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IS-4033

CROSSED-MOLECULAR BEAM APPARATUS TIME-OF-FLIGHT COMPUTER INTERFACE

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Date Transmitted: January 1977

PREPARED FOR THE U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION UNDER CONTRACT W-7405-eng-82

DISCLAIMER

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ABSTRACT

A variety of the gas phase reactions of barium and tin atoms have been studied using a crossed molecular beams machine with a universal quadrapole mass filter based detection system incorporating a time-of-flight (TOF) spectrometer for velocity analysis. Center-of-mass (CM) reactive product recoil angle and relative recoil energy distributions have been measured for the following reactions: 1) Ba + N_2O -- BaO + N_2 2) Ba + CO_2 -- BaO + CO 3) Ba + O_2 -- BaO + O 4) Sn + Cl_2 -- SnCl + Cl 5) Sn + CH_3I -- SnI + CH_3 6) Sn + n-C_3H_7I -- SnI + C_3H_7I and 7) Sn + CCl_4 -- SnCl + CCl_3. At relative collision energies below 15kJmole^{-1}, the BaO product of reaction 1) is seen to be sharply backwards scattered with only 10 to 20% of the total available energy in product recoil energy. These results are consistant with near 100% efficiency for production of electronically excited BaO. Evidence of a significant effect of N_2O vibrational energy on the total reactive cross section is presented. Reaction 2), at collision energies as high as 31kJmole^{-1}, and reaction 3), at a collision energy of 13kJmole^{-1}, both seem to proceed via a long-lived complex, and their product recoil energy distributions are resonably well fit by the transition state theory of Herschbach et. al. No evidence of a CO_2 internal energy effect on the total reactive cross section for reaction 2) was found. The SnCl product

of reaction 4) was predominately forward scattered with low product recoil energy; the SnI product of reactions 5) and 6) were sharply backwards scattered with relatively high recoil energies; the SnCl product of reaction 7) was sideways scattered. Thus the reactions of tin atoms studied here are very similar to the corresponding alkali and alkaline earth metal atom reactions. A minicomputer interface for collection and display of TOF spectrums and product angular distributions was built using a Digital Equipment Corp. PDP8/e computer and is described here in detail.

INTRODUCTION

This report describes a time-of-flight spectrometer system for a crossed molecular beams machine utilizing a PDP8/e computer for on-line collection and display of data. Detailed descriptions, circuit diagrams, and program listings are presented. This report constitutes a chapter from the authors thesis, and is printed as an IS report so that the system, remaining at ISU, may be understood. The abstract lists those chemical reactions that have been studied with this system while at ISU. Further detail on these studies may be found in the author's thesis, from the University of California, Berkeley.

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APPARATUS AND EXPERIMENTAL

A. General Description

The crossed molecular beam machine used in this investigation is a modification of one designed by Y. T. Lee[1], and the details of its design criteria and construction have already been discussed[5] by R. Behrens[2], who was responsible for the building of this apparatus. For the benefit of the reader, a brief description of the machine will be given here along with a more detailed description of the portions of the experimental set-up for which the author was responsible.

The two molecular beams are produced in two source chambers as shown in figure 1 with the following exception; the source in source chamber 2 is not a nozzle gas source as shown but a high temperature oven designed by A. Freedman, described in his thesis[3], and shown in figure 2.

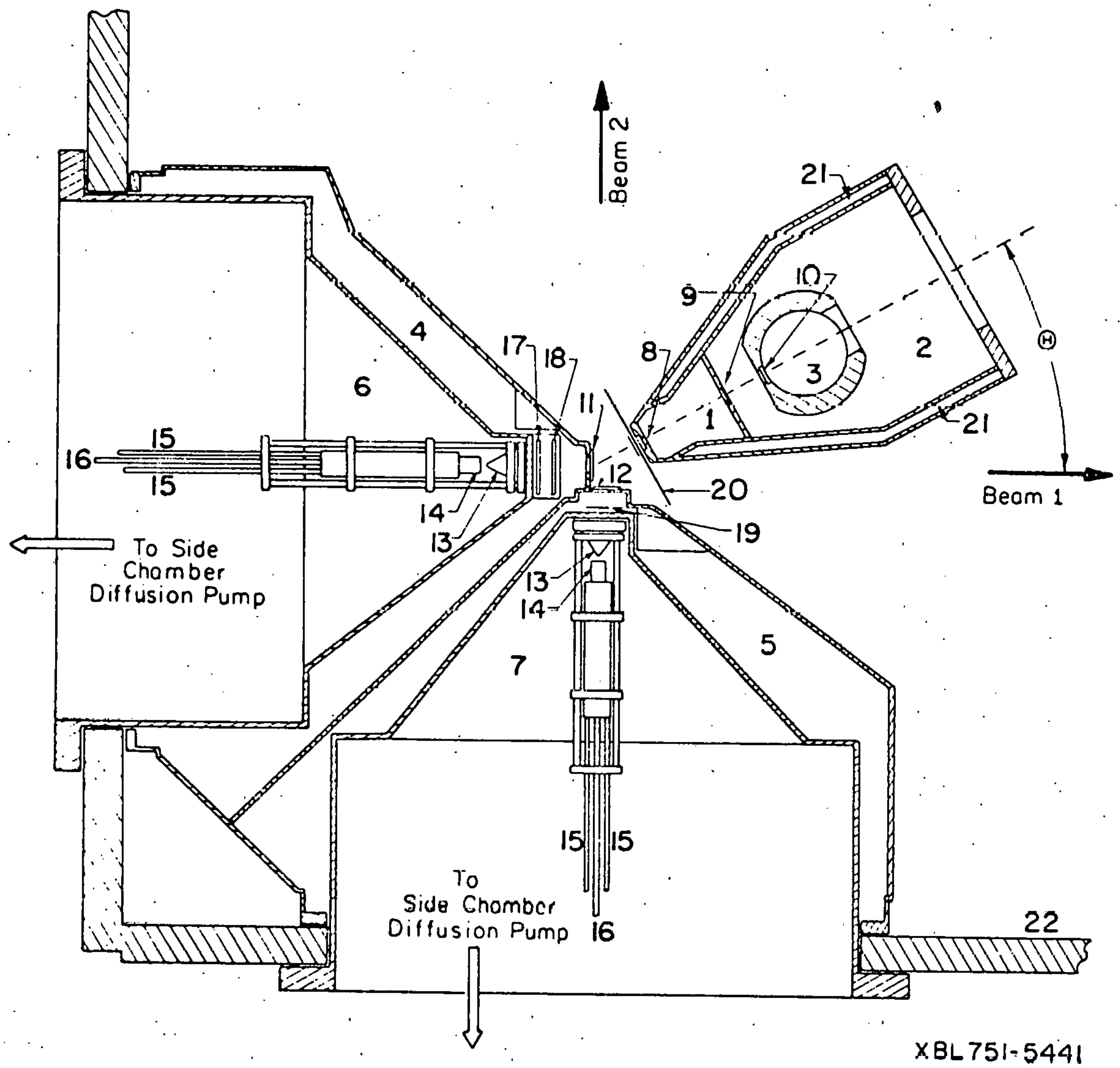
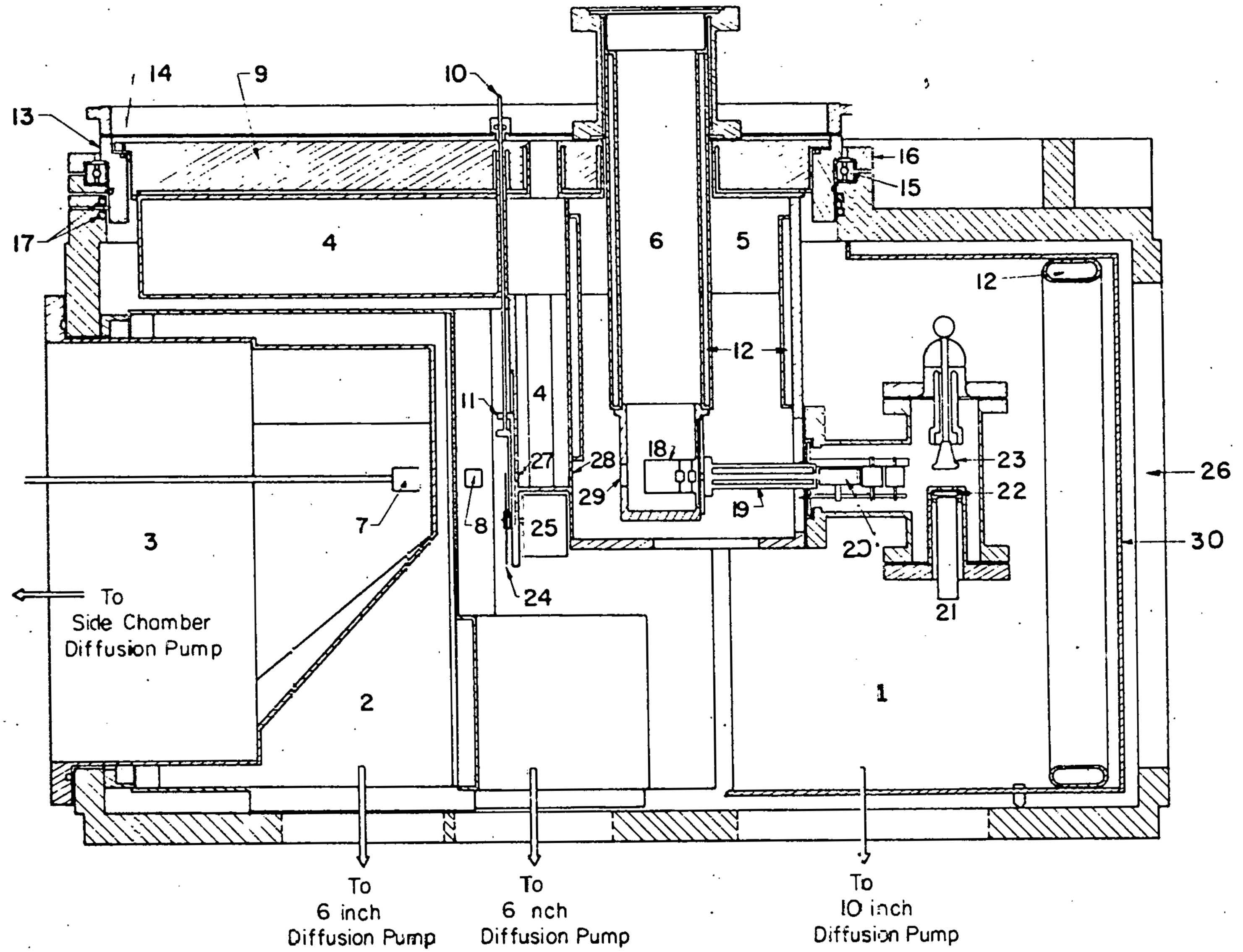


Fig. 1 A. Top Cross Sectional View of the Apparatus

Figure IA. Top Cross Sectional View of the Apparatus

1. Detection Chamber No. 1.
2. Detection Chamber No. 2.
3. Ionization Chamber.
4. Collimation Chamber 1.
5. Collimation Chamber 2.
6. Source Chamber 1.
7. Source Chamber 2.
8. Detector Chamber 1 entrance slit.
9. Detector Chamber 2 entrance slit.
10. Ionization Chamber entrance slit.
11. Beam 1 Collimating slit.
12. Beam 2 Collimating slit.
13. Skimmers
14. Nozzles
15. Heating or cooling fluid tubes.
16. Gas inlet.
17. Beam Flag 1.
18. Beam chopper
19. Beam Flag 2.
20. Time-of-flight wheel.
21. Liquid nitrogen cooling.
22. Main Chamber.



XBL 751-5449

Fig. 1 B. Cross Sectional View of the Apparatus

Figure IB. Cross Sectional View of the Apparatus

1. Main chamber.
2. Collimation chamber No. 2
3. Source chamber No. 2.
4. Detector chamber No. 1.
5. Detector chamber No. 2
6. Ionization chamber.
7. Nozzle source No. 2.
8. Beam source No. 1.
9. Rotating detector lid.
10. Gate valve drive rod.
11. Detector gate valve.
12. Liquid nitrogen cooling reservoirs.
13. Rotating ring.
14. Rotating lid O-ring seal.
15. Kaydon KG350XPO 35 inch bearing.
16. Bearing retainer ring.
17. Tec-Ring seals No. A-01926.
18. Ionizer
19. EAI Quad 250 quadrupole mass filter.
20. Quadrupole exit lenses.
21. EMI 9524S photomultiplier tube.
22. Pilot B plastic scintillator.
23. High voltage cathode.
24. Time of flight chopping wheel.
25. IMC time of flight motor.

Figure IB (cont'd).

26. Access port.

27. Detector chamber 1 entrance slit.

28. Detector chamber 2 entrance slit.

29. Ionization chamber entrance slit.

30. Cold shield.

HIGH TEMPERATURE OVEN

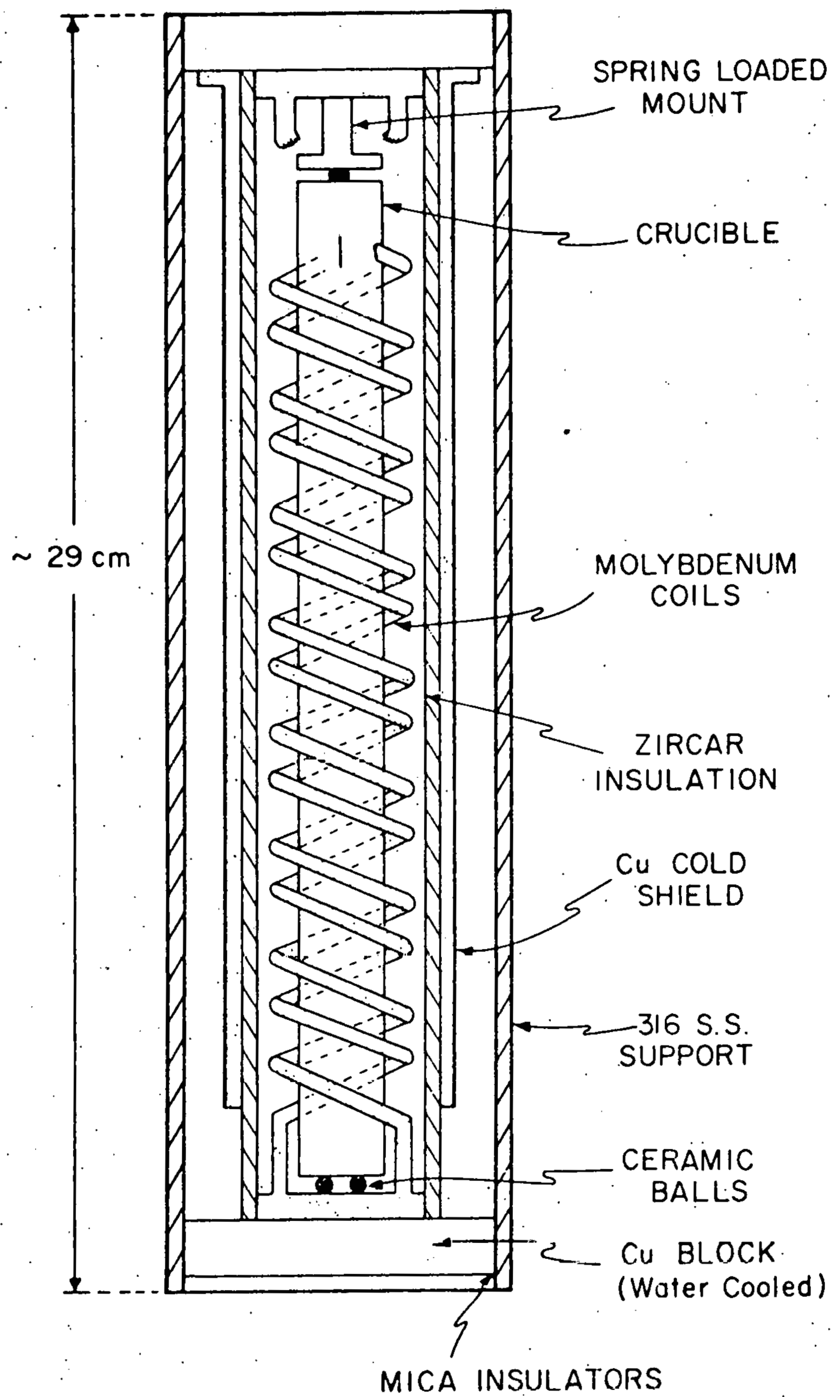


Fig. 2

Briefly it consists of , for the barium experiments, a molydenum crucible, 1. 9 cm in dia and 25 cm long, that holds the charge, with a 0.025 cm slit 0.5 cm long cut in the face as shown. The lid of the crucible is welded shut to prevent any barium effusion or creepage from the top of the crucible, a problem with press fit lids. The crucible is heated radiatively by molydenum resistance heating coils wound around it operating at typical power levels of between 1 and 2 kW depending on the desired temperature. Wound around, but not touching, the heating coils is a layer of Zircor[4] insulation, which is contained by a copper cold shield connected to water cooling. In front of the oven is a solenoid operated beam flag. For the tin experiments the molyden crucible had to be replaced because the molten tin literally dissolved and alloyed with the molydenum. At first a quartz liner for the molydenum was tried, but the tin reacted with the quartz, turning it white and crystalline and producing a strong tin oxide component to the beam. Finally a crucible almost identical in design to the molydenum one but made from graphite was tried with great success. This crucible, shown in figure 3, employed a press fit lid which showed no signs of leaking, and could be easily reopened after a run without damaging either the lid or the crucible. Furthermore the graphite showed no signs of being attacked or penetrated by the tin (the old crucible showed signs of the tin diffusing through the moly so that the whole surface acted as a source rather than just the slit). The slit in the graphite crucible was cut by mechanical means, rather than the electron beam discharge cutter used on the molydenum; for this reason it is wider -- 0. 5 cm versus 0. 25 cm.

