
7D5B 1E29                 LD      E,41    ;# OF TIMES
7D5D 1605         JLOOP   LD      D,5     ;# OF CHANNELS
7D5F 3600                 LD      (HL),0
7D61 23                   INC     HL
7D62 3600                 LD      (HL),0
7D64 23           ILOOP   INC     HL
7D65 0A                   LD      A,(BC)  ;MOVE DATA
7D66 77                   LD      (HL),A
7D67 23                   INC     HL
7D68 3600                 LD      (HL),0
7D6A 03                   INC     BC      ;NEXT DATA POINT
7D6B 15                   DEC     D
7D6C 20F6                 JR      NZ,ILOOP;GOTO ILOOP IF D>0
7D6E 23                   INC     HL
7D6F 1D                   DEC     E
```

```
7D01             00100          ORG   32001
7D01  3E01       00110          LD    A,1
7D03  322C7E     00120          LD    (32300),A;STORE 1 IN 32300
7D06  3EC0       00130          LD    A,192
7D08  D3DF       00140          OUT   (223),A ;INITIALIZE SYSTEM
7D0A  3E00       00150 NOSIG    LD    A,0
7D0C  D3DF       00160          OUT   (223),A ;SELECT TRIGGER CHANNEL
7D0E  3A0138     00170          LD    A,(3801H);STROBE KEYBOARD
7D11  210238     00180          LD    HL,3802H
7D14  B6         00190          OR    (HL)
7D15  210438     00200          LD    HL,3804H
7D18  B6         00210          OR    (HL)
7D19  211038     00220          LD    HL,3810H
7D1C  B6         00230          OR    (HL)
7D1D  214038     00240          LD    HL,3840H
7D20  B6         00250          OR    (HL)      ;SET FLAG IF KEY PRESSED
7D21  C0         00260          RET   NZ        ;RETURN IF KEY PRESSED
7D22  3EFF       00270          LD    A,255
7D24  D3DF       00280          OUT   (223),A ;ENABLE TRIGGER
7D26  DBDF       00290          IN    A,(223) ;READ TRIGGER SIGNAL
7D28  CB7F       00300          BIT   7,A       ;TEST HIGH ORDER BIT
7D2A  28DE       00310          JR    Z,NOSIG ;RETURN IF TRIGGER < 128
7D2C  0ECC       00320          LD    C,204     ;NUMBER OF POINTS
7D2E  212D7E     00330          LD    HL,32301;BEGINNING MEMORY ADDRESS
7D31  1601       00340          LD    D,1
7D33  7A         00350          LD    A,D
7D34  D3DE       00360          OUT   (222),A ;SELECT CHANNEL 1
7D36  14         00370 CONT     INC   D         ;INCREMENT CHANNEL NUMBER
7D37  7A         00380          LD    A,D
7D38  FE06       00390          CP    6         ;HIGHEST CHANNEL # EXCEEDED?
7D3A  2002       00400          JR    NZ,MORE ;GOTO MORE IF D<>6
7D3C  1601       00410          LD    D,1       ;RESET TO FIRST CHANNEL
7D3E  0606       00420 MORE     LD    B,6       ;DELAY BETWEEN POINTS
7D40  10FE       00430 LOOP     DJNZ  LOOP      ;LOOP UNTIL B=0
7D42  3EFF       00440          LD    A,255
7D44  D3DF       00450          OUT   (223),A ;ENABLE DATA
7D46  DBDF       00460          IN    A,(223) ;READ DATA
7D48  77         00470          LD    (HL),A ;STORE DATA
7D49  7A         00480          LD    A,D
7D4A  D3DE       00490          OUT   (222),A ;SELECT CHANNEL
7D4C  23         00500          INC   HL        ;INCREMENT MEMORY LOCATION