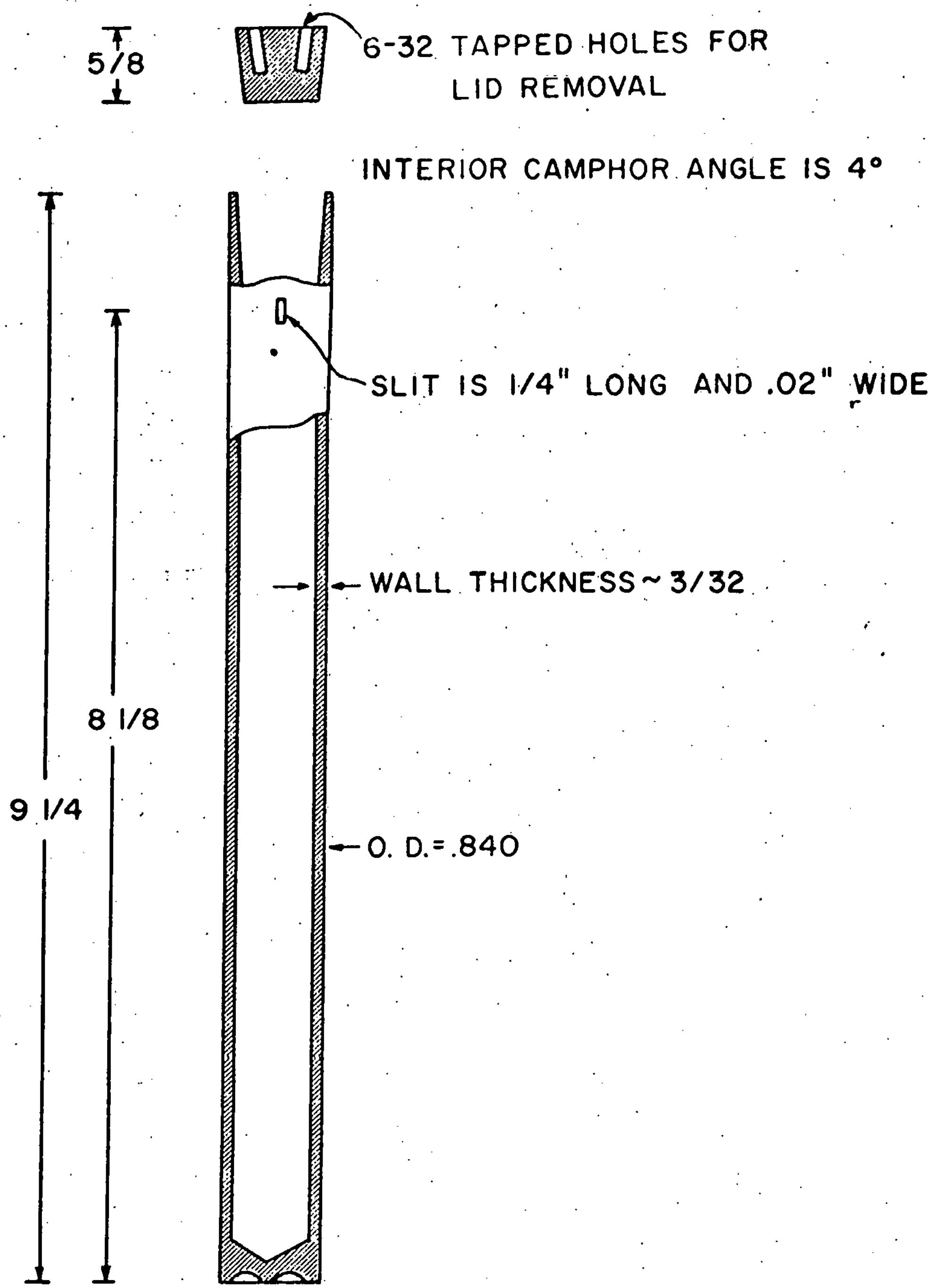


Fig. 3. Graphite Crucible

Since this oven certainly doesn't need the benefits of a differently pumped collimation chamber, the inside source chamber part 7 of figure 1 is removed and the oven source is mounted in the collimation chamber 2 which becomes the source chamber now pumped by the 10" side chamber oil diffusion pump through a 20" dia stainless steel el shaped chamber. The mounting is such that the slit in the crucible is 16.2 cm from the collimating slits (12 of figure 1) and 8.5 cm from the beam collision region. The collimating slits are two strips of Ta ribbon 0.2 cm apart and the geometry is such that the beam has an angular FWHM of 1.83 degrees and a special FWHM at the collision region of 0.27 cm for the barium experiments and the same for the tin experiments. (For the tin experiments the umbra is smaller and the penumbra larger, giving the same FWHM.

The other change involves the removal of the inside source chamber 1 (part 6 figure 1) and the remounting of the supersonic nozzle skimmer assembly (for a description see ref 2) on the collimation chamber on the back face of the now removed collimating slits (part 11). This was done in order to increase the intensity of the nozzle beam at the collision zone since it now placed the skimmer opening only 2.76 cm and the nozzle (which can be moved back and forth with respect to the skimmer) at a typical 4.11 cm from the collision region, compared to previous skimmer and nozzle distances of 10.5 and 11.9 cm respectively. Since the intensity of the beam falls off as the inverse of its distance to the collision zone squared one would expect an 8 fold increase in signal and alternations in the new configuration. The best way to compare beam intensity in the two configurations is to look at how much the nozzle beam attenuates the oven beam. In the old configuration we could never really measure any substantial attenuation, less than .1%, unless the source pressure was turned up so high as to swamp the diffusion pump or the nozzle moved very close (less than 2 nm) to the skimmer (both procedures causing adverse broadening of the beam speed distribution). Furthermore in the old configuration the nozzle beam never made any measurable rise in the main chamber pressure suggesting that not much beam was getting into the main chamber. In the new configuration we typically run with between 1 and 4% attenuations with reasonable source pressures (between 200 and 300 torr) and turning on the beam would cause the main chamber pressure to rise from a typical background pressure of 4×10^{-7} torr to between 1 and 2×10^{-6} torr. This is just the pressure rise expected according to a simple calculation based on the measured attenuation and main chamber pumping speed estimates. Some of this improvement was due to the use of larger diameter nozzle and skimmer orifices, and was made at the expense of beam angular resolution; the new configuration was calculated to have a FWHM angular spread of 7° compared to the old configurations 0.8°. The 7° wide beam is suitable for reactive scattering where fine angular resolution is not needed, but is unsuitable for some elastic scattering studies where poor angular resolution would wash out the details of the angular distribution (see ref. 5). Another disadvantage of this configuration is that there is now no room for the beam flag and beam chopper as shown in figure 1 (parts 17 and 18), and to chop the beam a solenoid, (actually a relay), with a metal flag attached, is mounted on the main chamber face of the collimation chamber so that when not energized it blocks the beam's path to the collision zone and when energized it allows the beam to pass. The disadvantage is that when blocked the deflected beam still passes into the main chamber in the vicinity of the collision zone and might react with the barium or tin on surfaces surrounding the collision zone, either the collimation chambers or the detector. The products of these surface reactions might be picked up by the detector and cause negative signals i.e. signals larger when the beam is off than on, that would invalidate the single collision reactive signal desired. No evidence of this problem was observed except with the bromine time of flight experiments discussed later. Also discussed later, in Appendix I, are the details of the nozzle beam geometry.

With the inside source chamber 1 removed, the nozzle beam is pumped by both the 10" CVC oil diffusion pump via the el chamber and the 6" NRC oil diffusion pump at the bottom of the collimation chamber. (The 10" pump is backed by a KDM-65 mechanical and a KMB 230 booster pump; the 10" diffusion pump on chamber 2 by a KDM-80, and all other diffusion pumps by KC-15 mechanical pumps manufactured by Kinney vaccum.) Typical source chamber 1 pressure while operating the nozzle is 2×10^{-4} torr.

The two beams pass into and collide in the main chamber made, as are almost all components of this machine that are in vaccum, of stainless steel, and pumped by a cyrogenically baffeled 10" CVC oil diffusion pump and indirectly by a 6" NRC pump. Typical main chamber background pressure is 5×10^{-7} torr. The size of the main chamber, 132 cm x 130 cm x 84 cm, was dictated by the size of the rotating lid, housing the detector. Inside the main chamber, encompassing the region that the detector rotates in, is a cyrogenically cooled copper cold shield, affording large pumping speed for condensible gases (LN_2 temperatures). (The area between the cold shield and main chamber is a semi-sealed region pumped by the aforementioned 6" NRC oil diffusion pump and the nozzle beam strikes a beam deflector and is pumped out through this region unless the detector is in the way.)

The detector is housed in a triply differentially pumped cyrogenically cooled vacuum chamber made of stainless steel and mounted on an 89 cm dia lid in a horizontal plane defined by the two beams, from -8° to 105° where 0° is defined as the nozzle beam (source 1). The rotating seal consists of two Teflon Tec-Ring gaskets (Tec Seal Corp). The detector entrance slit (figure 1 part 8) is 0.380 cm square and 4.44 cm from the collision zone, (for measuring the beams another slit is available which is only 0.008 cm in diameter to decrease the intensity of incoming gas and prevent overload of the detector). This chamber is pumped by an Ultek 150 l/sec ion pump, backed by a titanium sublimator, and the next chamber (2 on figure 1) surrounds the ionizing chamber and is pumped by a Vecco 225 l/sec ion pump, backed by a titanium electron beam sublimator. The third chamber (3 of figure 1) houses the ionizing portion of the mass spectrographic detection system, is liquid nitrogen cooled, and pumped by a Vecco 100 l/sec noble gas pump and by a liquid He pump not used in these experiments... typical background pressures in this chamber are 2×10^{-9} torr. The detection system consists of an axial electron bombardment ionizer housed in chamber 3 and constructed so that particles from the collision region which enter and are not ionized pass out through the back, are pumped away in chamber 2, and do not contribute to the background gas near the ionizer. Particles that are ionized are drawn out and focussed by an electrostatic lens system to enter a quadrupole mass filter and ions of the selected mass are passed out the back of the quadrapole and accelerated by a pair of lenses to strike an aluminum plated cathode held at minus 30 kV with respect to the energy of the ions. The resulting shower of ejected electrons are accelerated and strike an aluminum coated plastic scintillator causing a shower of photons which are coupled to a photomultiplier tube (EMI 95245) producing a current burst at the output for each ion produced in the ionizer. The advantage of this system over using an electron multiplier to measure the ions is twofold: first the PM is sealed and therefore not subject to rather rapid degradation (by the corrosive gases used in some experiments) as open electron multipliers are. Second, each ion that strikes the Al cathode produces many electrons (estimated 2 to 6) which, when they strike the plastic scintillator, (Pilot B) produce about 12 photons; therefore each ion produces a burst of about 50 photons, and the problem of discriminating ion counts from stray light photon background counts becomes very easy. A disadvantage was that the high voltage needed for the cathode would cause electrical interference, by some form of non-sustaining discharge phenomen, that would cause the computer interface to malfunction. This was completely solved by electrostatically shielding all conductors of the high voltage inside the vaccum chamber. The current bursts from the PM tube are counted electronically by a system described later. The ionizer used for the barium experiments, similar in design to that of Brink[6] and designed and described by Behrens[2], was normally operated at an electron energy of 60 V, electron current of between 10 and 15 mA and had an estimated ionizing region length of about 4 cm. The ionizer for the tin experiments, an Extranuclear Labs Model 041-1, was normally operated at 100 V electron energy and 5mA emission, and had an estimated ionizing length of 0.5 cm. For looking at the beams the emission was dropped to between 10μ A and 100μ A for both ionizers. Although not carefully measured (a difficult procedure), the typical ionizing efficiency of this type of ionizer lies between 0.01 and 0.1 so the probability of ionizing a particle is directly proportional to the length of time it spends in the ionizer and therefore inversely proportional to the particles velocity causing the detector to measure a number density as oppossed to a flux. (Particles per sq. cm per sec. times inverse velocity bias equals particles per cubic cm.) The quadrapole mass filter used for the barium experiment was an Electronics Assoc. Inc. Model Quad 250 along with its associated driving electronics. The quadrapole used in the tin experiments was an Extranuclear Labs Model 4-270-9 with Models 11, 13 and 15 Hi-Q heads and Models 020-2, and 011-15 driving electronics. The motivation for the change was hoped increased sensitivity of the companion ionizer, better resolution of the mass filter, and more accurate and stable mass selection (the EAI mass filter's calibration was non-linear and changed frequently enough to make hunting for a mass peak an annoying procedure).

B. AC Syncronous Detection

Along with the reactive signal coming from the collision region there is also present at the output a background signal due to background gas in the detector or in the main chamber. One way to subtract out this background, or baseline, is to measure it before the beams are on and subtract that quantity from all later measurements, but this assumes that the baseline is constant with time. A better method, the one used here is to constantly measure this baseline by periodically interrupting the nozzle beam and accumulating the baseline count in one set of counters and the signal plus baseline count, when the beam is not interrupted, in a different set of counters. The difference between the two will then be that portion of the signal that depends on the collision of the beams without any added baseline. (An even better method, judged too complicated in this application, would be to chop both beams and measure the signal at the beat of the two chopping frequencies; this would subtract all components of the signal not dependent on having both the beams on and colliding.) The duty cycle (time of beam on/total time) was chosen to be 50% for reasons of simplicity. (50% is not always the optimum duty cycle: if the baseline is very small or zero there is of course no point in measuring it so the optimum duty cycle would be 100%. It can be shown, appendix II, that the optimum duty cycle is equal to (S+B)/(S+2B) where S and B are the signal and baseline rates respectively.) Although one would like to have a high chopping frequency so as to average out fast drifts in the baseline, the frequency is limited by the spread in flight times of the beam particles from the chopping mechanism to the collision region and to the detector. There may be a sharply defined burst of particles at the chopping mechanism but since some travel faster than others, both in the beam and after they have reacted at the collision region, they may get to the detector before the slow particles from the previous pulse arrive; the phase information has been lost and syncronous detection won't work. For an idea of the time scale involved we make the more stringent requirement that we will discard all counts obtained for that amount of time past each beam on or off transition such that all but the slowest few percent of the particles in the beam have time to get to the detector. With a typical distance of 7 cm and typical slow velocity of 5×10^3 cm/sec we get 1.4 msec, so a chopping frequency of 180 Hz would be wasting half the counting time on waiting for this "dead time".

In the original configuration of this machine, the beam was chopped using a motor driven wheel with slots in it that interrupted the beam in the collimation chamber as shown in figure 1 (part 18). An advantage of this system was that when the beam was chopped off all of it was pumped away in the collimation chamber and none got into the main chamber to cause the previously discussed negative signals. from surface reactions. (A lesser advantage is that only half the total beam winds up in the main chamber as background gas.) A disadvantage was that the motor was inside the source chamber and the relatively high concentration of corrosive gases (when running such gasses in the nozzle) caused frequent failure of the motor bearings. Another disadvantage was, as previously mentioned, the nozzle had to be further away from the collision zone causing less beam intensity, so it was moved up to the collimation chamber face and the new beam chopper, mounted in the main chamber, was used. This beam chopper (the metal flag mounted on a relay) is much slower that the rotating wheel because, mechanically, the relay won't move much faster than a few cycles per second. A chopping period of 200 msec on and 200 msec off was chosen with 20 msec thrown out at each transition to allow the flag to move into position and the transients (the flag oscillates slightly) to die down. (The chopping frequency could be made much slower, all the way to DC, but problems would develop with the computer interface to be discussed later.)

C. Time of Flight Spectrometry

The system described so far measures the reactive signal as a function of scattered angle. It is also useful to measure it as a function of the velocity of its constituant particles. For inelastic scattering studies this velocity distribution, giving a translational energy distribution, would be helpful in elucidating the energy transfer mechanism being studied. The translational energy distribution of reactive scattering would also be helpful in elucidating the total reactive product energy partitioning, an important part of microscopic kinetics. Finally the velocity distribution of the beams and scattered signal are needed to form the Newton diagram and transform the differential cross section from the lab to the more meaningful center of mass frame of reference (see chap. 3). Therefore it would be advantageous to have some device that specifies or selects velocity in conjuncture with the rotatable lid that selects angle.

Conventional velocity selectors operate on a time of flight principle and consist of arrays of slotted disks, arranged in series on a common shaft, and spun by a variable RPM motor. The disks are precisely aligned so that only those particles within a certain small velocity range will traverse through the slots without hitting any of the tines and being deflected out of the path to the detector. The selected velocity range is varied by changing the motor RPM and the resolution is given by the construction of the slotted disks. These selectors are however, too big to incorporate in most rotatable detector molecular beam machines, and furthermore since it takes considerable time to complete a velocity sweep, changing beam conditions could distort the measured velocity distributions. A much simpler way to obtain velocity information is by means of a single slotted disk, spun so that it allows short bursts of molecules to enter the detector. Each of the molecules in the burst travels the distance, d, between the slotted disk and the ionizer portion of the detector, where they are ionized and quickly detected. It is obvious that the faster ones get there sooner than the slow ones. The signal at the detector therefore consists of a burst of counts, where each count is delayed from the initial pulse by a time $t = d/v$, v being the velocity of the particular molecule being counted and d being the distance from the slotted disk and the detector. This "time of flight spectrum", i.e. the intensity of counts as a function of flight time, can be inverted to obtain a velocity distribution, since the flight distance, d, is known. See eq 1 where I(t) and I(v) are intensities as a function of time and velocity respectively.

eq 1) $\left| I(v)dv \right| = \left| I(t)dt \right| \Rightarrow I(v) = I(t)\left|\frac{dt}{dv}\right| \Rightarrow I(v=\frac{d}{t}) = \frac{I(t)t^2}{d}$

Notice that the resolution for this method of velocity measurement is poorest for highest velocities i.e. $dv = \frac{v^2}{d} dt$.

The slotted disk, shown in figure 1 as part 20 and called the "time-of-flight" wheel (TOF wheel) is mounted below the detector so that the slots pass directly in front of the detector opening. (The wheel is spun by an AC synchronous hysteresis motor.) It is 14 cm in diameter and the diameter to the center of the detector opening is 13.2 cm. The perfect TOF wheel would let through an infinitely narrow (both time and therefore special) burst of particles for maximum possible time, and therefore velocity, resolution. It would also have an unusable zero transmission, defined as percentage open time. If the fractional time resolution is defined as the open time for each slot (being equal to the uncertainty in starting time for each burst of particles) divided by the period between slots (being the total time scale of the TOF spectrum), it is obvious that the fractional time resolution is equal to the transmission. It can also be seen that the absolute resolution is given by the fraction transmission times the wheel period divided by the number of slots. It is also given by wheel period times slot width divided by total wheel circumference. If the fractional resolution is made better by decreasing the slot size then the transmission will suffer; if the transmission is then made larger by increasing the number of slots then another problem, wrap-around, will occur. Wrap-around occurs when the burst of particles from one slot comes before all the particles from the previous burst have gone the flight distance and been counted by the detector, thus falsely showing up as very high velocity particles rather than their true slow velocity. The actual design of the wheel was chosen as follows. First the gate function, the transmission of the wheel as a function of time, actually depends on the size of the hole in the detector as well as the slot size of the wheel. In fact the convolution of the square slot passing in front of the square detector hole produces a trapezoidal gate function. In the case of equal sizes, the design chosen was both equal to 0.38 cm, the gate function is a triangle. If the wheel slot size is made much smaller than this the transmission (for a given wrap-around condition) will suffer while the fractional resolution will now, due to the convolution with the hole in the detector, not get much better. (Example: if the slot is halved in size the transmission is halved but the gate function total width is only decreased by 25%). If the slot is made much larger the resolution will suffer, so equal sizes were chosen as a compromise. The number of slots was governed by the maximum RPM of the motor and the requirements of wrap-around problems. The maximum motor RPM was about 12500 because above that vibration of the motor was transmitted through the lid to the ion pumps causing pressure bursts and instabilities and increasing the background count rate. Thus at maximum RPM, and therefore maximum absolute resolution, the wheel period was 4.8 msec. In order to give a TOF spectrum length of 1.2 msec, very adequate protection against wrap-around even for the heaviest and therefore slowest molecules such as tin iodide, a wheel with four slots was chosen, each slot being the previously mentioned 0.38 cm wide. Another good choice would have been six slots giving a minimum TOF spectrum length of 0.8 msec, but this would have necessitated slowing the wheel down and decreasing the absolute resolution when wraparound became a problem. (The wheel must have an even number of slots for reason of balance and for reasons pertaining to the interface to the computer.) From the above design it can be seen that the wheel has a transmission of 3.7% and a minimum gate function of 0.44 μsecs FWHM. (For a velocity of 5×10^4 cm/sec this is a resolution of $(5 \times 10^4)^2(4.4 \times 10^{-6})/19.3 = 5.7 \times 10^2$ cm/sec, which is using the previously given equation $dv = V^2 dt/d$.

Not yet mentioned in this discussion is the flight distance d, which is the distance from the TOF wheel to the center of the ionizing region of the ionizer. There is an uncertainty in the flight distance given by ± 1/2 the length of the ionizing region. For the barium experiments the average d and uncertainty are 19.3 and ±2 cm and for the tin experiments 18.85 and ±0.250 cm owing to the different ionizers used[3]. The gate function (uncertainty in flight time due to uncertainty in starting time) and the length of the ionizing region (uncertainty in flight distance) cause the measured TOF spectrum to be broader than the true spectrum. In fact the measured spectrum is a complicated two dimensional convolution of the true spectrum with the gate function and the ionizer length. A program to deconvolute the measured to obtain the true spectrum has been written by A. Freedman and is discussed in his thesis[3].

A TOF parameter of lesser importance is the delay time from ionizing a particle and detecting it as a pulse from the photomultiplier, basically the time it takes an ion to drift through the quadrupole at some given ion energy V (measured as the difference in potential between the ionizer grid and the quadrupole or ground). Since the actual fields involved are not known, the delay time can be given approximately by the equation $t(m) = k\sqrt{M/V}$ ($Mv^2 \alpha V$, $t \alpha 1/v$. so $t \alpha \sqrt{M/V}$) where M is the ion mass (gm molecular weight) and V is the ion energy (volts). If the TOF spectrum of species of two different mass, yet assumed same velocity distributions, are taken, then the constant k can be determined:

$$t(M_2) - t(M_1) = k\left\{\sqrt{M_2 V} - \sqrt{M_1 V}\right\} = \Delta t \qquad \text{so}$$

$k = \Delta t \left\{\sqrt{M_2/V} - \sqrt{M_1/V}\right\}^{-1}$ where Δt is the difference in time between the peaks of the two TOF distributions. For example the TOF spectrums of SF^+ and SF_5^+, both from fragmentation of SF_6 in the ionizer, were measured and the peaks differed by 15 μsecs. Therefore $k = 15\left\{\sqrt{127/23} - \sqrt{51/23}\right\}$ or $k = 2 \times 10^{-5}$ sec $V^{1/2} gm^{-1/2}$ valid for the tin experiments (done on the ENI ionizer and quadrupole.) For the barium experiments $k = 1 \times 10^{-5}$. For a typical ion energy of 60V and mass of 153 (BaO) this would give an ion flight time of 16 μsecs a small correction.

D. Cross Correlation TOF Spectrometry

Another TOF technique, not used here due to lack of time for conversion, is cross correlation TOF spectrometry, with the added advantage that the transmission is always 50% regardless of the resolution[7, 8]. (50% transmission, compared to 3.7%, would require only 7% of the counting time.) This method would also involve a slotted disk spun in front of the detector opening, as before, except that the disk would be divided into 127 equally spaced regions and the presence of a slot or a time would be given by a pseudo-random maximal length binary sequence. These sequences of binary numbers are finite in length, $N=2^n - 1$, where n is an integer, and possess many of the properties of random white noise. The auto correlation function for each sequence, over the length of the sequence, approximates a delta function ie is equal to -1 for all time shifts other than zero for which it is equal to N (discrete sum rather than integral. The autocorrelation of true random noise is a delta function.) Although the output of the detector will now look like random noise, the time of flight spectrum can be extracted by cross correlating the output signal with the pseudorandom gating function. Suppose we have a constant incoming signal of K gated by a gate function $A_n = 1/2\,(G_n + 1)$ where the subscripts denote discrete steps in time equal to the time for one time or slot to pass the detector hole and also equal to the bin time of the measuring system (discussed below).

G_n is the pseudorandom sequence taking on values of +1 or -1; therefore An, the gate function, takes on values of +1 or 0 (open or closed). The signal measured by the detector will be the convolution of the gate function and the response function of the particles i.e. their TOF spectrum h_n.

$S_n = K \sum_{m=1}^{N} 1/2(G_{n-m} + 1)h_m$ which is to say that the signal at some time n is equal to the gate function at time n times the response function for zero time (infinite velocity) plus the gate function for previous times multiplied by the response function for non-zero flight time. Now to extract the TOF spectrum, h_m, we cross correlate S_n with G_n:

$$R_{SG} = \sum_{n=1}^{N} S_{n+p}\, G_n = \frac{K}{2} \sum_{n=1}^{N} \Big[\sum_{m=1}^{N} (G_{n-m+p} + 1)h_m \Big] G_n$$

$$= \frac{K}{2} \sum_{m=1}^{N} \Big[\sum_{n=1}^{N} (G_{n-m+p} + 1)\, G_n \Big] h_m$$

but $\sum G_{a-b} G_a = N$ if $b=0$, $= -1$ if $b \neq 0$, and $\sum_{n=1}^{N} G_n = +1$

$$\text{so } R_{SG} = \frac{K}{2} \sum_{m=1}^{N} \big[(N+1)\, \delta_{m,p} - 1 + 1 \big] h_m$$

$$R_{SG} = \frac{K}{2} (N+1) \sum_{m=1}^{N} \delta_{m,p} h_m = \frac{K}{2} (N+1) hp$$

so TOF spectrum hp = $2R_{SG}/K(N+1)$

The advantage in cross correlation TOF spectrometry are mainly the high transmission, 50%, and the variable resolution set by the motor RPM (and theroretically arbitrarly small if it weren't for the finite size of the detector opening and finite ionizer length.) Another advantage can be seen by example when the cross correlation of the pseudorandom sequence and true random noise is taken and found to be proportional to the square root of- the sequence length, N. As seen above the cross correlation of a true signal is proportional to the sequence length + 1. Thus there is an improvement in signal to noise ratio, proportional to N . A disadvantage, also seen by example, is that statistical noise from a large peak in the TOF spectrum will be spread out by the cross correlation to all regions of the spectrum and possibly mask small ancillary peaks or at least make their signal to noise ratio worse. Thus this technique is most attractive when colorless TOF spectrum are anticipated, and least attractive when small peaks of interest are dominated by large peaks. Furthermore there is the problem of the design of the wheel. If the slot size is taken as 0.38 cm for reasons given before, then the wheel most have 127 "slots" since this number must be equal to $(2^n - 1) \cdot m$ where n and m are integers. If a sequence length of 127 (n=7) is chosen then only one sequence per circumference is allowed (m=1), and this would mean that, at the maximum RPM of 12,500, the TOF spectrum would be taken out to an unrealistically long 4.8 msec. If a sequence length of 31 (n=5) is chosen then four sequences can be included (m=4, No. slots=124) and the TOF period is 1.2 msec, but the added signal to noise improvement of longer sequences is lost. A solution to this would be to remount the motor to one side of the detector and use a larger diameter wheel. (The current 14 cm dia. wheel is mounted below the detector and restricts angular movement between 0° and 90°. Mounting to the side would allow a 28 cm dia wheel and would restrict angular movement to one half the total range so that, if the wheel could be mounted on either side, the full range of angles could be reached by doing each experiment in two sections.) A good compromise design would be a 28 cm dia wheel with two sequences of length 63 giving a minimum TOF spectrum length of 12 msec and a minimum resolution twice as good as before (21 μsecs).

E. TOF Computer Interface

The time of flight (TOF) spectrum could be displayed on an oscilliscope; the horizontal sweep would be synchronized with the pulses from the slotted wheel, the horizontal axis would be the flight time t, and the vertical axis would be the intensity (signal from the detector). This will not work at all for scattered species because the signal is buried in too much noise. Some sort of signal averaging is needed, where many bursts of molecules are let into the detector and the time of flight spectrums from each burst are averaged together. This is best done by using a computer. The flight time is compartmentalized into "bins" where each bin has a width of Δt and the n^{th} bin corresponds to a flight time of $n \cdot \Delta t$. In reality these bins are locations in the computer memory. Counters count the signal occurring during the first bin's time $t = o$ to Δt, and add these counts to those already in the first bin; then they reset and count the signal occurring in the next Δt segment in time and add these to the contents of the next bin etc.; whenever the wheel opens up to let in another burst, the counters go back to the first bin and start over again. After a while the TOF spectrum builds up in the computer memory, where consecutive locations in memory hold data from consecutive flight times.

A block diagram of the time of flight system used by our group is shown in figure 4. (The interface is built with standard TTL circuitry and detailed schematics are shown in figres 5 to 13.) The computer used is Digital Equipment Corp.'s PDP 8/e. It is operated in the Direct Memory Access (DMA) mode using the one cycle data break for collection of data. Thus the collection of data is totally transparent to the program being run on the computer, which is usually a display routine that shows the developing TOF spectrum on an oscilliscope. A programmed interrupt system is used to transfer commands to the interface and to receive status signals from it.

As shown in the diagram, the experiment consists of two beams that are crossed to form a scattered signal which is passed through the rotating slotted disk to form short bursts of molecules. (A light bulb-photo diode assembly is mounted 180° away from the detector opening so as to generate an electrical signal that tells when the wheel is "open". A discriminator-line driver circuit shapes this pulse and sends it via co=ax to the computer as the "FAST WHEEL SIGNAL" (positive going pulses).) The molecules traverse the flight distancc, d, and are ionized by the ionizer, selected as to mass by the quadrapole mass filter, and accelerated to strike the aluminum cathode by the exit lens. The Al cathode then emits a shower of electrons which, when they hit the scintillator, create a burst of photons, which is detected as a pulse by the photomultiplier tube. (Each of these pulses corresponds to a single ion from the ionizer.) The pulses are detected by the PM discriminator-line driver circuit and sent via coax to the computer as "DATA PULSES" (negative going pulses.). After the slotted wheel lets in a burst of molecules the fast wheel signal pulse resets the DMA address counters to zero. The contents of these counter's specify, partially, what memory address in the computer will receive the data being transfered. ((The rest of this address is given by the field control which sets bits 0 to 3 and is discussed later. A total of 512 locations are reserved for single precision data;

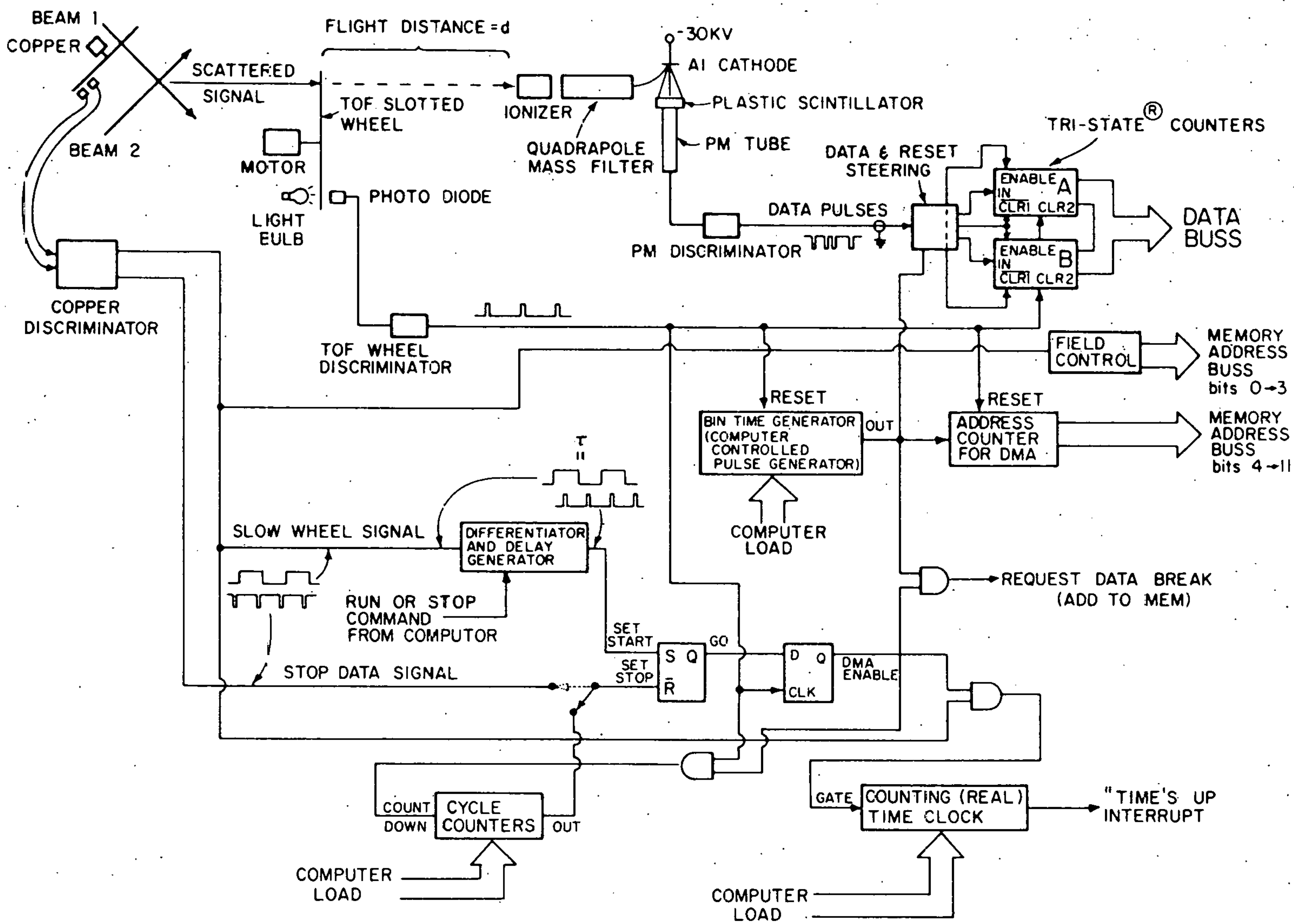

BEAM 1
COPPER
BEAM 2
SCATTERED
SIGNAL
FLIGHT DISTANCE = d
TOF SLOTTED
WHEEL
MOTOR
LIGHT
BULB
PHOTO DIODE
IONIZER
QUADRAPOLE
MASS FILTER
-30KV
Al CATHODE
PLASTIC SCINTILLATOR
PM TUBE
PM DISCRIMINATOR
DATA PULSES
DATA & RESET
STEERING
TRI-STATE® COUNTERS
ENABLE
IN
CLR1 CLR2
A
B
DATA
BUSS
COPPER
DISCRIMINATOR
TOF WHEEL
DISCRIMINATOR
FIELD
CONTROL
MEMORY
ADDRESS
BUSS
bits 0→3
RESET
BIN TIME GENERATOR
(COMPUTER
CONTROLLED
PULSE GENERATOR)
OUT
ADDRESS
COUNTER
FOR DMA
MEMORY
ADDRESS
BUSS
bits 4→11
COMPUTER
LOAD
T
SLOW WHEEL SIGNAL
DIFFERENTIATOR
AND DELAY
GENERATOR
RUN OR STOP
COMMAND
FROM COMPUTOR
REQUEST DATA BREAK
(ADD TO MEM)
SET
START
SET
STOP
S Q
R
GO
D Q
CLK
DMA
ENABLE
STOP DATA SIGNAL
COUNT
DOWN
CYCLE
COUNTERS
OUT
COMPUTER
LOAD
GATE
COUNTING (REAL)
TIME CLOCK
"TIME'S UP
INTERRUPT
COMPUTER
LOAD

Fig. 4

256 for signal plus noise and 256 for noise.) The fast wheel signal pulse also reset plus noise and 256 for noise.) The fast wheel signal pulse also resets the data counters A and B and the bin time generator (BTGO which is a computer setable pulse generator. (The operator can load from the teletype keyboard whatever "bin time", Δt, discussed before, that he wants the BTG to generate.) After the fast wheel pulse the data gate sends the data pulses to data counter A. (These are Schottky TTL counters and can count up to 100 MHz although the PM tube in use can't get much above 5 MHz). After a time Δt, the BTG generates a pulse that initiates a number of things. First the data pulses from the PM disc are routed to the B counter (identical to A counter). Also the address counter is incremented by one (address now equal to 2001_8 if beam on, 2401_8 if beam off), and a data break is requested of the DMA circuit. When the DMA circuit grants this request the contents of the address counter (and field control) are gated onto the memory address lines and the contents held in data counter A, those counts that occurred in the first Δt of the flight time, are added to the contents of memory location specified by the address buss. When this transfer is over, the A counter is cleared. Thus those counts destined for "bin number one" are loaded into the computer while the B counter is accumulating the counts to be added to bin number two. When the nex BTG pulse comes, the process repeats except that the contents of the B counter will be added to bin number two (location 2002_8 or 2402_8) while the A counter accumulates bin number three's counts. This continues until the next fast wheel pulse*, when the address is again set to zero and the cycle repeats. (note that this process of counting has zero dead time since one counter is accumulating data while the other is sending data to the computer.)

---

*If the address counters go through all 256 locations before the next fast wheel pulse, they stop the data taking until the next fast wheel pulse comes.

From the above description it can be seen that the TOF spectrum will reside in the computer memory with the contents of each location being the intensity and the address of each location being directly related to the flight time t.

The majority of remaining circuitry of the interface is concerned with controlling the above data collection process i. e. telling the computer when to start and stop taking data. This is done syncronously with the "slow wheel signal", named for the beam chopping wheel used in the old configuration of the machine. As mentioned before, in the new configuration, the nozzle beam, beam 1, is chopped by a flag type chopper and the electronics that drives this relay chopper also generates the slow wheel signal, a 50 ohm TTL level signal that is 2.5V when the beam is open and OV when its blocked. The sequence of events is as follows: the operator types an "R" for run and the computer sends a RUN command to the interface. The next positive going transition of the slow wheel signal (i.e.beam turns on) is then passed through the differentiator (which generates a short positive going pulse for every transition of the slow wheel signal, either positive or negative) and then is delayed by a time τ (internally set in the computer by a 20 msec one-shot). The delay time τ is required to allow time for the beam flag to move since the slow wheel signal is coincident with the relay driving signal but the relay can't move instantaneously. (This delay time also allows time for the chopped beam to reach the collision zone and the detector as previously mentioned, thus eliminating transients in the TOF spectrum.) The delayed pulse then sets the GO flip-flop so that the next TOF wheel pulse will set the DMA ENABLE true allowing the BTG to generate data break requests and, in effect, iniating TOF data taking. Also enabled are the TOF wheel pulse CYCLE COUNTERS which, having been preset by the operator (through the keyboard) to some number N, now start to count down to zero.

When they reach zero they reset themselves to the number N and generate a narrow pulse that clears the GO flip-flop allowing the (negative going transition of the) current TOF wheel pulse to clear the DMA ENABLE flip-flop thereby halting the data breaking process and stopping the TOF spectrum. On the next transition of the slow wheel signal (which would now be the beam turning off) the process repeats itself identically except that the field control is now set such that data are being added to the beam off field. (When the slow wheel signal is low the data field control output is 0101 for address bits 0 to 3 i.e. locations 2401_8 to 2777_8. When high, (beam on), the data field is 0100 or locations 2001_8 to 2377_8 for the beam on field.) The process continues to repeat itself until either 1) the operator types "S" for stop 2) the counting time clock times out and generates a TIME'S UP interrupt or 3) the overflow circuit (discussed later) generates interrupt. In all of these cases the computer issues a stop command to the interface and the control circuitry is set such that the next positive going transition of the slow wheel signal is not allowed to restart data breaking. Therefore the computer stops taking data after having executed the same number of beam on as beam off cycles.

The TOF wheel CYCLE COUNTERS must be preset by the operator who must calculate the value of N beforehand as follows: the beam chopper is driven so that the open (and closed) time is 200 msec, subtracting the delay time of 20 msec gives 180 msec into which N TOF wheel cycles must fit. If the TOF period (from one pulse to the next) is 1.2 msec then N = 180/1.2 = 150 or 135 for a safety factor. Notice that the system is constrained to count exactly equal amounts of time with the beam on as off since the CYCLE COUNTERS always allow only N cycles of the TOF period per each half cycle of the beam chopper. (The counting time scale during each TOF cycle is governed by the crystal controlled BTG and so the beam on and beam off counting times are precisely equal to each other to within almost the limits of reasonable measurement.) This feature was not operational for some of the early studies of this group.[13]

Note that the COUNTING TIME CLOCK, a real time crystal controlled clock that can be set, as an alarm clock, to generate an interrupt after any given amount of time between 0.2 and 200000 seconds, is only enabled during beam on data counting so that the count rate is the number of counts divided by the counting time.