7D4D  0D         00510          DEC   C         ;DECREASE C BY 1
7D4E  20E6       00520          JR    NZ,CONT ;CONTINUE IF MORE DATA
7D50  3E00       00530          LD    A,0
7D52  322C7E     00540          LD    (32300),A;STORE 0 IN 32300
7D55  2A2A7E     00550          LD    HL,(32298);X BLOCK ADDRESS
7D58  012D7F     00560          LD    BC,32557;DATA BLOCK ADDRESS
7D5B  1E29       00570          LD    E,41      ;# OF TIMES
7D5D  1605       00580 JLOOP    LD    D,5       ;# OF CHANNELS
7D5F  3600       00590          LD    (HL),0
7D61  23         00600          INC   HL
7D62  3600       00610          LD    (HL),0
7D64  23         00620 TLOOP    INC   HL
7D65  0A         00630          LD    A,(BC)    ;MOVE DATA
7D66  77         00640          LD    (HL),A
7D67  23         00650          INC   HL
7D68  3600       00660          LD    (HL),0
7D6A  03         00670          INC   BC        ;NEXT DATA POINT
7D6B  15         00680          DEC   D
7D6C  20F6       00690          JR    NZ,TLOOP;GOTO TLOOP IF D>0
7D6E  23         00700          INC   HL
```

```
7D70 20EB      00720            JR     NZ,JLOOP;GOTO JLOOP IF E>0
7D72 DD2A2A7E  00730            LD     IX,(32298);START X ADDRESS
7D76 FD2A287E  00740            LD     IY,(32296);START XB ADDRESS
7D7A 0EF6      00750            LD     C,246    ;# OF X VALUES
7D7C 0602      00760 BLINE      LD     B,2      ;# OF BYTES/VALUE
7D7E AF        00770            XOR    A        ;RESET CARRRY
7D7F DD7E00    00780 BLOOP      LD     A,(IX)   ;GET X
7D82 FD9E00    00790            SBC    A,(IY)   ;SUBTRACT XB
7D85 DD7700    00800            LD     (IX),A   ;STORE RESULT
7D88 DD23      00810            INC    IX       ;PNT TO NEXT HIGHER X
7D8A FD23      00820            INC    IY       ;PNT TO NEXT HIGHER XB
7D8C 10F1      00830            DJNZ   BLOOP    ;GOTO BLOOP IF MORE
7D8E 0D        00840            DEC    C        ;NEXT VALUE
7D8F 20EB      00850            JR     NZ,BLINE;GOTO BLINE IF MORE
7D91 C9        00860            RET
7D01           00870            END    32001
00000 TOTAL ERRORS
BLOOP    7D7F
BLINE    7D7C
ILOOP    7D64
JLOOP    7D5D
LOOP     7D40
MORE     7D3E
CONT     7D36
NOSIG    7D0A
```

APPENDIX C

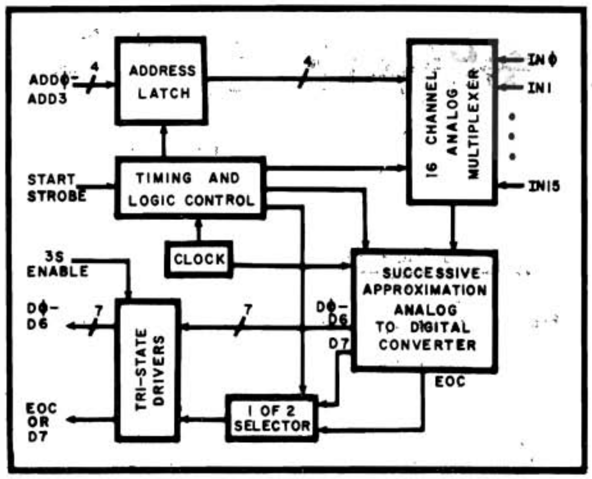
AIM16 Data Sheet Excerpts

AIM16 DATA SHEET

ANALOG PORT - 16 Channels - Specifications for each channel -
- Vina - analog input voltage conversion range: 0 to 5.12 volts
- Vin (max) - absolute maximum input voltage: –.3 to plus 5.4 volts
- Iina (max) - maximum analog input current: 2 microamps
- Vref - - reference voltage: 5.120 volts plus or minus .01 volts

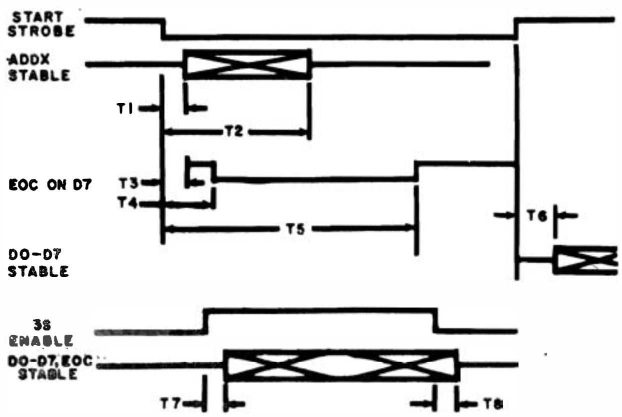
Conversion data -
- Tc - conversion time, per channel: 100 microsec max, 80 typ
- counts per channel: 256
- output range (each channel): 00-FF (hex)
0-255 (decimal)
000-377 (octal)
0000 0000-1111 1111 (binary)
- Absolute maximum error: .7 %
- Typical maximum error: .5 %

Physical Dimensions - 5 1/4 x 6 1/4 x 2 1/4.



AIM16 BLOCK DIAGRAM

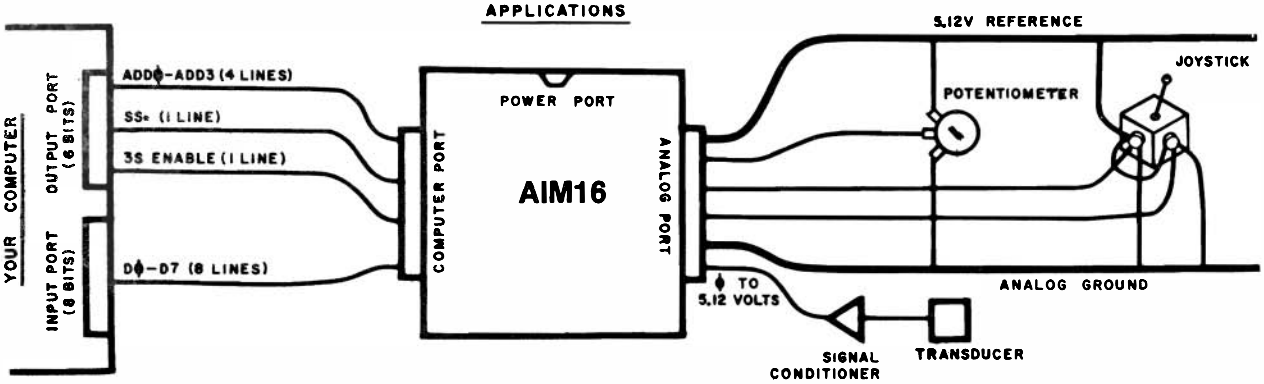
AIM 16 TIMING



AIM 16 Timing Diagram

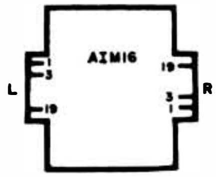
SYMBOL	CHARACTERISTIC	MIN	MAX	UNIT
T1	ADDX must become stable		1	microsec
T2	ADDX must remain stable	.3		microsec
T3	EOC becomes stable on D7		60	nanosec
T4	EOC is reset		100	nanosec
T5	EOC goes high indicating conversion complete		100	microsec
T6	DO-D7 becomes stable after SS goes high		290	nanosec
T7	DO-D7 or EOC becomes stable after 3S enable goes high		290	nanosec
T8	DO-D7 or EOC enter tri-state after 3S enable goes low		290	nanosec

APPLICATIONS



PORT PIN FUNCTIONS

TOP VIEW



Computer Port (Connector L)

Top Pin No.	Top Function	Bottom Pin No.	Bottom Function
1	GND	2	GND
3	DO (LSB)	4	D4
5	D1	6	D5
7	D2	8	D6
9	D3	10	D7 (MSB), EOC
11	plus 12v	12	plus 12v
13		14	
15	3s enable	16	Start Strobe (SS*)
17	Add 0	18	Add 2
19	Add 1	20	Add 3

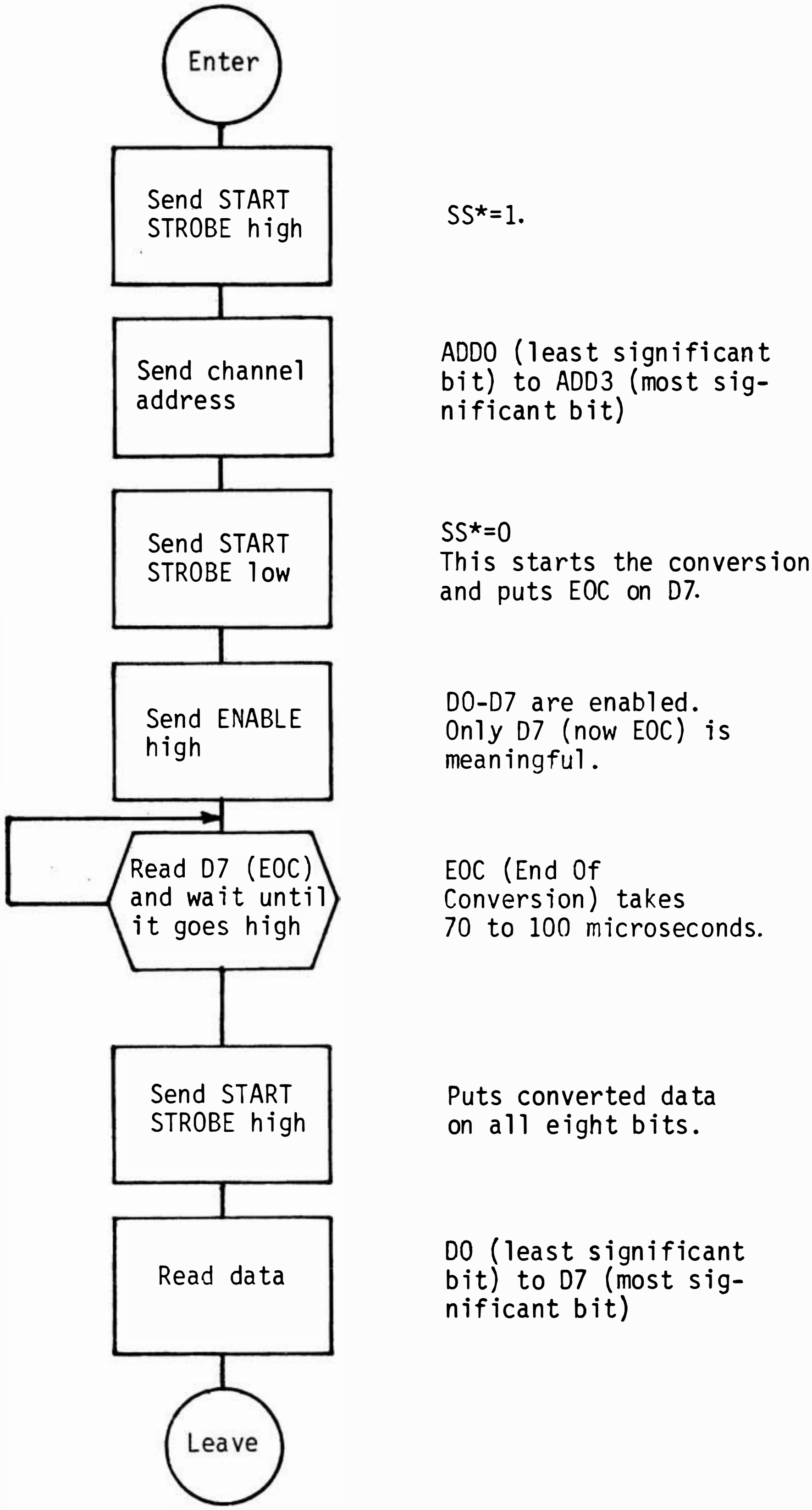
Analog Port (Connector R)

Top Pin No.	Top Function	Bottom Pin No.	Bottom Function