The DMA system is used in the add to memory mode, i.e. the 12 bit content of the data counters is added to the 12 bit content of the selected memory location in the computer. If this sum should overflow into the 12th bit the hardware has been designed to generate an interrupt telling the computer that this has occurred and that further data taking would result in non-retrievable overflow errors. On receiving this interrupt the computer clears the run flip-flop so that data taking will stop on the next slow wheel on transition. After DMA'ing has stopped, the computer goes to a software double precision add routine that takes data existing in the single precision data fields and adds them to double precision data fields (locations 3002 to 3777 for signal plus noise and locations 4002 to 4777 for noise). After this is complete the computer restarts the data taking, with the single precision data fields now empty and ready to accept more counts.

The above description is for the mode in which the "fast wheel" is installed and the computer is taking time of flight data. It is also useful to remove the "fast wheel" and take angular distribution data. The advantage to this is higher total signal (increased by a factor of the inverse of the resolution of the particular "fast wheel"), and the ability to rotate the lid through a larger range of angles. The simple way to get the computer interface to operate in an angular distribution mode is simply to fool it into thinking it's taking TOF data. "Fake" fast wheel pulses are generated by a pulse generator set by the operator, (who then also recalculates and reloads N.) The computer is set up to run exactly as in the TOF mode. The only difference is that the display and printout routines are told to show the total sum of all the addressed bins*, which is the total signal (or signal plus noise or noise, depending on display mode) at the particular angle being looked at. (The bin number, bin time, velocity, and flux columns are ignored in this mode.)

As mentioned before, the computer system operates in both the direct memory access mode and the programmed interrupt mode. The DMA process is totally transparent to the program being run. The software written for this system consists of a background program that displays the developing TOF spectrum on an X-Y oscilliscope and a foreground program that services the interrupts generated by the interface and also transfers commands to the interface. A complete description of these programs can be found in the comment portion of the program listing. Briefly, the display routine can display either the single precision or the double precision data fields, either signal plus noise (beam on), noise (beam off), or the difference (signal). It can be told to display any number of points and can be told to average over (sum up) any number of consecutive points. This last feature is useful for very noisy signals where structure may become apparent if portions of the signal are averaged together, i.e. resolution is sacrificed for better signal to noise ratio. The display routine automatically scales both axis (to within a factor of 2). It can also inform the operator what full scale corresponds to in number of counts. The display routine is always running, even while data are being taken, so that the TOF spectrum can be seen to "grow".

The foreground program handles interrupts both from the interface and from the teletype keyboard. If the interface wishes to inform the computer

*Actually the number of addressed bins minus 2 or 3 for a safety factor since the last bin is interrupted by the TOF pulse and is not always valid.

of something, it generates an interrupt and then the computer generates on Input Output Transfer that transfers a STATUS WORD into the accumulator. The computer then "interrogates" this status word where each bit has the following meanings. Bit zero active (equal to 1) means the bin time is too small i. e. the DMA system is attempting to data break faster than the computer can handle it. The computer will type "BIG TOO FAST" and the operator must reload the bin time generator (see Table I) with a larger time and hit "R" for run again. A reasonable minimum bin time is 5 μsecs (bintime must be in whole number μsecs only) although the computer can go as fast as 3 μsecs if everything stays in sync.

Bit one active means that the prescribed counting time has elapsed. The computer stops the data taking and types out "TIME'S UP". The operator may then do one of several things. He may print out the data (see below). He may continue data taking for another prescribed counting time by pressing "R". If the present data do not look good the operator may erase them by pressing "K" and start over. Both the counting time clock and the bin time generator "remember" their values unless reloaded or unless the computer is turned off. The contents of the counting time clock can be read even while the experiment is running so the operator can see how much longer he has to wait. Also he may stop the experiment at any time (press "S") and read the CTC to see how long the experiment has been counting for. Loading the CTC entails an inaccuracy of about ±3%, but reading the CTC gives the counting time exactly.

Bit two active signifies an overflow into the 12th bit while DMA adding to memory. The computer stops the data taking and then executes the previously described double precision add routine. After this is complete the computer restarts the data taking.

The computer can also send commands to the interface. They can be in the form of an IOT that transfers a command work to the interface. The details are shown in Table II.

The machine-operator interface consists of a teletype for input and output and the previously mentioned X-Y oscilliscope for output. The operator initiates computer operations by pressing a single key on the teletype keyboard. Some of these keys are "non printing" i. e. they transfer commands to the computer but the computer does not echo back anything so the Teletype does not print anything. Table I gives a list of all the eyboard commands. Any character other than those listed causes the computer to echo a carriage return and line-feed back to the Teletype. When loading numbers the format should be as described in "Introduction to Programming" Vol II floating point package DEC-08-YQ2B-B. (When loading the BTG only whole μsecs are loaded. Thus 13.8 will be loaded as 13 μsecs.). Note that while the experiment is running, the computer should not be in the comment mode since the interrupt system is off in this mode and a computer won't be able to process a "TIME'S UP" or "OVERFLOW" interrupt. Note also that single precision data can be added to the double precision data at any time while the data taking is in process by pressing "L" (or "W"). If the experiment is "STOPPED", however, pressing either L or W will result in the computer adding single precision to the double precision data and printing out the double precision data. Note also the discrepencies listed under "N" (NUM. BINS) and "[" (NS).

The "delay time" mentioned under "LOAD PARA" and "NS" is merely a constant that is subtracted off the accumulated bin time in the "WRITE DATA" program. For example, if the bin time is 10 μsecs and the delay time is -50 μsecs then the first bin is at 55 μsecs, the second at 65 μsecs etc. The sense of this delay time is such that positive delay

Table I.

OPERATING INSTRUCTIONS FOR THE EXPERIMENT CONTROL PROGRAM

KEY	NAME	DESCRIPTION
A	NCYCLE	LOADS TIME TOF WHEEL PULSE COUNTER. HIT A, COMPUTER WILL TYPE "#CYCLES=", TYPE AND INTEGER HIT RETURN
B	BIN TIME	LOADS THE BIN TIME GENERATOR. HIT 'B', COMPUTER WILL TYPE "BT=", THEN OPERATOR CAN TYPE IN THE VALUE HE WANTS (IN MICRO-SECONDS). SEE 'INPUT FORMAT'.
C	CONTINUE	TELLS THE COMPUTER TO CONTINUE COUNTING AFTER HAVING BEEN STOPPED. DOES NOT RESET THE COUNTING TIME CLOCK. (IF CT=100 AND EXP. STOPPED AT 70, THEN HITTING 'C' WILL CAUSE COMPUTER TO CONTINUE COUNTING FOR 30 SEC.)
E	READ CTC	CAUSES COMPUTER TO PRINT OUT THE CURRENT CONTENTS OF THE COUNTING TIME CLOCK, I. E. HOW LONG THE COMPUTER HAS BEEN COUNTING FOR.
F	FULL SCALE	CAUSES THE COMPUTER TO PRINT WHAT FULL SCALE (10 VOLTS) ON THE DISPLAY CORRESPONDS TO IN TERMS OF COUNTS. WORKS FOR ANY MODE OF THE DISPLAY ROUTINE.
K	KILL	ERASES DATA FIELD. 'RUN' DOES NOT DO THIS.
L	LOAD	CURRENTLY IDENTICAL TO 'W'.
N	NUM. BINS	LOADS THE NUMBER OF 'BINS' THAT THE COMPUTER DISPLAYS OR PRINTS OUT. HIT 'N', COMPUTER WILL NOT TYPE ANYTHING, OPERATOR CAN THEN TYPE IN WHAT HE WANTS. CURRENT DISCREPENCY: N IS THE NUMBER OF POINTS THAT THE DISPLAY WILL SHOW BUT THE WRITE OUT ROUTINE WILL ONLY PRINT UP TO BIN NUMBER N. THESE ARE NOT EQUIV-ALENT UNLESS 'NS' IS EQUAL TO ONE.
Q	QUEARY	CAUSES THE COMPUTER TO PRINT OUT THE STATUS OF THE EXPERIMENT: RUNNING OR STOPPED.
U	SINGLE PRE.	CAUSES THE DISPLAY ROUTINE TO LOOK AT THE SINGLE PRECISION DATA FIELD.
V	DOUBLE PRE.	CAUSES THE DISPLAY ROUTINE TO LOOK AT THE DOUBLE PRECISION DATA FIELD.
X	SIG. + NOISE	CAUSES THE DISPLAY TO LOOK AT BEAM ON DATA FIELD.
Y	NOISE	CAUSES THE DISPLAY TO LOOK AT THE BEAM OFF DATA FIELD.
Z	SIGNAL	CAUSES THE DISPLAY TO SHOW THE ARITHEMATICAL DIFFERENCE OF THE BEAM ON AND BEAM OFF DATA FIELDS.
R	RUN	RESETS THE COUNTING TIME CLOCK AND THEN STARTS COUNTING.
S	STOP	STOPS THE EXPERIMENT.
T	COUNT TIME	LOADS THE COUNTING TIME. HIT 'T', COMPUTER WILL TYPE "CT=", THEN OPERATOR CAN ENTER THE AMOUNT OF TIME HE WANTS THE EXPERIMENT TO COUNT FOR. THIS TIME MUST BE BETWEEN 2049 AND 204799 SECONDS. SECONDS IS THE ONLY UNIT TO BE USED. THIS TIME IS ACCURATE TO ABOUT + OR - 3%. THE TIME READ WHEN 'E' IS HIT IS, HOWEVER, EXACT.
W	WRITE DATA	CAUSES COMPUTER TO PRINT OUT THE CONTENTS OF THE DATA FIELD IN THE FOLLOWING FORMAT. BIN NUMBER, TIME IN MICRO-SECONDS THAT THIS BIN CORRESPONDS TO, TOTAL SIGNAL PLUS NOISE (BEAM ON DATA FIELD), TOTAL NOISE (BEAM OFF DATA FIELD), SIGNAL (BEAM ON - BEAM OFF), STATISTICAL NOISE (SQUARE ROOT(S+N + N)), VELOCITY IN CM/SEC, AND FLUX AT THIS VELOCITY.

←	COMMENT	ALLOWS OPERATOR TO TYPE COMMENTS. HIT ' ←' (SHIFT O), COMPUTER WILL TYPE '/', TYPE ANYTHING YOU WANT. RETURN WILL CAUSE CARRIAGE RETURN LINE FEED AND WILL GET COMPUTER OUT OF COMMENT ROUTINE. TO TYPE FURTHER COMMENTS, OPERATOR MUST HIT ' ← ' AGAIN.
↑	LOAD PARA.	LOADS EXPERIMENTAL PARAMETERS. HIT ' ', (SHIFT N), COMPUTER WILL DO NOTHING, TYPE IN THE DELAY TIME IN MICRO-SECONDS (PLUS OR MINUS), TYPE SPACE, TYPE IN THE FLUX FUDGE FACTOR, (USUALLY 10000), TYPE RETURN. (WHERE RETURN AND SPACE ARE THE SINGLE KEYS ON THE KEYBOARD.)
[	NS	TELLS COMPUTER HOW MANY BINS YOU WANT IT TO SUM UP, (AVERAGE OVER). HIT '[', (SHIFT K), COMPUTER WILL PRINT "NS= ", TYPE IN AN INTERGER, TYPE RETURN. EXAMPLE: IF NS=3, THEN COMPUTER WILL, (WHEN TOLD), TYPE THE SUM OF THE CONTENTS OF BINS 1, 2, AND 3 AND CALL IT BIN NUMBER 3. CONTINUING, IT WILL SUM BINS 4, 5, AND 6 AND CALL IT BIN NUMBER 6. ETC. CURRENT DISCREPENCY. THE PROPER AVERAGE TIME FOR THE SUM OF THE FIRST 3 BINS WOULD BE HALF WAY THROUGH THE SECOND ONE. I. E. IF THE BIN TIME WERE 10 μSECS, (AND THE DELAY TIME ZERO), THIS PROGRAM TYPES OUT THE TIME HALF-WAY THROUGH THE LAST BIN OF THE SUM, I. E. IN THIS EXAMPLE 25 μSECS.

Table II

OP-CODE	INSTRUCTION
6170	LOAD COMMAND WORK
6171	SEND STATUS WORD TO ACC
6172	SEND COUNTING TIME CLOCK TO ACC
6173	LOAD COUNTING TIME CLOCK (CTC)
6174	LOAD BIN TIME GENERATOR
6175	LOAD MODE

DATA BIT	COMMAND	DATA BIT	STATUS
0		0	BIN TIME TOO FAST FLAG
1		1	TIME'S UP FLAG
2	CLEAR TIME'S UP FLAG	2	OVERFLOW FLAG
3	CLEAR OVERFLOW FLAG	3	
4	RESET CTC	4	
5	SET RUN	5	
6	SET STOP	6	
7	CLEAR BIN TIME TOO FAST	7	
8		8	
9		9	
10		10	
11		11	"GO" FLAG (1 = running, 0 = stopped)

corresponds to the detected ions somehow being delayed i. e. by the transit time through the quadrapole. Negative delay corresponds to the fast wheel pulse being "late" as in a mispositioned photo diode assembly or an externally applied delay of the fast wheel signal for purposes of "throwing away" the beginning portions of a TOF spectra. The latter process concerns the use of a delay generator between the fast wheel signal line driver and the computer.

The problem mentioned under "NS", i. e. that the printed accumulated bin time for an average over NS bins is not the proper average time, may be corrected by temporarily loading a new delay time = old delay time + NS x BIN TIME/2. Example: if delay time setting is - 20, NS = 4, and BIN TIME = 20 μsecs then temporary new delay time, for this NS, is +20 μsecs.

In the WRITE DATA routine the last column is called the FLUX. This is a crude inversion of the time of flight data to give a velocity distribution. As shown in Eq. 1) the "FLUX" is equal to the measured intensity as a function of time multiplied by a Jacobian of t^2/d, which is also equal to d/v^2. Our detector, however, is not a flux detector; it is a number density detector because of the following. Normally the intensity would be given by the number of counts per sec per sq cm of detector area, a flux. However, the ionization probability, at low ionization efficiency, is inversely proportional to particle velocity because those molecules going faster spend less time in the detector and therefore have less probability of being ionized. Thus we measure flux x 1/v or number density, No./cm^3. The last column, called FLUX, therefore prints out F x intensity x d/v, instead of divided by v^2. F is a fudge factor, normally 10^4, to make the flux come out to reasonable numbers.

All of the above program fits into the 4K memory space of the computer with only a few scattered locations left. Even minor additions would require purchasing more memory. Such additions could include a program to punch data onto paper tape in a format that could be read by the Computation Center's computer, or possibly a program to time normalize angular distributions and plot them out on an X-Y recorder. Finally the existing hardware would be usable, without modification, with a pseudo random TOF technique but the program would have to be expanded to include the cross correlation (actually a relatively simple procedure).

Other TOF systems, described in references 9, 10 and 11, use interfaces similar to the one presented here.

APPENDIX I: Nozzle Geometry.

The geometry of the nozzle beam source, as modified for these experiments, is as follows. The nozzle has an oriface 0.02 cm in diameter and can be moved back and forth with respect to the skimmer to maximize the beam intensity.... the normal operating distance was 1.35 cm. The conical shaped skimmer has an oriface of 0.10 cm, is 2.76 cm from the center of the collision zone (CZ), and "empties" directly into the main chamber. The beam chopper is directly in front of the downstream side of the skimmer, about 1 cm from the CZ center. This geometry was calculated so as to not produce a viewing factor if the skimmer is assumed to act as a collimator. The viewing factor is simply the fraction of the total collision region that the detector can see as a function of the laboratory angle. The slit geometry of the detector (0.38 cm at entrance 4.44 cm from CZ and 0.3 cm at the ionizer entrance 18.44 cm from CZ) gives an umbra that subtends 0.4 cm at the CZ. If the collision zone, which is trapezoidal in shape, is larger than 0.4 cm then the detector will be looking at varying volumes of reaction region as the lid is rotated causing an experimental bias in angular distribution measurements for certain angular regions over others. The easiest way to avoid this is to make sure that the largest dimension of the collision zone is less than 0.4 cm so that the detector is always viewing the whole collision zone (plus certain areas around it) at all angles.

If the skimmer was acting as a collimator, i.e. "casting" the standard umbra and penumbra "shadows", then there would be no viewing factor. However if the nozzle expansion has not frozen by the time it reaches the skimmer (i.e. the particles are still interacting with and deflecting each other) then the skimmer might act as a source giving a more divergent beam and possibly leading to a viewing factor. In fact, measurements made on the beam in this configuration, implied that this might partially be the case. Because of the geometry of the detector and because the detector rotates about the collision zone center and not about the beam radiant point the detection system can't see the beam beyond about +0.4° (assuming the skimmer as the source). Therefore another method of measuring the beam profile was used: the background pressure in detector chamber one, which should be proportional to the amount of beam entering the detector, was monitored as a function of the lid angle which could be back calculated to the detector opening distance from the beam centerline. With the nozzle at 1.35 cm from the skimmer, and if the skimmer is assumed to collimate, then the beam at the detector opening should have an umbra of 1.07 and penumbra of 1.23 cm. Approximating this as a rectangle of width 1.15 cm and convoluting with the detector opening of 0.38 cm we get an expected FWHM of 1.53 cm. The measured distribution, with 150 torr in the nozzle, had a FWHM at the detector of 1.6 cm but contained a weak tail that went out to 2.7 cm (FW1/10M), so that the skimmer might be partially operating as a source.

In order to assure freedom from a viewing factor a beam collimator/deflector was spot welded to the face of the collimating chamber directly in front of the beam chopper. It consisted of a 0.5 cm wide horizontal strip of metal with a centrally located 1 cm diameter deflector containing a 0.23 cm wide by 0.38 cm high slot for the beam to pass through. The top and bottom of the deflector portion were angled away from the beam to deflect it above and below the region of the collision zone. For a proof of the absence of a viewing factor with this collimator installed, refer to figure 14 to which the following equations apply:

$d_1 = 8.47(.1125/6.25) - .0125 = .140$ cm

$d_2 = (2.76 + .115)(.12/1.81) - .05 = .140$ cm

Now we approximate the CZ by the dotted rectangle 0.28 x 0.28 cm, an overestimate, and calculate its longest dimension, the dotted line, to be .39 cm which is less than the 0.4 cm that the detector sees. Therefore, according to this calculation, there is no viewing factor. This was confirmed when the beam and detector geometries for both the Ba and Sn experiments were fed into a computer program, written by C. A. Mims[12], that does a detailed calculation of the viewing factor taking all considerations into account. The factor was equal to 1.0 to within 0.002 for all angles. This was also confirmed experimentally by a repeat of the aforementioned beam profile measurement method.