1	GND	2	5.120 VREF
3	INO	4	IN8
5	IN1	6	IN9
7	IN2	8	IN10
9	IN3	10	IN11
11	IN4	12	IN12
13	IN5	14	IN13
15	IN6	16	IN14
17	IN7	18	IN15
19	5.120 VREF	20	GND

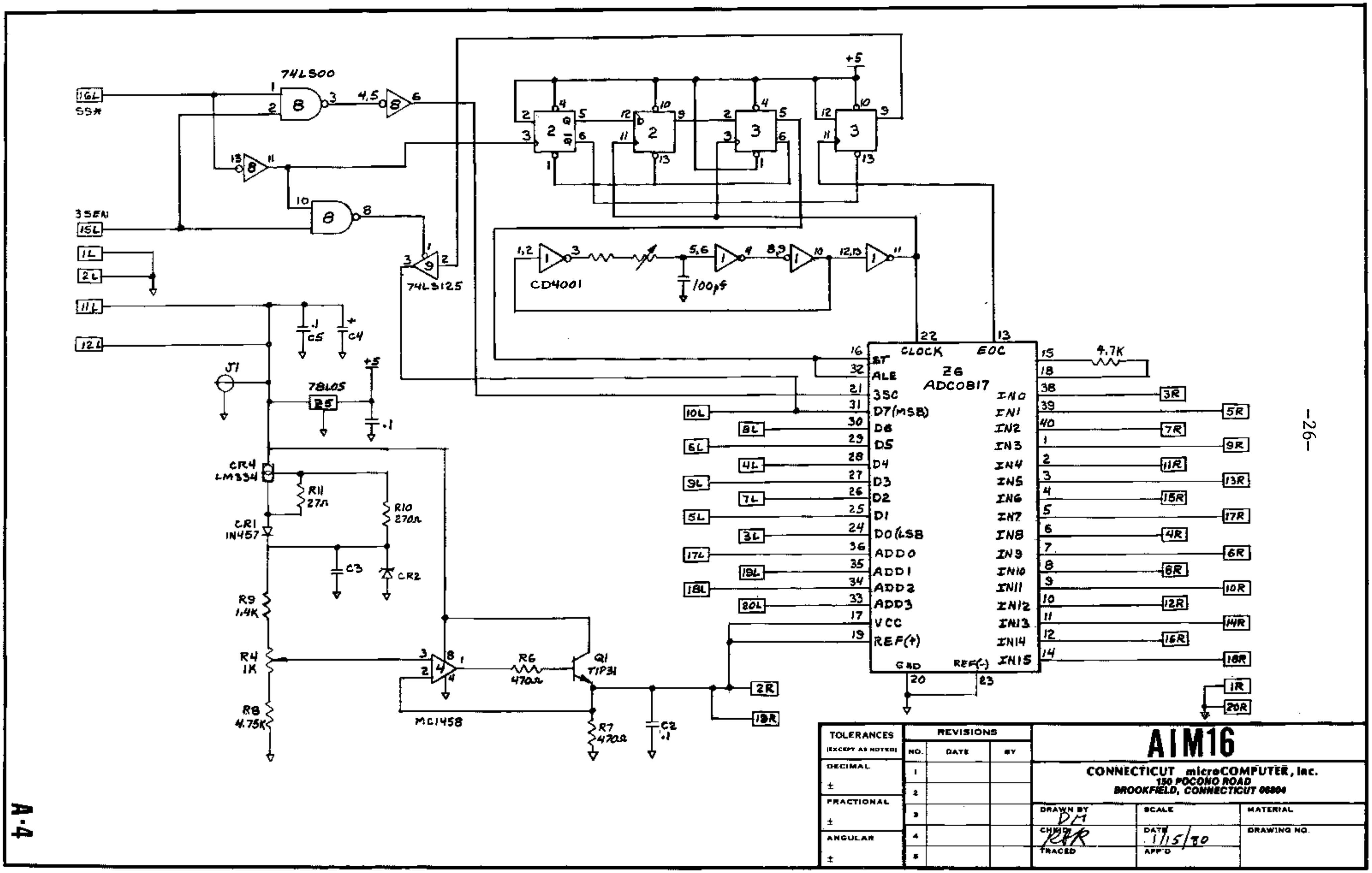
COMPUTER PORT PIN FUNCTIONS

PIN	NAME	DIRECTION WITH RESPECT TO THE AIM16	FUNCTION	Loading or Drive
1	GND		Signal ground - tied to analog ground	
2	GND			
3	DP (LSB)	out	Digital output for analog inputs. DO is the least significant bit. D7 is the most significant bit. A lo voltage is a logical 0. A hi voltage is a logical 1.	1 TTL Load
5	D1	out		
7	D2	out		
9	D3	out		
4	D4	out	D7 (when SS* pin 16, is lo) is the end of conversion signal, EOC, When EOC is lo, the AIM16 is busy. When EOC is hi, the AIM16 has finished a conversion and the converted valve may be read.	
6	D5	out		
8	D6	out		
10	D7 (MSB)	out		
11	plus 12 volts	in or out	12 volts DC power from a DAM SYSTEMS power pack or other source. If a DAM SYSTEMS power pack is used at the POWER PORT then this voltage is available to supply other DAM SYSTEMS modules. If a DAM SYSTEMS power pack is not used at the POWER PORT then a positive 12 volts (well-filtered DC) must be supplied at these pins.	60 ma in
12	plus 12 volts	in or out		
			!!CAUTION!! DO NOT USE A DAM SYSTEMS POWER PACK AT THE POWER PORT WHILE POWER IS APPLIED TO THESE PINS.	
13	not used			
14	not used			
15	3S ENABLE	in	Three state enable, A lo voltage disables the outputs D0-D7. a hi voltage enables D0-D7.	1 LSTTL Load
16	SS*	in	Start Strobe not. A hi to lo transition resets the AIM 16 and starts the comversion of the analog input selected by the digital inputs on pins 17 to 20. While SS* remains lo, and the 3S ENABLE is hi, the EOC (End of Conversion) signal appears on pin 10. When is SS* is hi, and the 3S ENABLE is hi, D7 is on pin 10 and D0 to D6 are on pins 3 to 9. respectively.	1 LSTTL Load
17	ADD0	in	Address lines - select the analog input to be converted according to the following table:	Vin(hi)-3.5 volts min Vin(lo)-1.5 volts max
19	ADD1	in		
18	ADD2	in		
20	ADD3	in		

Analog input	ADD3	ADD2	ADD 1	ADD 0
IN0	lo	lo	lo	lo
IN1	lo	lo	lo	hi
IN2	lo	lo	hi	lo
IN3	lo	lo	hi	hi
IN4	lo	hi	lo	lo
IN5	lo	hi	lo	hi
IN6	lo	hi	hi	lo
IN7	lo	hi	hi	hi
IN8	hi	lo	lo	lo
IN9	hi	lo	lo	hi
IN10	hi	lo	hi	lo
IN11	hi	lo	hi	hi
IN12	hi	hi	lo	lo
IN13	hi	hi	lo	hi
IN14	hi	hi	hi	lo
IN15	hi	hi	hi	hi

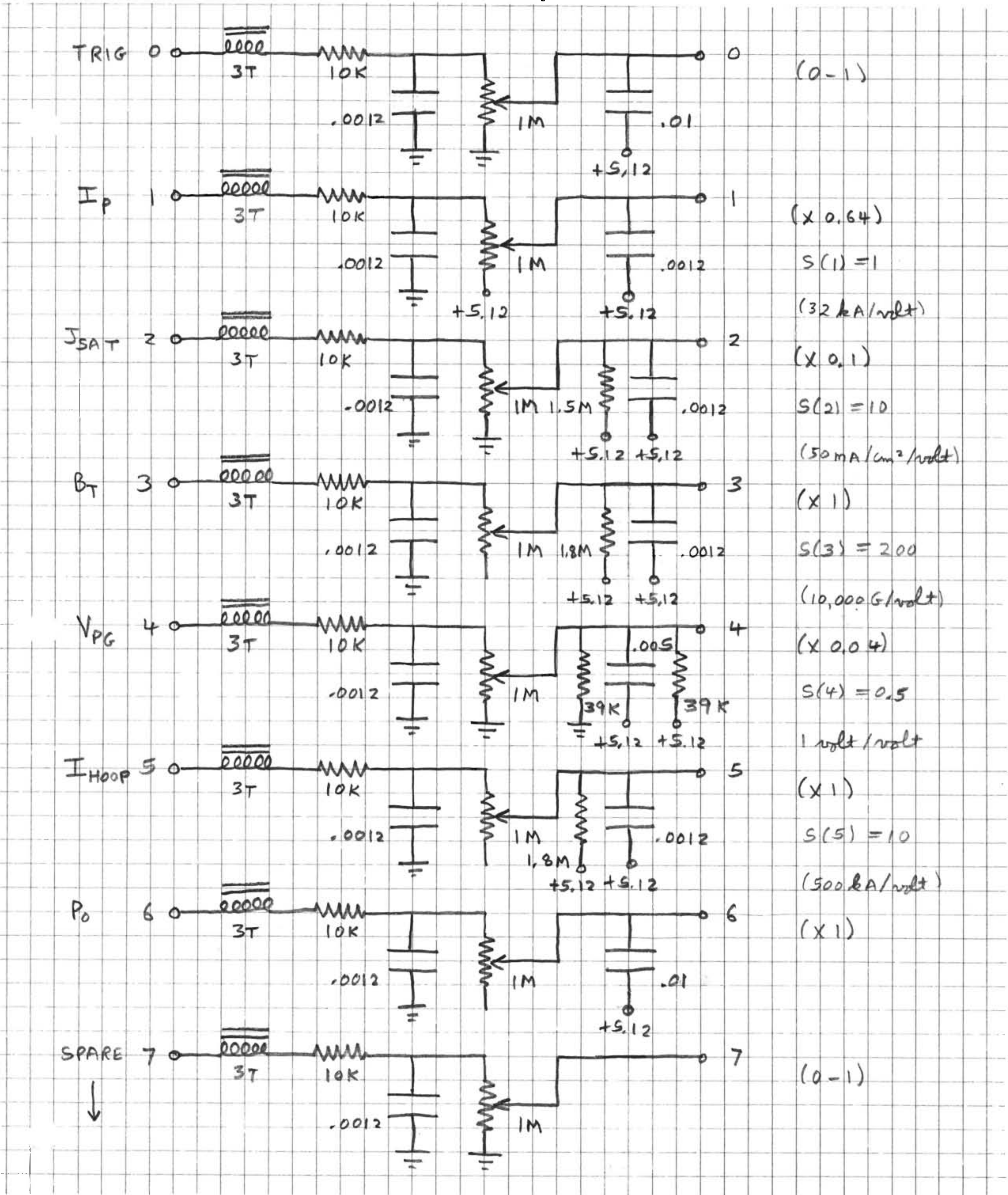


Flowchart for reading one channel of data from the AIM16.


74LS00
16L
SS#
3SEN
15L
1L
2L
11L
12L
C5
C4
J1
78L05
25
CR4
LM334
R11
27Ω
R10
270Ω
CR1
IN457
C3
CR2
R9
1.4K
R4
1K
R8
4.75K
MC1458
R6
470Ω
Q1
TIP31
R7
470Ω
C2
.1
2R
19R
74LS125
+5
CD4001
100pf
16
32
21
31
30
29
28
27
26
25
24
36
35
34
33
17
19
CLOCK
EOC
Z6
ADC0817
ST
ALE
3SC
D7(MSB)
D6
D5
D4
D3
D2
D1
D0(LSB)
ADD0
ADD1
ADD2
ADD3
VCC
REF(+)
GND
REF(-)
IN0
IN1
IN2
IN3
IN4
IN5
IN6
IN7
IN8
IN9
IN10
IN11
IN12
IN13
IN14
IN15
4.7K
10L
8L
6L
4L
9L
7L
5L
3L
17L
13L
18L
20L
3R
5R
7R
9R
11R
13R
15R
17R
4R
6R
8R
10R
12R
14R
16R
18R
1R
20R
TOLERANCES
(EXCEPT AS NOTED)
DECIMAL
±
FRACTIONAL
±
ANGULAR
±
REVISIONS
NO.
DATE
BY
AIM16
CONNECTICUT microCOMPUTER, Inc.