APPENDIX II Duty Cycle

Let S and B be the signal and background cant rates respectively and let T on and T off be the time counted with the beam on and off. Then the absolute counts accumulated in the on channel is N on = T on (S+B) and off channel N off = T off (B). Now the desired quantity is the total signal counts N_s given by the equation

$$N_s = N\text{ on }(T\text{ on } + T\text{ off})/2\,T\text{ on} - N\text{ off }(T\text{ on} + T\text{ off})/2\,T\text{ off}$$

$(N_s = ((S+B)-B)(T\,on + T\,off)/2 = S(T\,on + T\,off)/2)$

Now we make the condition that statistical noise in each of the two terms of N_s be equal so as to not put too much influence on one or the other. The statistical noise of the first term is $\sqrt{N\,on}\,(T\,on + T\,off)/2\,T\,on$ since N on is an absolute number of counts with, therefore, an error of $\sqrt{N\,on}$, and (T on + T off)/2 T on is just a multiplying factor. Therefore we have the equation:

$$\sqrt{N\,on}\,(T\,on + T\,off)/2T\,on = \sqrt{N\,off}\,(T\,on + T\,off)/2\,T\,off \qquad \text{or:}$$

$$\sqrt{T\,on(S+B)}/T\,on = \sqrt{T\,off(B)}\,/T\,off \qquad \text{or:}$$

$$\sqrt{(S+B)/B} = \sqrt{T\,on/T\,off} \qquad \text{so}$$

$T\,on/T\,off = (S+B)/B$ or duty cycle $T\,on/(T\,on + T\,off) = D$

$D=[(S+B)/B]\,/[(S+B)/B+1] = (S+B)/(S+2B)$

APPENDIX III Circuit Diagrams

The detailed circuit diagrams for the TOF computer interface presented here are shown in figures 5 through 13. Only a brief description of each figure will be given. The circuits are built using mostly standard TTL circuits assembled on wire-wrap boards that plug into the PDP8/e Unibus. Not shown are the two D to A circuits that control the X-Y oscilliscope.

Fig. 5: Experiment control board including the GO flip flop (E30), the differentiator (E38), the delay generator (E26), the DMA ENABLE (E21), the DMA ADDRESS counters (E41 and E20) and the BTG too fast interrupt flag (E29). The differentiated slow wheel signal is gated into the delay generator by the GO flip-flop. The RUN command (data G valid) is loaded into E22 by IOTO and enables GO on the rising edge of SLOW WHEEL signal. The delayed signal (E26 pin 6 and 12) is passed to E18/E22 which is a glorified R/S flip flop. The rn signal enables (E21 pin 8) the DMA

enable (E21 pin 5) on the next falling edge of the TOF wheel pulse (E17 pin 10 from E39-6). This gates the BTG pulses (HA1-18) into the address counters (E41, E20). If the address counters time out before the next TOF pulse (256 cycles) the data breaking is stopped via the action of E21 pin 2 on the clear (pin 10). The BREAK REQUEST flag (E29) initiates DMA request via the action of the BTG (2, E25 pin 6). If another such request should come before the previous one is granted (CLR REQUEST) the BTG TOO FAST flag (E29 pin 3) will be set (on the coincidence of BRK REQUEST and BTG). The steering logic (E18 pins 5 and 6) is toggled by BTG.

Fig. 6: CYCLE COUNTERS. The cycle counters are loaded via IOTS. Upon being enable by the delayed slow wheel signal (E18 pin 3) the leading edges of TOF pulses start decrementing the cycle counters (E03, E04, E09). Upon time out the counters generate a pulse at E09 pin 13 which is passed through a one shot (E28) to generate the stop data pulse which disables the DMA ENABLE flip flop on the falling edge of the present TOF pulse (fig 6 E21). This pulse also presets the cycle counters to the value stored in the cycle count memory (Eo7, E02), and the process continues as described in the text of this chapter. The detailed timing diagram of this system is shown in figure 13. (The circuit works for any case of DSW coincident with FW).

Fig. 7: DATA COUNTERS. The signal counts from the PM discriminator (TTL level, negative going) are passed via the steering logic (C7-1, C7-2) to the A or B counters (A, B, C, 5 or A, B, C, 6). The 82591 is manufactured by Signetics Corp. The sterning logic also directs which counters are to be read by the computer (C3; A, B, D3; A, B, D, 4; the 74126's are TRI-STATE buffers), and also which are to be

cleared by CLEAR REQUEST (B8). The TOF pulses (C7-6), from the TOF wheel discriminator (B8 pin 9) also clear the counters.

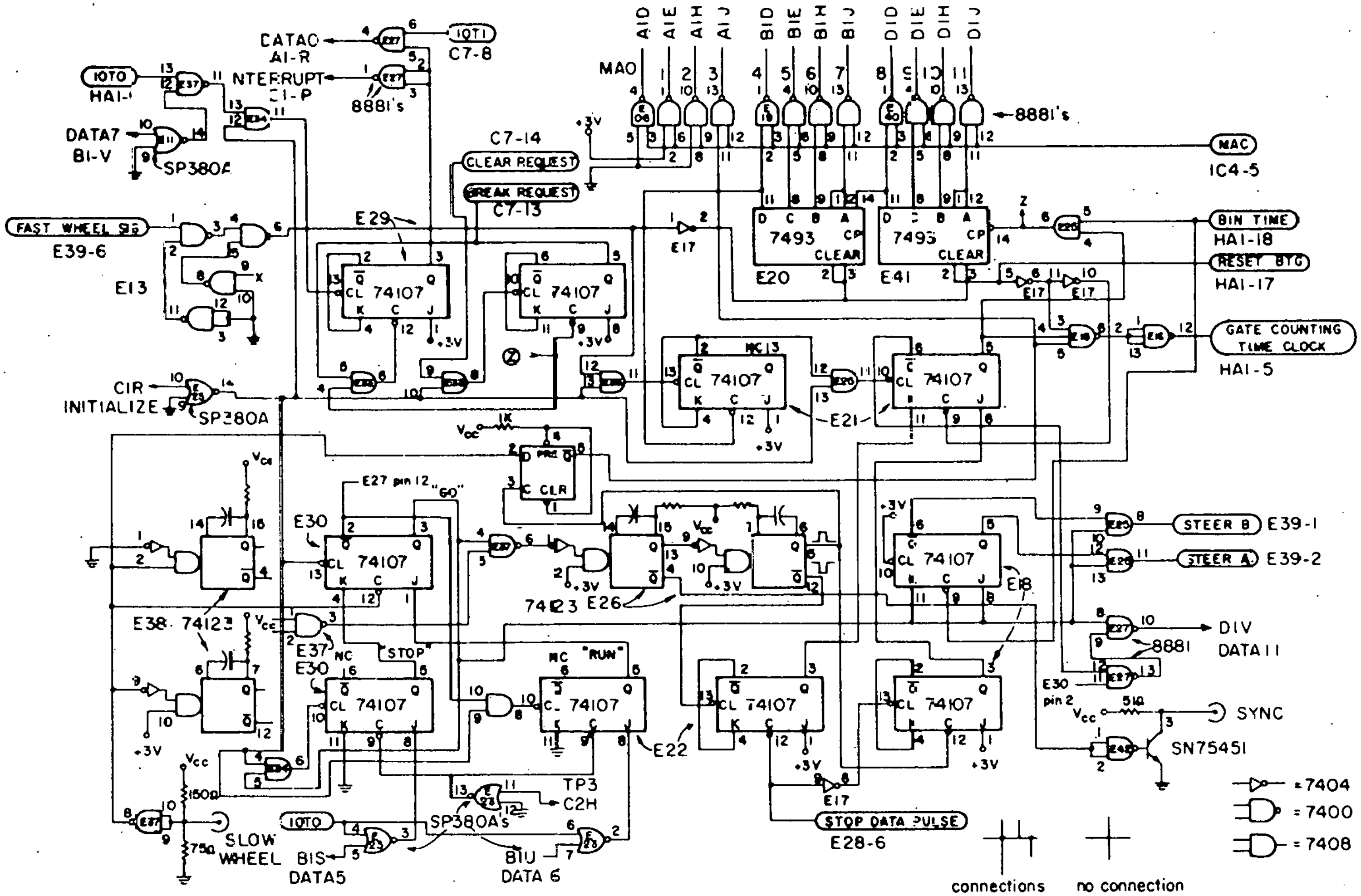
Fig. 8: BIN TIME GENERATOR (BTG). The bin time (μsecs) is loaded by IOT4 into the 74174's. The crystal oscillator (E34) toggles the counters (E29, E25, E22) until their out matches the value held in the 74174's at which time the comparators (E28, E24, E20) bring the one shot's input up (E18 pin 2) causing a BTG pulse at (HA1-18) and resetting the counters for another cycle. (The counters are also reset by the TOF pulse (MA1-17))

Fig. 9: COUNTING TIME CLOCK (CTC). The binary mantissa of the desired count time is loaded by IOT3 from DATA lines 0 through 7 and this number is stored in 74174's and compared with the contents of counters much the same way the BTG works. In order to have a large range of count times, the CTC is designed to accept a binary exponent, in addition to the mantissa, loaded the same way from bits 7 through 11. This exponent is read by the MK5009 which is a MDS crystal oscillator and programmable divider. The MK5009 produces an out-put count at the rate of $1 \text{MHz} \div 2^n$ where n is the binary exponent. These output pulses (E37 pin 1) are counted by the binary counters (E33, E21, E08) and when the output of the last two (E21, E08) is equal to the stored mantissa the comparators trigger the TIME'S up interrupt flag (74107 pin 3). The count time can be read by IOT2... notice that while the "alarm" feature triggers off only the last two counters the read feature reads all three counters and gives the exact time.

Fig. 10: DMA CONTROL and Fig. 11: IOT CONTROL see the DEC manual "Small Computer Handbook" for an explanation of these circuits.

(Fig. 10 is correct.... DEC's figure contains an error.)

Fig. 13: The circuits for the small auxillary electronic devices are self explanatory. The following power supply voltages apply to fig. 13: NES29K: pin 10 = +6V, pin 3 = -6V, pin 9 = +SV; SN 75451P pin 8 = + 5V, pin 4 = GND. Use ground plane PC construction and bypass all power supplies with .05μF at 20 V ceramic capacitors.



DATAO
AI-R
IOTI
C7-8
IOTO
HAI-
INTERRUPT
CI-P
8881's
DATA7
BI-V
SP380A
MAO
AID
AIE
AIH
AIJ
BID
BIE
BIH
BIJ
DID
DIE
DIH
DIJ
+3V
MAC
IC4-5
C7-14
CLEAR REQUEST
BREAK REQUEST
C7-13
FAST WHEEL SIG
E39-6
E13
E29
74107
E17
7493
CLEAR
E20
E41
BIN TIME
HAI-18
RESET BTG
HAI-17
GATE COUNTING TIME CLOCK
HAI-5
CIR
INITIALIZE
E21
E27 pin 12 "GO"
E30
E38 74123
74123
E26
E37
"STOP"
"RUN"
E22
E18
STEER B
E39-1
STEER A
E39-2
DIV
DATA11
8881
E30 pin 2
SYNC
SN75451
TP3
C2H
SP380A's
SLOW WHEEL
BIS
DATA5
BIU
DATA 6
STOP DATA PULSE
E28-6
=7404
=7400
=7408
connections
no connection

Fig. 5

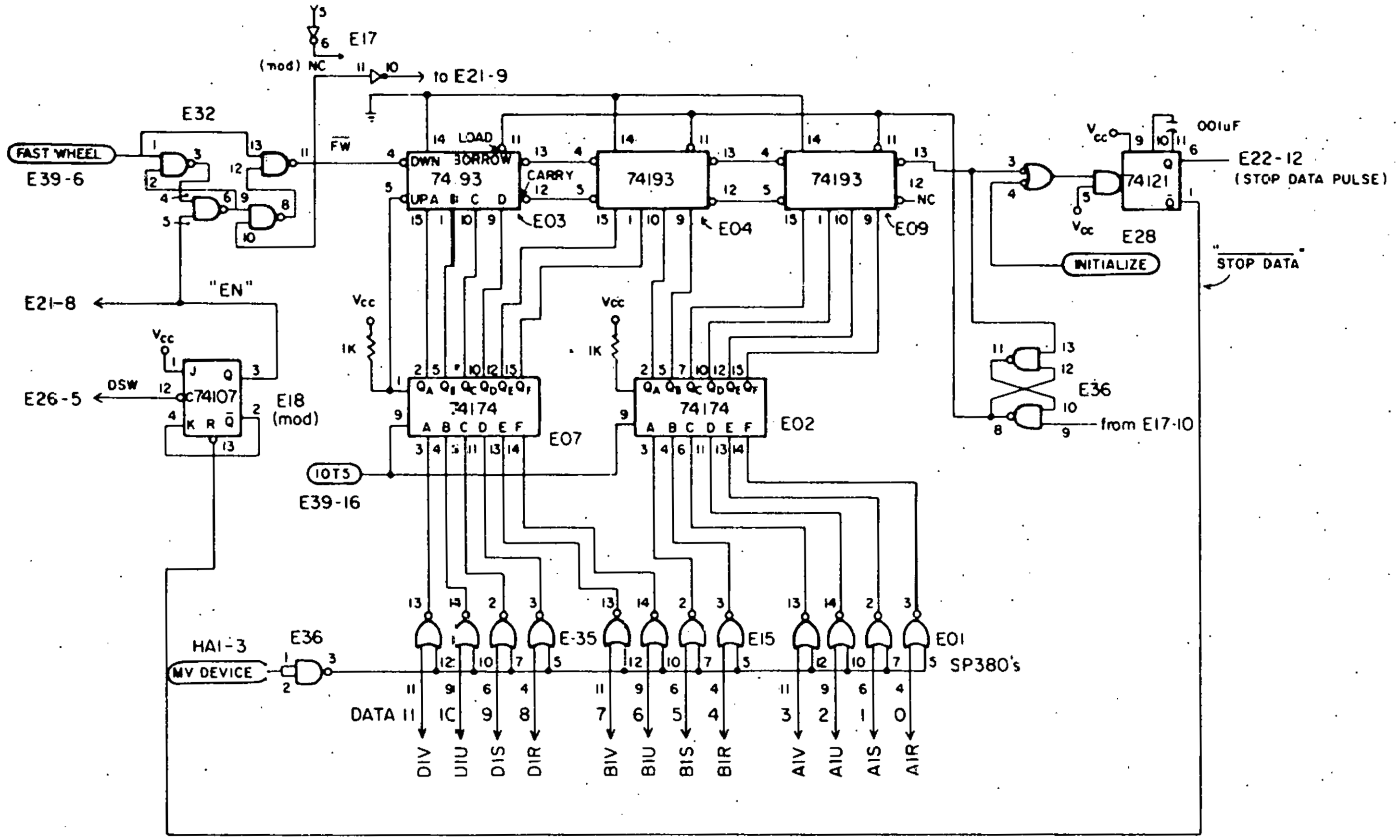

FAST WHEEL
E39-6
E32
E17
(mod) NC
to E21-9
FW
74 93
LOAD
BORROW
CARRY
E03
74193
E04
74193
E09
E28
74121
.001uF
E22-12
(STOP DATA PULSE)
INITIALIZE
"STOP DATA"
E21-8
"EN"
E26-5
DSW
74107
E18
(mod)
74174
E07
74174
E02
E36
from E17-10
IOTS
E39-16
HA1-3
MV DEVICE
E36
E-35
E15
E01
SP380's
DATA 11
10
9
8
7
6
5
4
3
2
1
0
DIV
DIU
DIS
DIR
BIV
BIU
BIS
BIR
AIV
AIU
AIS
AIR

Fig. 6

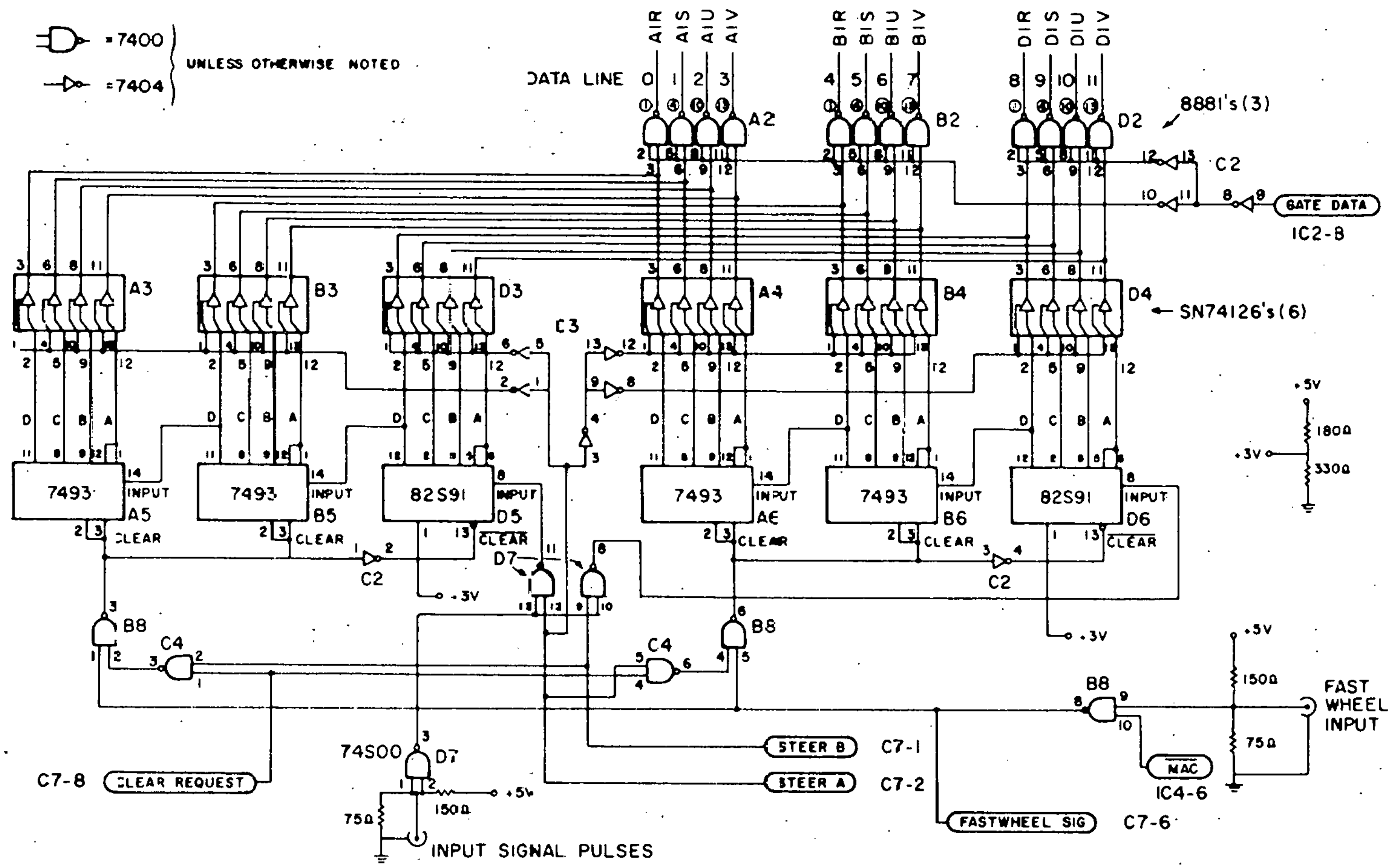
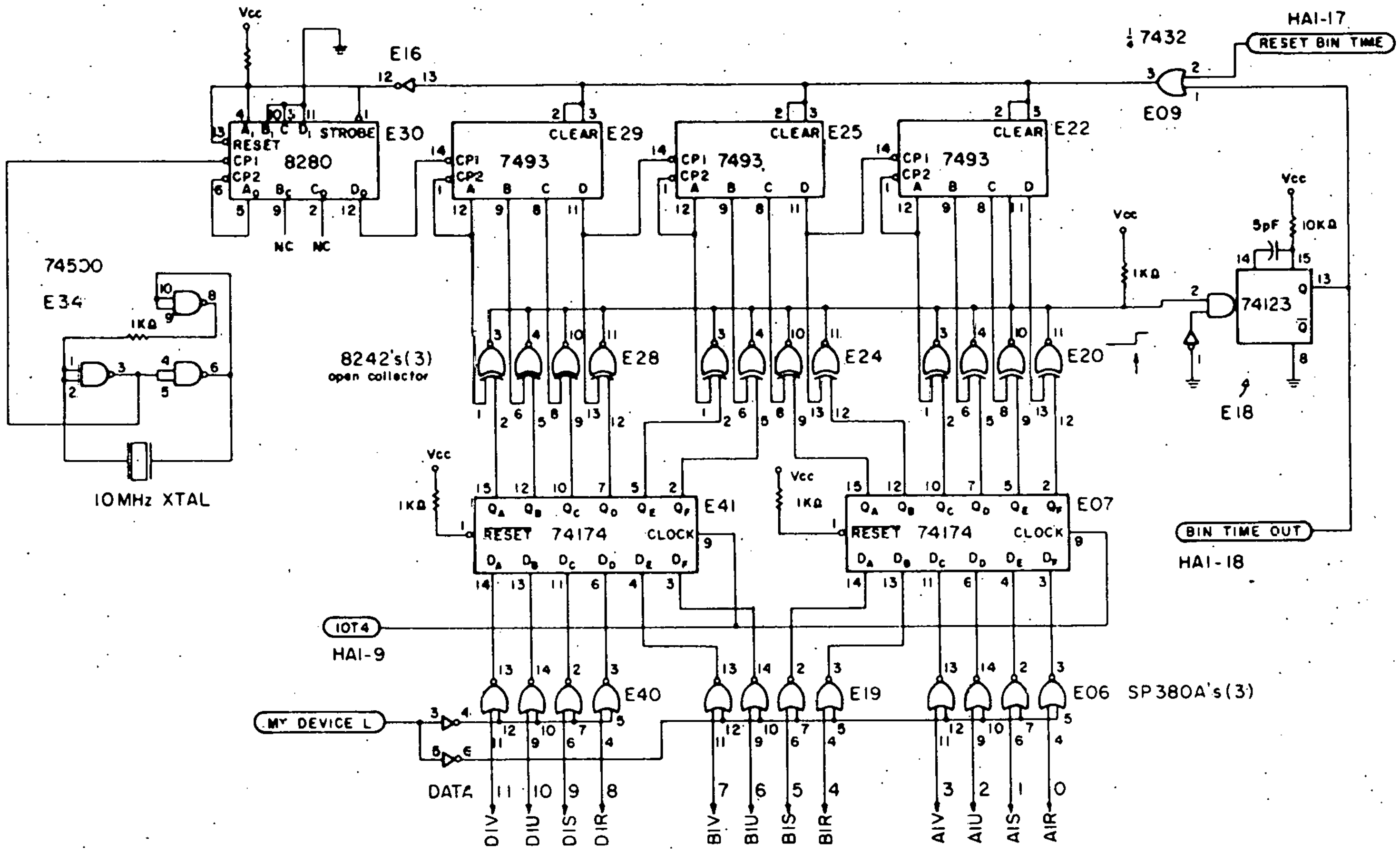

=7400
=7404
UNLESS OTHERWISE NOTED
DATA LINE 0 1 2 3 4 5 6 7 8 9 10 11
AIR AIS AIU AIV
BIR BIS BIU BIV
DIR DIS DIU DIV
A2
B2
D2
8881's (3)
C2
GATE DATA
IC2-8
A3
B3
D3
C3
A4
B4
D4
SN74126's (6)
7493
INPUT
A5
CLEAR
7493
B5
CLEAR
82S91
D5
CLEAR
7493
A6
CLEAR
7493
B6
CLEAR
82S91
D6
CLEAR
+5V
180Ω
+3V
330Ω
C2
D7
B8
C4
C4
B8
+3V
+5V
150Ω
75Ω
FAST WHEEL INPUT
B8
MAC
IC4-6
STEER B
C7-1
STEER A
C7-2
FASTWHEEL SIG
C7-6
C7-8
CLEAR REQUEST
74S00
D7
+5V
150Ω
75Ω
INPUT SIGNAL PULSES

Fig. 7



Vcc
E16
¼ 7432
HAI-17
RESET BIN TIME
E09
RESET
CP1
CP2
8280
STROBE
E30
7493
CLEAR
E29
E25
E22
NC
74S00
E34
1KΩ
10MHz XTAL
8242's(3)
open collector
E28
E24
E20
5pF
10KΩ
74123
E18
74174
CLOCK
E41
E07
BIN TIME OUT
HAI-18
IOT4
HAI-9
MY DEVICE L
E40
E19
E06 SP380A's(3)
DATA
DIV
DIU
DIS
DIR
BIV
BIU
BIS
BIR
AIV
AIU
AIS
AIR

Fig. 8

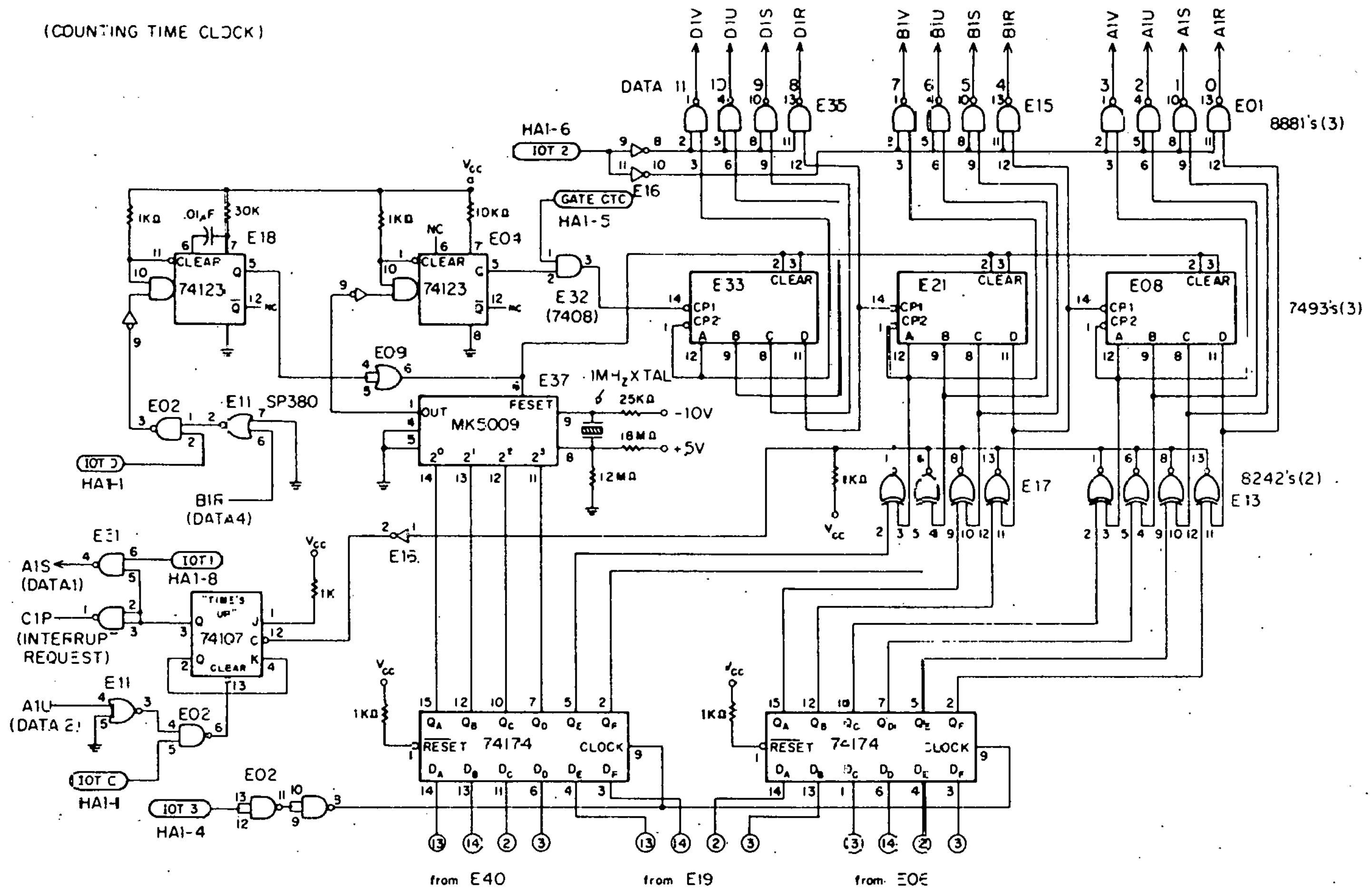

(COUNTING TIME CLOCK)
D1V D1U D1S D1R
B1V B1U B1S B1R
A1V A1U A1S A1R
DATA 11 10 9 8
E35
7 6 5 4
E15
3 2 1 0
E01
8881's (3)
HA1-6
IOT 2
E16
GATE CTC
HA1-5
E18
74123
E04
74123
E32
(7408)
E33
E21
E08
CLEAR
7493's (3)
E09
E37
1MHz XTAL
MK5009
25KΩ
-10V
18MΩ
+5V
12MΩ
E02
E11
SP380
IOT D
HA1-1
B1R
(DATA4)
E17
E13
8242's (2)
A1S
(DATA1)
IOT 1
HA1-8
C1P
(INTERRUPT REQUEST)
"TIME'S UP"
74107
A1U
(DATA 2)
IOT C
HA1-1
IOT 3
HA1-4
74174
RESET
CLOCK
from E40
from E19
from E08

Fig. 9

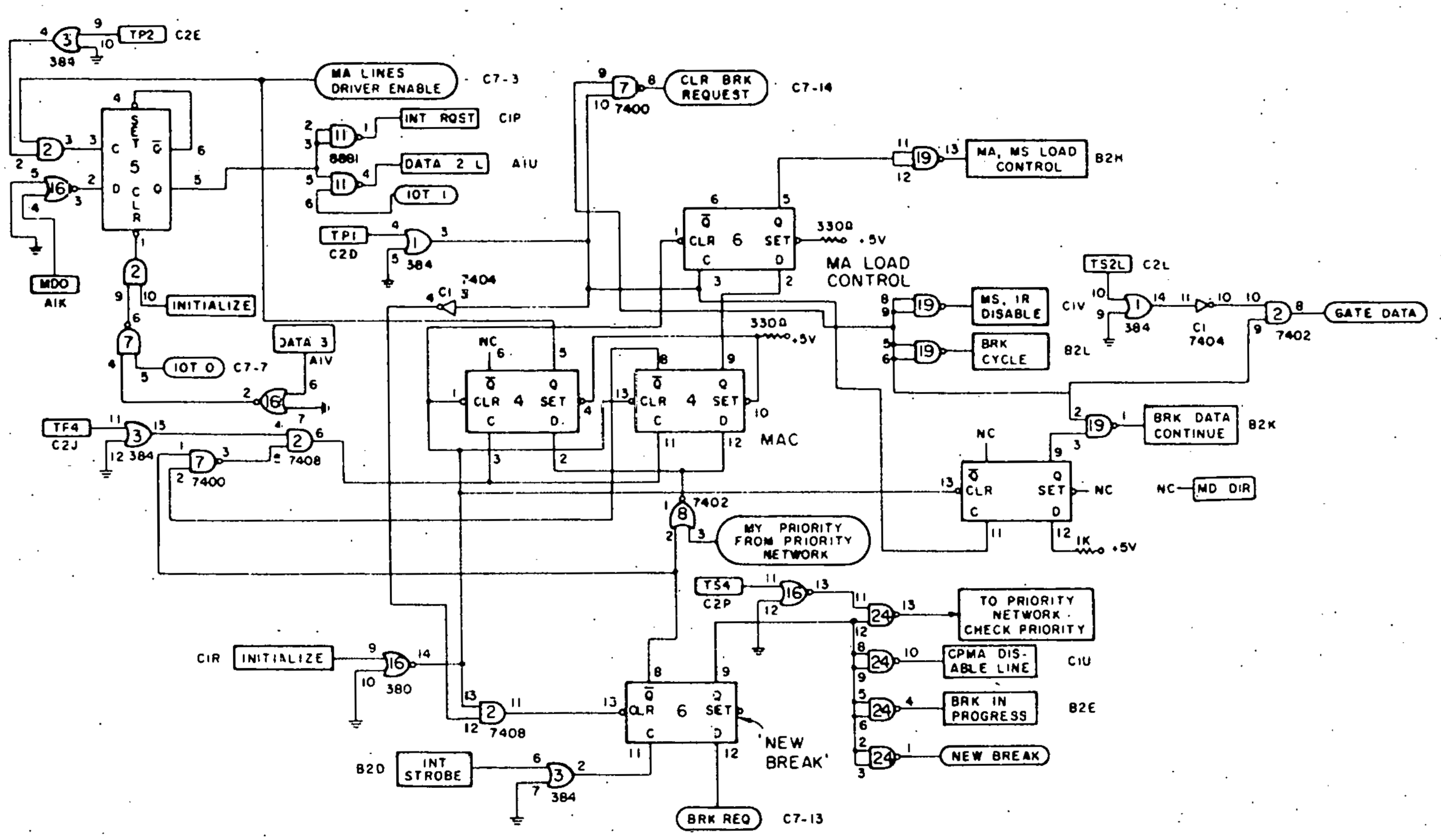

TP2
C2E
MA LINES DRIVER ENABLE
C7-3
CLR BRK REQUEST
C7-14
INT RQST
CIP
DATA 2 L
AIU
IOT 1
MDO
AIK
INITIALIZE
IOT 0
C7-7
DATA 3
AIV
TP1
C2D
TF4
C2J
MA, MS LOAD CONTROL
B2H
MA LOAD CONTROL
MS, IR DISABLE
CIV
BRK CYCLE
B2L
TS2L
C2L
GATE DATA
MAC
BRK DATA CONTINUE
B2K
MD DIR
MY PRIORITY FROM PRIORITY NETWORK
TS4
C2P
TO PRIORITY NETWORK CHECK PRIORITY
CPMA DISABLE LINE
CIU
BRK IN PROGRESS
B2E
NEW BREAK
'NEW BREAK'
CIR
INITIALIZE
B2D
INT STROBE
BRK REQ
C7-13

Fig. 10

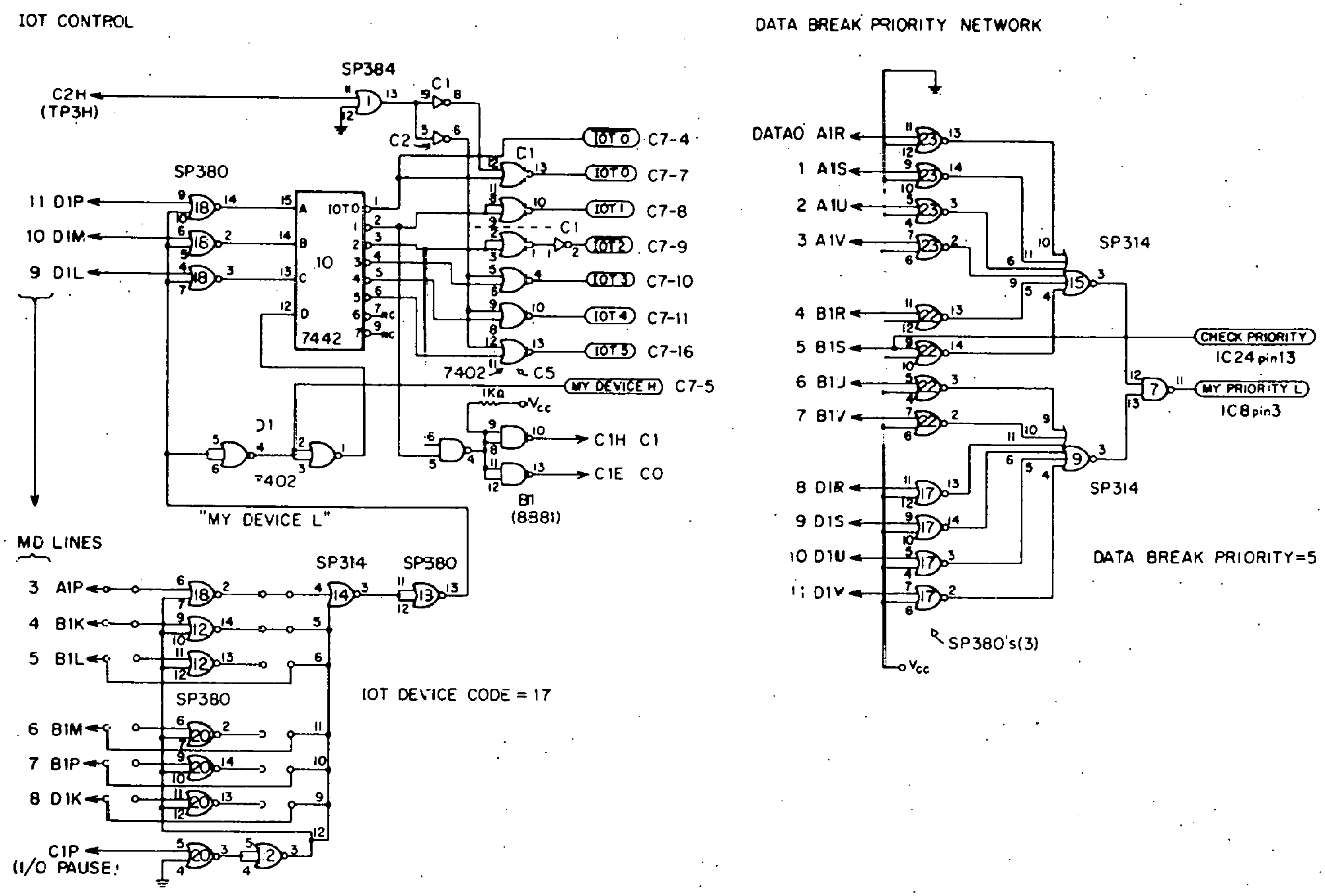
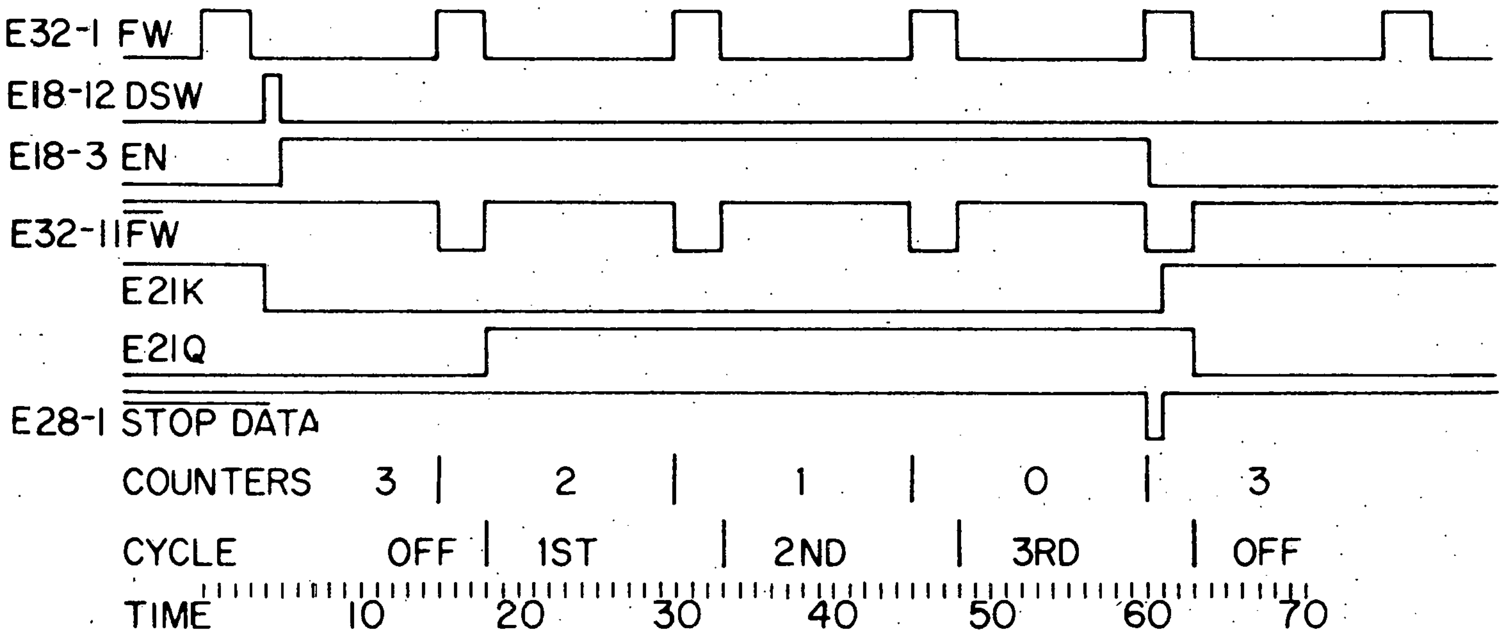