150 POCONO ROAD
BROOKFIELD, CONNECTICUT 06804
DRAWN BY
DM
CHKD
RAR
TRACED
SCALE
DATE
1/15/80
APP'D
MATERIAL
DRAWING NO.
A-4

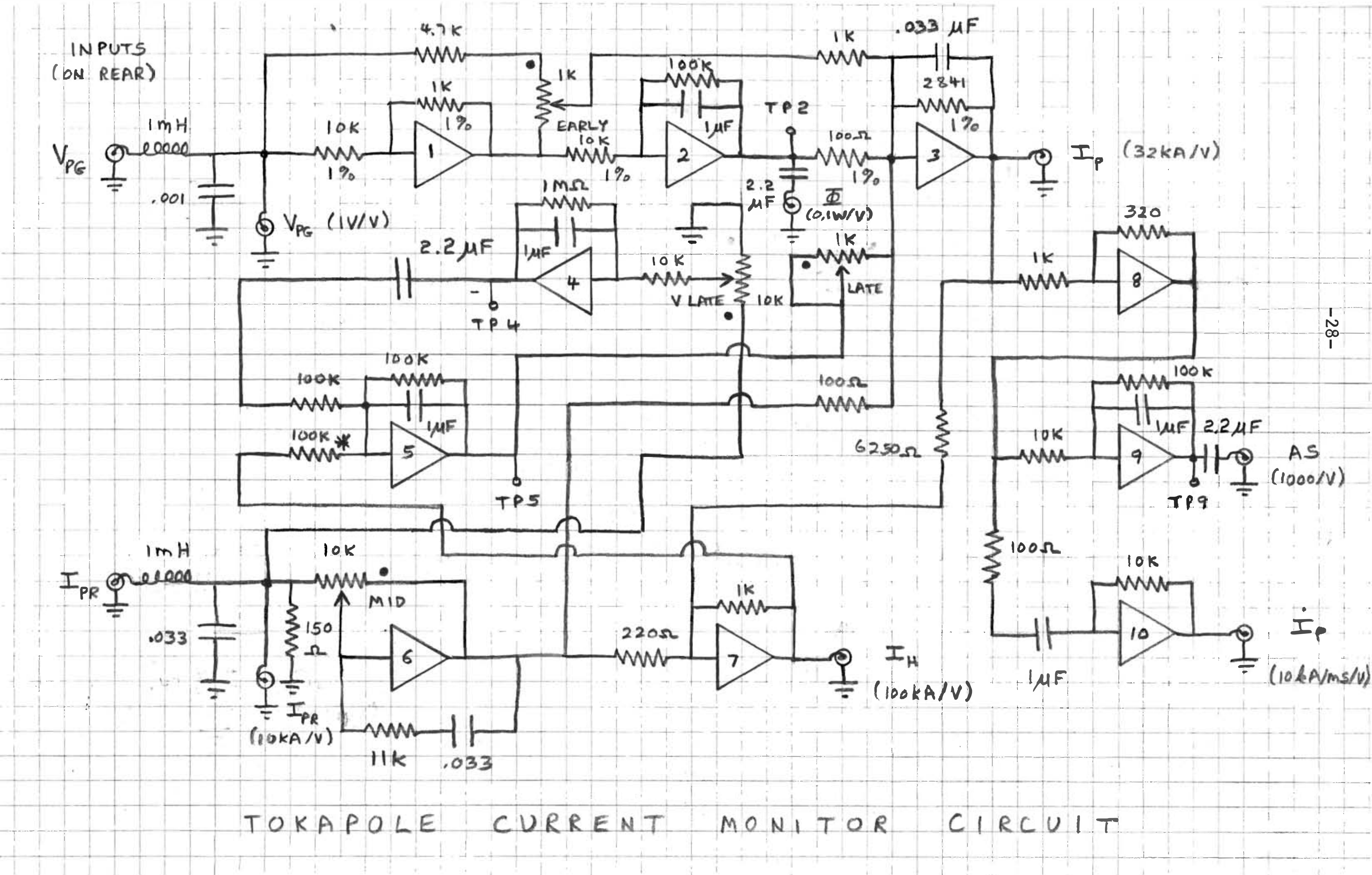
APPENDIX D

Schematic of A-to-D Input Circuit



APPENDIX E

Schematic of Tokapole Current Monitor Circuit

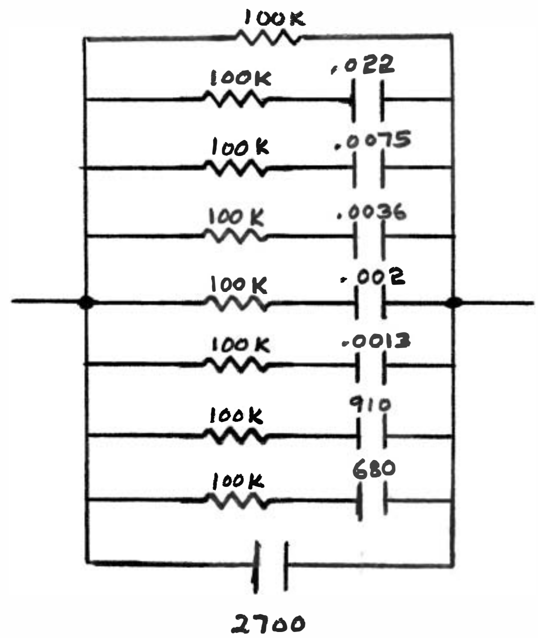


APPENDIX F

Schematic of Circuit to Model Hoop Resistance

$$Z = Z_{DC}\left[1 + \sum_{i=1}^{\infty} e^{-t/\tau_i}\right]$$

$R_i = 100\ k\Omega$



i	τ_i(msec)	C_i(pF)
1	2.43	24300
2	.73	7300
3	.35	3500
4	.2	2000
5	.132	1320
6	.0979	929
7	.0690	690
8	.0533	533
9	.0424	424
10	.0345	345
11	.0287	287
12	.0242	242
13	.0207	207
14	.0189	189
15	.0156	156
16	.0137	137
17	.0122	122
18	.0109	109
19	.0098	98
10	.0088	88
$\sum_{i=1}^{\infty} \tau_i =$	4.27	42700

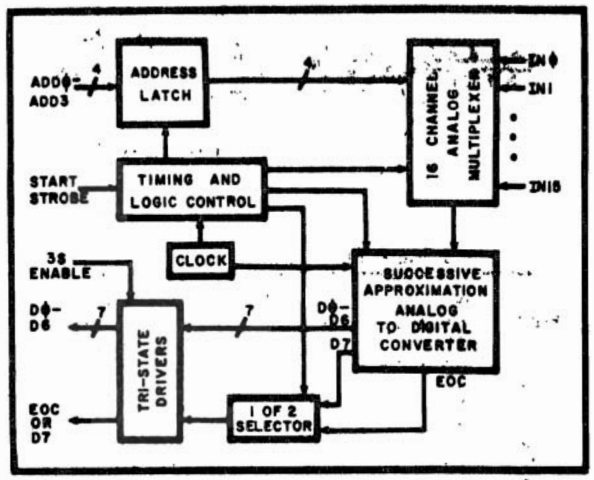
AIM16 Data Sheet Excerpts

AIM16 DATA SHEET

ANALOG PORT - 16 Channels - Specifications for each channel -
Vina - analog input voltage conversion range: 0 to 5.12 volts