IOT CONTROL
SP384
C2H
(TP3H)
C1
C2
SP380
11 D1P
10 D1M
9 D1L
7442
IOT0
IOT0 C7-4
IOT0 C7-7
IOT1 C7-8
IOT2 C7-9
IOT3 C7-10
IOT4 C7-11
IOT5 C7-16
7402
C5
MY DEVICE H C7-5
1KΩ
Vcc
C1H C1
C1E C0
B1
(8881)
D1
7402
"MY DEVICE L"
MD LINES
3 A1P
4 B1K
5 B1L
6 B1M
7 B1P
8 D1K
C1P
(I/O PAUSE)
SP314
SP380
IOT DEVICE CODE = 17
DATA BREAK PRIORITY NETWORK
DATA0 A1R
1 A1S
2 A1U
3 A1V
4 B1R
5 B1S
6 B1U
7 B1V
8 D1R
9 D1S
10 D1U
11 D1V
SP314
CHECK PRIORITY
IC24 pin13
MY PRIORITY L
IC8 pin3
SP380's(3)
DATA BREAK PRIORITY=5

Fig. 11



CYCLE COUNTER TIMING DIAGRAM
(NCYCLE=3)

Fig. 12

PM AND TOF DISCRIMINATORS
(TOF VALUES IN PARENTHESES)

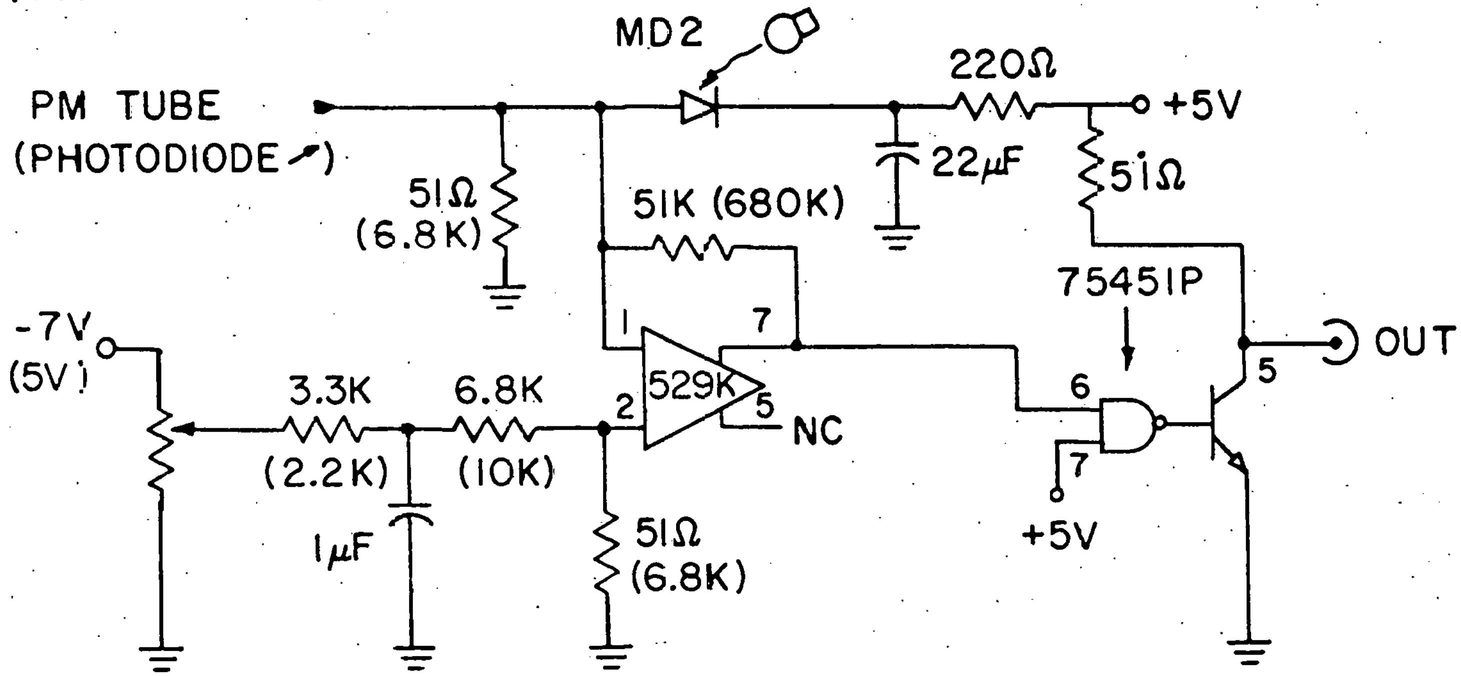
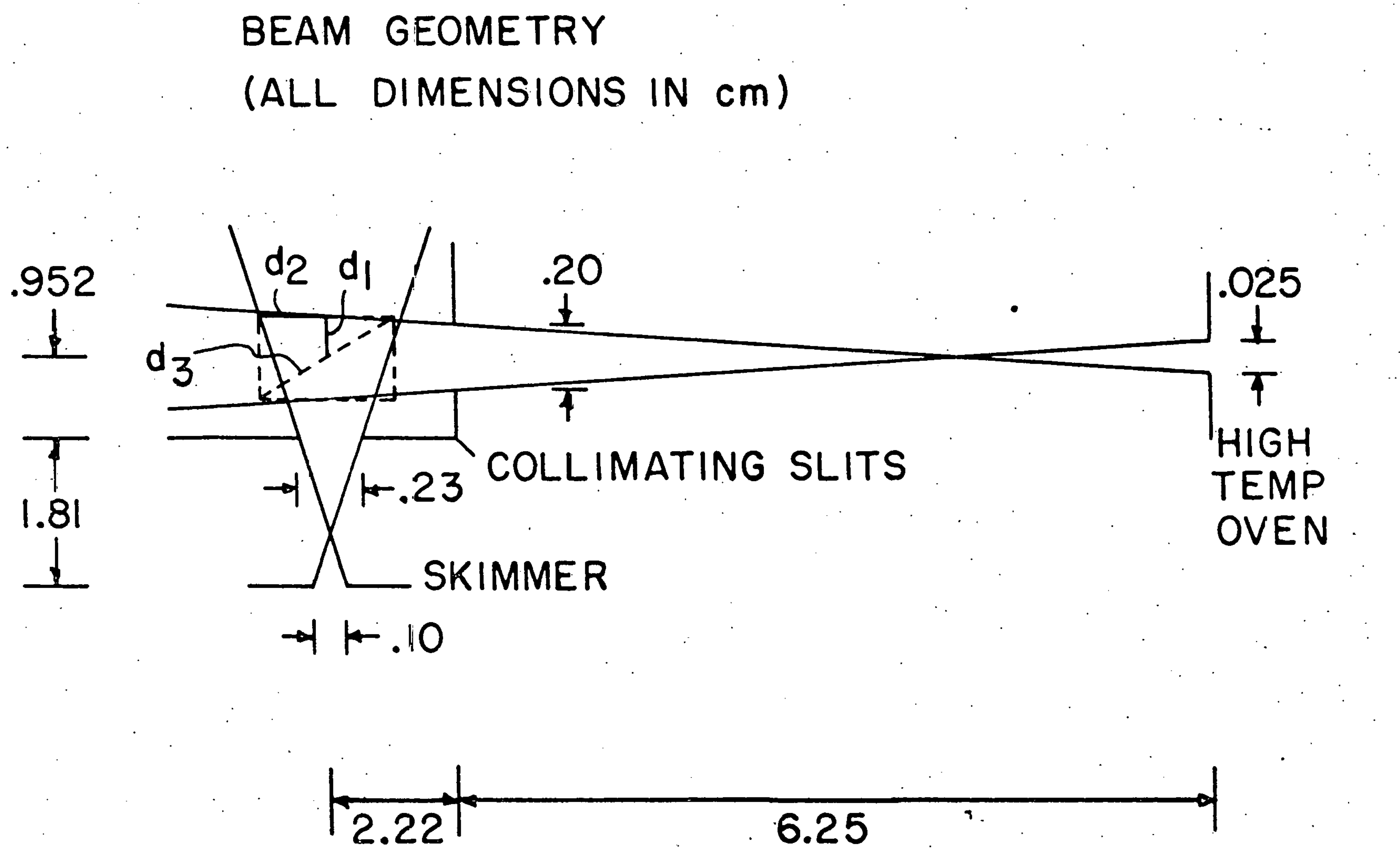


Fig. 13



BEAM GEOMETRY
(ALL DIMENSIONS IN cm)
.952
d_2
d_1
d_3
.20
.025
1.81
.23
COLLIMATING SLITS
HIGH TEMP OVEN
SKIMMER
.10
2.22
6.25