Vin (max) - absolute maximum input voltage: −.3 to plus 5.4 volts
Iina (max) - maximum analog input current: 2 microamps
Vref - - reference voltage: 5.120 volts plus or minus .01 volts

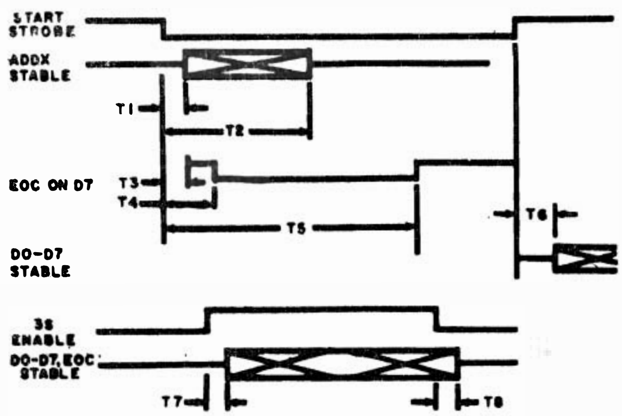
Conversion data -
Tc - conversion time, per channel: 100 microsec max, 80 typ
counts per channel: 256
output range (each channel): 00-FF (hex)
0-255 (decimal)
000-377 (octal)
0000 0000-1111 1111 (binary)
Absolute maximum error: .7%
Typical maximum error: .5%

Physical Dimensions - 5 1/4 x 6 1/4 x 2 1/4.



AIM16 BLOCK DIAGRAM

AIM 16 TIMING



AIM 16 Timing Diagram

SYMBOL	CHARACTERISTIC	MIN	MAX	UNIT
T1	ADDX must become stable		1	microsec
T2	ADDX must remain stable	.3		microsec
T3	EOC becomes stable on D7		60	nanosec
T4	EOC is reset		100	nanosec
T5	EOC goes high indicating conversion complete		100	microsec
T6	DO-D7 becomes stable after SS goes high		290	nanosec
T7	DO-D7 or EOC becomes stable after 3S enable goes high		290	nanosec
T8	DO-D7 or EOC enter tri-state after 3S enable goes low		290	nanosec

APPLICATIONS