Fig. 14

References

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COMPUTER PROGRAM LISTING

```
0000   0000              0000
0001   3030              DCA AC
0002   7004              RAL
0003   5010              JMP .+5
0004   0000              0000
0005   7400              7400
0006   7200              7200
0007   5600              5600
0010   3031              DCA L
0011   6171              6171                /READ STATUS WORD
0012   7100              CLL
0013   7010              RAR
0014   7440              SZA
0015   5100              JMP EXPS
0016   6031              KSF
0017   5022              JMP RESTOR
0020   5777              JMP KEYFLG
       7402              HLT
       7300   RESTOR,    CLA CLL
       1031              TAD L
       7010              RAR
       1030              TAD AC
       6001              ION
       5400              JMP I 0
0030   0000   AC,        0
       0000   L,         0
       0000   CRLF,      0
       7300              CLA CLL
       6046              TLS L
       1076              TAD LF
       5063              JMP 63
       1000   FLAGR,     1000R               /FLAGR=0, RUNNING
                                             /FLAGR≠0, STOPPED
0063   6046              TLS
       6041              TSF
       5064              JMP.-1
       7200              CLA
       1077              TAD CR
0070   6046              TLS
       6041              TSF
       5071              JMP.-1
       6042              TCF
       7300              CLA CLL
       5432              JMP I CRLF
       0212   LF,        212
       0215   CR,        215

              *100
0100   7300   EXPS,      CLA CLL
       6171              6171
       7006              RTL
       7004              RAL
```

```
0104  7420            SNL
      5710            JMP I 110
      5507            JMP I GRAND
      1000  GRAND,    1000
0110  1140            1140

            *111
0111  0000  SPACE,    0
      7300            CLA CLL
      1511            TAD I SPACE
      7041            CIA
      3126            DCA NSPCS
      1124            TAD TK240
      4525            JMS I ATLSX
0120  2126            ISZ NSPCS
      5116            JMP.-3
      2111            ISZ SPACE
      5511            JMP I SPACE
      0240  TK240,    240
      1242  ATLSX,    1242
      0000  NSPCS,    0

            *127
0127  4533  KILL,     JMS I CLRK
0130  2000            2000
      3000            3000
      5144            JMP 144
      1546  CLRK,     1546
      0000  INPUT,    0
      7300            CLA CLL
      6046            TLS
      4405            JMS I 5
0140  6041            TSF
      5140            JMP.-1
      6042            TCF
      5157            JMP FIX
      6001            ION
      5546            JMP I DISPZ
      1600  DISPZ,    1600
      0000  OUTPUT,   0
0150  7000            NOP
      6046            TLS
      4406            JMS I 6
      6041            TSF
      5153            JMP.-1
      6042            TCF
      5547            JMP I OUTPUT
      7300  FIX,      CLA CLL
0160  1171            TAD THIR
      1044            TAD 144
      3170            DCA NFIX
      1045            TAD 45
      7010            RAR
      2170            ISZ NFIX
```

```
00166  5164                JMP. -2
00167  5534                JMP I INPUT
00170  0000  NFIX,         O
00171  7765  TMIR,         (-13)
00172  0000  CTHOLD        O
00173  0000                O
00174  0000                O
00175  7600  ABSTOP,       7600
00176  0365
             *200
00200  6002                IOF
00201  5602                IMP I 202
00202  1300                1300
             *203
00203  4134                JMS  INPUT
00204  4407                JMS I 7
00205  6362                FPUT 362
00206  0000                FEXT
00207  5022                JMP  RESTOR
             *400
00400  7300  KEYFLG,  CLA CLL
00401  6036           KRB
00402  1223           TAD TZO
00403  7510           SPA
00404  5777           JMP QM
00405  3221           DCA      OFFSET
00406  1221           TAD      OFFSET
00407  1224           TAD TF
00410  7700           SMA CLA
00411  5777           JMP      QM
00412  1260           TAD      SLIST
00413  1221           TAD      OFFSET
00414  3222           DCA      INSTRR
00415  1622           TAD I    INSTRR
00416  3222           DCA      INSTRR
00417  5622           JMP I INSTRR
00420  2402           RLT
00421  0000  OFFSET,  0000
00422  0000  INSTRR,  0000
00423  7477  TZO,     -301
00424  7741  TF,      -37
             *425
00425  4631  STOPX,   JMS  SSTOP
00426  7240           CLA CMA
00427  3037           DCA FLAGR
00430  5022           JMP  RESTOR
00431  7600           SSTOP
00432  1237  RNX,     TAP  K17
00433  6170           6170
```

```
00433  6170                  6170
00434  7300                  CLA  CLL
00435  3037                  DCA  FLAGR
00436  5022                  JMP  RESTOR
00437  1700   147,           1700
00440  0000
00441  0000
00442  7000   STATUS,        NOP
00443  6171                  6171
00444  7010                  RAR
00445  7430                  SZL
00446  5252                  JMP 52
00447  4656                  JMS  I  ATYPX
00450  5251                  CMSTOP
00451  5254                  JMP 54
00452  4656                  JMS  I  ATYPX
00453  5245                  CMRUN
00454  4032                  JMS  CRLF
00455  5022                  JMS  RESTOR
00456  1200   ATYPX,         1200
00457  0005

              *460

00460  0461   SLIST,         0461          /ADDR. 1ST PNTR.
00461  1063                  NCYCLE        /A
00462  5000                  BTX           /B
00463  1307                  CONTX         /C
00464  1251                  QM            /D
00465  5146                  CTR           /E
00466  0532                  FS            /F
00467  1251                  QM            /G
00470  1251                  QM            /H
00471  1251                  QM            /I
00472  1251                  QM            /J
00473  0127                  KILL          /K
00474  1000                  OVERF         /L
00475  1251                  QM            /M
00476  1316                  NBINX         /N
00477  1251                  QM            /O
00500  1251                  QM            /P
00501  0442                  STATUS        /Q
00502  0432                  RUNX          /R
00503  0425                  STOPX         /S
00504  5142                  CTLX          /T
00505  1353                  SP            /U
00506  1360                  DP            /V
00507  1000                  WRITED        /W
00510  1341                  SPN           /X
00511  1344                  N             /Y
00512  1347                  SIG           /Z
00513  1251                  NS            /[
00514  1255                  QM            /\
00515  1251                  QM            /]
00516  1325                  PAPAL         /↑
00517  1255                  COMM          /←
```

```
00520  0000              O              1 ISZ  XN
00521  7650              SNA  CLA       1 IFF  D. P.
00522  5720              JMP I 520
00523  1731              TAD I 531
00524  7710              SPA  CLA
00525  2730              ISZ  I  530    1 ISZ  XN
00528  2320              ISZ  520
00527  5720              JMP I 520      1 RETURN
00530  1756              1756           1 AXN
00531  1545              1545           1 ASORD
00532  1775   FS,        TAD I AFI      1 FULL SCALE ROUTINE
00533  1364              TAD KF1
00534  7041              CIA
00535  3365              DCA KF2
00536  4407              JMS I 7        1 EMTER F. P.
00537  5366              FGET KF3
00540  0000              FEXT           1 EXIT F. P.
00541  4407              JMS I 7        1 ENTER F. P. (SEE 546)
00542  3371              FMULT KF4
00543  7000              FNOR
00544  0000              FEXT
00545  2365              ISZ KF2
00546  5341              JMP. -5
00547  7300              CLA CLL
00550  7000              NOP
00551  4776              JMS I AF2
00552  5255              CMFS
00553  6040              SPF
00554  7300              CLA CU
00555  1374              TAD FF8
00556  3062              DCA 62
00557  4406              JMS  OUTPUT
00560  6041              TSF
00561  5360              JMP. -1
00562  4032              JMS CRLF
00563  5022              JMP RESTOR
00564  0000   KF1,       6
00565  0000   JF2,       0
00566  0007   KFo,       FLTG 178
00567  2000
00570  0000
00571  0001   KF4,       FLTG 2
00572  2000
00573  0000
00574  0010   KF8,       10
00575  1762   AF1,       1762
00576  1200   AF2,       1200
00577  1251   QM,        1251
00600  4756   WRITED,    JMS SSTOP
00601  4487              JMS I 7        /SETS STOP
```

```
00602   5772              FGET
00603   6771              FPUT FBINN
00604   0000              FEXT
00605   5210              JMP. 13
00606   5210              JMS 32          /EXPECTS CRLF TO BE AT 0032
00607   4032              JMS 32
00610   5611              JMP I 611
00611   1371              1371
00612   0260              260
00613   4753              JMS I ATYPX     /EXPECTS TYPX TO BE AT 1200
00614   5300              CMBIN
00615   4111              JMS SPACE
00616   0005              5
00617   4753              JMS I ATYPX
00620   5302              CMTIME
00621   4111              JMS SPACE
00622   0006              6
00623   4753              JMS I ATYPX
00624   5305              CMSPEN
00625   4111              JMS SPACE
00626   0010              10
00627   4753              JMS I ATYPX
00630   5307              CMN
00631   7300              CLACLL
00632   3045              DCA95
00633   3046              DCA96
00634   4407              JMS I 7
00635   6779              FPUT FSF
00636   6773              FPUT FSFV
00637   0000              FEXT
00640   7300              CLA CLL
00641   1376              TAD (3002)
00642   3354              DCA BINNUM
00643   1375              TAD (4002)
00644   3355              DCA ZINNUM
00645   7000              NOP
00646   7300              CLA CU
00647   3045              DCA 95
00650   3046              DCA 46
00651   4407              JMS I 7
00652   6767              FPUT SPNREG
00653   6766              FPUT NREG
00654   0000              FEXT
00655   7300    RETWED,   CLA CLL
00656   1754              TAD I BINNUM
00657   3046              DCA 46
00660   2354              I SZ BINNUM
00661   1754              TAD I BINNUM
00662   3045              DCA 45
00663   1370              TAD (27)
00664   3044              DCA 44
00665   4407              JMS 17
00666   1767              FADD SPNREG
00667   6767              FPUT SPNREG     /LOADS S+N REG
00670   0000              FEXT
00671   1755              TAD I ZINNUM
00672   3046              DCA 46
00673   2355              I SZ ZINNUM
00674   1755              TAD I ZINNUM
00675   3045              DCA 45
00676   1370              TAD (27)
00677   3044              DCA 44
```

```
00701  1760          FADD NREG
00702  6766          FPUT NREG        /LOADS N REG
00703  5767          FGET SPNREG
00704  2766          FSUB NREG
00705  6765          FPUT SREG        /LOADS SIG (DIFF) REG
00706  57 71          FGET FBINN
00707  3764          FMPY FTWO
00710  2772          FSUB FONE
00711  3763          FMPY FBINT
00712  4764          FDIV FTWO
00713  2762          FSUB FDT
00714  6761          FPUT FTIME       /TIME=BINTIME*(2BIN#-1)/2 -DEL
00715  0000          FEXT
00716  5612          JMP I 612
00717  4760          JMS TYPE
00720  0003          3
00721  4407          JMS I 7
00722  57 61          FGET FTIME
00723  0000          FEXT
00724  4760          JMS TYPE
00725  0006          6
00726  4407          JMS I 7
00727  5767          FGET SPNREG
00730  0000          FEXT
00731  4760          JMS TYPE
00732  0007          7
00733  4407          JMS I 7
00734  57 66          FGET NREG
00735  0000          FEXT
00736  47 60          JMS TYPE
00737  0007          7
00740  4407          JMS I 7
00741  57 65          FGET SREG
00742  0000          FEXT
00743  47 60          JMS TYPE
00744  0007          7
00745  4407          JMS I 7
00746  5767          FGET SPNREG
00747  1766          FADD NREG
00750  0002          SQROOT
00751  0000          FEXT
00752  5757          JMP 210
00753  1200  ATYPX,  1200
00754  0000  BINNUM, 0
00755  0000  ZINNUM, 0

00756  7600
00757  0210
00760  0302
00761  0332
00762  0351
00763  0346
00764  0340
00765  0327
00766  0324
00767  0321
00770  0027
00771  0335
00772  0343
00773  0316
00774  0313
```

```
00777  0040
              *210
00210  4302          JMS TYPE
00211  0004          4
00212  5613          JMS I 213      /FOR FLUX 212=4407
00213  0233          233            /AND 213-5354
00214  3357          FMPY FMILL
00215  4332          FDIV FTIME
00216  6321          FPUT SPNREG    /SPNREG NOW USED TO HOLD VELOCIY
00217  0000          FEXT
00220  4302          JMS TYPE
00221  0007          7
00222  4407          JMS I 7
00223  5327          FGET SREG
00224  3354          FMPY FDIST
00225  4321          FDIV SPNREG
00226  6324          FPUT NREG      /NREG NOW USED FOR FLUX
00227  3362          FMPY FTTHOU
00230  0000          FEXT
00231  4302          JMS TYPE
00232  0007          7
00233  4407          JMS I 7
00234  5324          FGET NREG
00235  1313          FADD FSF
00236  6313          FPUT FSF
00237  5324          FGET NREG
00240  3321          FMPY SPNREG
00241  1316          FADD FSFV
00242  6316          FPUT FSFV
00243  5335          FGET FBINN
00244  1343          FADD FONE
00245  6335          FPUT FBINN
00246  2365          FSUB FNBINS
00247  0000          FEXT
00250  4032          JMS CRLF
00251  1045          TAD 45
00252  7550          SPA SNA
00253  5274          JMP KEYQ
00254  5022          JMP RESTOR
00255  4032          JMS CRLF
00256  4032          JMS CRLF
00257  5022          JMP RESTOR
00260  2777          ISZ BINNUM
00261  2776          ISZ ZINNUM
00262  2370          ISZ NSP
00263  5773          JMP I 373
00264  7300          CLA CLL
00265  1271          TAD NBIND
00266  7041          CIA
00267  3370          PCA NSP
00270  4407          JMS I 7
00271  5335          FGET FBINN
00272  0000          FEXT
00273  5772          JMP I 372
00274  6031   KEYQ,  KSF
00275  5774          JMP RETUR
00276  6030          KCF
00277  4775          JMS TYPX
00300  5351          CMTERM
00301  5255          JMP 255
00302  0000   TYPE,  0
00303  6046          TLS
```

```
00777  0040
              *210
00210  4302          JMS TYPE
00211  0004          4
00212  5613          JMS I 213       /FOR FLUX 212 =.4407
00213  0233          233             I AND 213 = 5354
00214  3357          FMPY FMILL
00215  4332          FDIV FTIME
00216  6321          FPUT SPNREG     /SPNREG NOW USED TO HOLD VELOCIT
00217  0000          FEXT
00220  4302          JMS TYPE
00221  0007          7
00222  4407          JMS I 7
00223  5327          FGET SREG
00224  3354          FMPY FDIST
00225  4321          FDIV SPNREG
00226  6324          FPUT NREG       /NREG NOW USED FOR FLUX
00227  3362          FMPY FTTHOU
00230  0000          FEXT
00231  4302          JMS TYPE
00232  0007          7
00233  4407          JMS I 7
00234  5324          FGET NREG
00235  1313          FADD FSF
00236  6313          FPUT FSF
00237  5324          FGET NREG
00240  3321          FMPY SPNREG
00241  1316          FADD FSFV
00242  6316          FPUT FSFV
00243  5335          FGET FBINN
00244  1343          FADD FONE
00245  6335          FPUT FBINN
00246  2365          FSUB FNBINS
00247  0000          FEXT
00250  4032          JMS CRLF
00251  1045          TAD 45
00252  7550          SPA SNA
00253  5274          JMP KEYQ
00254  5022          JMP RESTOR
00255  4032          JMS CRLF
00256  4032          JMS CRLF
00257  5022          JMP RESTOR
00260  2777          ISZ BINNUM
00261  2776          ISZ ZINNUM
00262  2370          ISZ NSP
00263  5773          JMP I 373
00264  7300          CLA CLL
00265  1271          TAD NBIND
00266  7041          CLA
00267  3370          PCA NSP
00270  4407          JMS I 7
00271  5335          FGET FBINN
00272  0000          FEXT
00273  5772          JMP I 372
00274  6031  KEYQ,   KSF
00275  5774          JMP RETUR
00276  6030          KCF
00277  4775          JMS TYPX
00300  5351          CMTERM
00301  5255          JMP 255
00302  0000  TYPE,   O
00303  6046          TLS
00304  1702          TAD I TYPE
```

```
00306  4406            JMS I 6
00307  4111            JMS SPACE
00310  0003            3
00311  2302            ISZ TYPE
00312  5702            JMP I TYPE


00313  0000  FSF,      FLTG 0
00314  0000
00315  0000
00316  0000  FSFV,     FLTG 0
00317  0000
00320  0000
00321  0000  SPNREG,   FLTG 0
00322  0000
00323  0000
00324  0000  NREG,     FLTG 0
00325  0000
00326  0000
00327  0000  SREG,     FLTG 0
00330  0000
00331  0000
00332  0000  FTIME,    FLTG 0
00333  0000
00334  0000
00335  0000  FBINN,    FLTG 0
00336  0000
00337  0000
00340  0002  FTWO,     FLTG 2
00341  2000
00342  0000
00343  0001  FONE,     FLTG 1
00344  2000
00345  0000
00346  0007  FBINT,    FLTG 100
00347  3100
00350  0000
00351  0000  FDT,      FLTG 0
00352  0000
00353  0000
00354  0004  FDIST,    FLTG 10
00355  2400
00356  0000
00357  0024  FMILL,    FLTG 1.0E06
00360  3641
00361  1000
00362  0016  FTTHOU,   FLTG 1.0E04
00363  2342
00364  0000
00365  0006  FNBINS,   FLTG 32
00366  2000
00367  0000
370    7777
371    1764
372    0717
373    5334
```

```
00375  1200
00376  0755
00377  0754
              *5300
05300  0211   CMBIN,   TEXT "BI
05301  1600   N"

05302  2411   CMTIME,  TEXT "TI
05303  1505   ME
05304  0000   "

05305  2353   CMSPN,   TEXT "S+
05306  1600   N"

05307  1600   CMN,     TEXT "N

05310  4040
05311  4040
05312  4040
05313  0411   CMD
05314  0606   FF
05315  4040
05316  4040
05317  2321   SQ
05320  4022    R
05321  2440   T
05322  4026    V
05323  0514   EL
05324  1703   OC
05325  1124   IT
05326  3140   Y
05327  4040
05330  4006    F
05331  1425   LU
05332  3037   X←
05333  3700   ←"
05334  4407            JMS I 7
05335  5742            FGET FBINN
05336  1743            FADD FONE

05337  6742            FPUT FBINN
05340  0000            FEXT
05341  5744            JMP RETWED
05342  0335  FBINN,    335
05343  0343  FONE,     343

05344  0655  RETWED,   655
05345  0000            0
05346  0000            0
05347  0000            0
05350  0000            0

05351  4024  CMTERM,   TEXT " T
05352  0522  ER
05353  1511  MI
05354  1601  NA
05355  2405  TE
05356  0400  D "
             *1000
01000  7300  OVERF,    CLA CLL
01001  1377            TAD (40)
01002  6170            LCW                /________________STOPS EXP.
```

```
    01005  3333            DCA AOV
    01006  1330            TAD BIOV
    01007  3334            DCA BOV
    01010  3336            DCA FLGOV
    01011  6171            RSW
    01012  7010            RAR
    01013  7430            SZL
    01014  5211            JMP .-3
    01015  7300            CLA CLL
    01016  1332  GOAUNO,   TAD KOV2
    01017  6170            LSW
    01020  7000            NOP
    01021  7300  RETOV,    CLA CLL
    01022  2333            ISZ AOV
    01023  2334            ISZ BOV
    01024  1734            TAD I BOV
    01025  1733            TAD I AOV
    01026  3734            DCA I BOV
    01027  3733            DCA I AOV
    01030  7004            RAL
    01031  2334            ISZ BOV
    01032  1734            TAD I BOV
    01033  7430            SZL
    01034  4255            JMS TYPOVR
    01035  7510            SPA
    01036  2336            ISZ FLGOV
    01037  3734            DCA I BOV
    01040  5243            JMP 1 to 43
    01041  1337            TAD KOV1
    01042  5314            JMP 1114
    01043  1330            TAD BIOV
    01044  7041            CIA
    01045  1333            TAD AOV
    01046  7710            SPA CLA
    01047  5221            JMP RETOV
    01050  5307            JMP GOBCK
    01051  1037            TAD FLAGR
    01052  7440            SZA
    01053  5727            JMP I 1127
    01054  5241            JMP 1041
    01055  0000  TYPOVR,   0
    01056  7300            CLA CLL
    01057  7604            LAS              /SET SWITCH REG. BIT 11 TO 1
    01060  7010            RAR              /TO KILL MESSAGES
    01061  7430            SZL
    01062  5655            JMP I TYPOVR
    01063  4032            JMS CRLF
    01064  7000            NOP
LG  01065  4776            JMS TYPX
    01066  5233            CMOVER           /TYPES ERROR MESSAGE
    01067  1326            TAD AIOV
    01070  7041            CIA
    01071  1333            TAD AOV
    01072  3045            DCA 45
    01073  3046            DCA 46
    01074  1375            TAD (13)
    01075  3044            DCA 44
    01076  4407            JMS I 7
    01077  7000            FNOR
    01100  0000            FEXT
    01101  7240            CLA CMA
    01102  3055            DCA 55
    01103  1374            TAD (3)
```

```
   01104  3062           DCA 62
   01105  4547           JMS OUTPUT
   01106  5655           JMP I TYPOVR
   01107  7300 GOBCK,    CLA CLL
   01110  1336           TAD FLGOV
   01111  7440           SZA
   01112  5317           JMP .+5
   01113  5251           JMP 1051
   01114  6170           6170
   01115  5022           JMP RESTOR
   01116  7600           ASTOP
   01117  4716           JMS SSTOP
   01120  4032           JMS CRLF
LG 01121  4776           JMSTYPX
   01122  5200           CMFULL
   01123  7201           CLA IAC
   01123  3037           DCA FLAGR
   01125  5022           JMP RESTOR
   01126  1777 AIOV,     1777
   01127  0600           0600
   01130  2777 BIOV,     2777
   01131  0000           0
   01132  0440           440
   01133  0000 AOV,      0
   01134  0000 BOV,      0
   01135  0000 NOV,      0
   01136  0000 FLGOV,    0
   01137  0500 KOVI,     0500
   01140  4575           JMS I 175
   01141  4575           JMS I 175
   01142  6171           RSW
   01143  7004           RAL
   01144  7430           SZL
   01145  5353           JMP 1153
   01146  7004           RAL
   01147  7430           SZL
   01150  5361           JMP 1161
   01151  7402           HLT
   01152  5022           JMP RESTOR
   01153  4767           JMS TYPX
   01154  5263           CMBTG
   01155  4032           JMS CRLF
   01156  1370           TAD KE20
   01157  6170           LSW
```

```
1160    5022            JMP RESTOR
1160    5022            JMP RESTOR
1161    4767            JMS TYPX
1162    5272            CMTIME
1163    4032            JMS CRLF
1164    1371            TAD KEIK
1165    6170                LSW
1166    5372            JMP 1172
1167    1200
1170    0020
1170    0020  KEZO,     20
1171    1000  KEIK,     1000
1172    3037            DCA FLAGR
1173    5022            JMP RESTOR
01174   0003
01175   0013
01176   1200
01177   0400
              *1200
01200   0000  TYPX,     0
01201   7300            CLA CLL
01202   1600            TAD I     TYPX
01203   3214            DCA       TYPNT
01204   2200            ISZ       TYPX
01205   1614  TYPXI,    TAD I     TYPNT
01206   7002            7002
01207   4215            JMS       TYPY
01210   1614            TAD I     TYPNT
01211   2214            ISZ       TYPNT
01212   4215            JMS       TYPY
01213   5205            JMP       TYPX1
01214   0000  TYPNT,    0

01215   0000  TYPY,     0
01216   0234            AND       TK77
01217   7450            SNA
01220   5600            JMP I     TYPX
01221   1235            TAD       TKM37
01222   7440            SZA
01223   522u            JMP       TYPY1
01224   1236            TAD       TK215
01225   4242            JMS       TLSX
01226   1237            TAD       TKM125
01227   7510  TYPY1,    SPA
01230   1240            TAD       TK100
01231   1241            TAD       TK237
01232   4242            JMS       TLSX
01233   5615            JMP I     TYPY
01234   0077  TK77,     77
01235   7741  TKM37,    -37
01236   0215  TK215,    215
01237   7653  TKM125,   -125
01240   0100  TK100,    100
01241   0237  TK237,    237
```

```
01243  6046          TLS
01244  6041          TSF
01245  5244          JMP      .-1
01246  6042          TCF
01247  7200          CLA
01250  5642          JMP I    TLSX
01251  4654  QM,     JMS I QMK
01252  7300          CLA CLL
01253  5022          JMP RESTOR
01254  0032  QMK,    CRLF

             *QMK+1

01255  7300  COMM,   CLA CLL
01256  1275          TAD TK334
01257  4242          JMS TLSX
01260  6031          KSF
01261  5260          JMP .-1
01262  6036          KRB
01263  7041          CIA
01264  1236          TAD TK215
01265  7440          SZA
01266  5271          JMP ECHO
01267  4032          JMS CRLF
01270  5022          JMP RESTOR
01271  7041  ECHO,   CIA
01272  1236          TAD TK215
01273  4242          JMS TLSX
01274  5260          JMP COMM+3
01275  0257  TK257   257
```

```
                  *1400
01400   0000   DPDADD, 0
01401   7300           CLA CLL
01402   1345           TAD SORD          /S.P. DATA MUST BE IN N
01403   7710           SPA CLA           /D.P. DATA MUST BE IN M
01404   1377           TAD (400)
01405   1377           TAD (400)
01406   1776           TAD XN            /ADDS PRESENT DATA
01407   3261           DCA YN            /TO HOLDING REG (ALSDSN ETC.)
01410   1776           TAD XN
01411   3260           DCA PADD
01412   1373           TAD AADDI
01413   3257           DCA AADD
01414   7100   RETADD, CLL
01415   1660           TAD I PADD
01416   1657           TAD I AADD
01417   3657           DCA I AADD
01420   1345           TAD SORD
01421   7700           SMA CLA
01422   5227           JMP .+5
01423   7004           RAL
01424   2260           ISZ PADD
01425   1660           TAD I PADD
01426   7410           SKP
01427   7004           RAL
01430   2257           ISZ AADD
01431   1657           TAD I AADD
01432   3657           DCA I AADD
01433   7004           RAL
01434   2257           ISZ AADD
01435   1657           TAD I AADD
01436   3657           DCA I AADD
01437   1257           TAD AADD
01440   7041           CIA
01441   1371           TAD AADDI3
01442   4770           JMS I 1570
01443   5600           JMP I DPDADD
01444   1361           TAD YN
01445   3260           DCA PADD
01446   1372           TAD AADDI2
01447   3257           DCA AADD
01450   5214           JMP RETADD
01451   0000   ALSDSN, 0
01452   0000   AMSDSN, 0
01453   0000   AHSDSN, 0
01454   0000   ALSDN,  0
01455   0000   AMSDN,  0
01456   0000   AHSDN,  0
01457   0000   AADD,   0
01460   0000   PADD,   0
01461   0000   YN,     0
01462   0000   DPDSUB, 0                 /TAKES SUM(S+N)-SUM(N) AND PUTS
01463   7300           CLA CLL           /IT IN LSDH ETC. ('TRIPLE PREC')
01464   1254           TAD ALSDN
01465   7041           CIA
01466   1251           TAD ALSDSN
01467   3307           DCA LSDH
01470   7004           RAL
01471   3312           DCA KEEPD
01472   1255           TAD AMSDN
01473   7040           CMA
01474   1252           TAD AMSDSN
01475   1312           TAD KEEPD
```

```
01477  7004            RAL
01500  3312            DCA KEEPD
01501  1256            TAD AHSDN
01502  7040            CMA
01503  1253            TAD AHSDSN
01504  1312            TAD KEEPD
01505  3311            DCA HSDH
01506  5662            JMP I DPDSUB
01507  0000  LSDH,     0
01510  0000  MSDH,     0
01511  0000  HSDH,     0
01512  0000  KEEPD,    0
01513  7200  CHECKD,   CLA              /CHECKS WHETHER YOU WANT TO DIS
01514  1344            TAD SORN         /S+N, N, OR S+N-N=S AND LOADS L
01515  7510            SPA              /ACCORDINGLY
01516  5325            JMP NOISE
01517  7640            SZA CLA
01520  5335            JMP SIGPN
01521  4262            JMS DPDSUB
01522  7420            SNL
01523  5775            JMP 1704
01524  5774            JMP SROT
01525  7300  NOISE,    CLA CLL
01526  1254            TAD ALSDN
01527  3307            DCA LSDH
01530  1255            TAD AMSDN
01531  3310            DCA MSDH
01532  1256            TAD AHSDN
01533  3311            DCA HSDH
01534  5774            JMP SROT
01535  1251  SIGPN,    TAD ALSDSN
01536  3307            DCA LSDH
01537  1252            TAD AMSDSN
01540  3310            DCA MSDH
01541  1253            TAD AHSDSN
01542  3311            DCA HSDH
01543  5774            JMP SROT
01544  0001  SORN,     1                /SORN>0, S+N; <0, N; =0, S+N-N=S
01545  0001  SORD,     1                /SORD>0, DMA SINGLE PREC.
01546  0000  CLEAR,    0                /CLEARS MEMORY LOCATIONS STADD
01547  7200            CLA              /PLUS N. ENTERED THUSLY:
01550  1746            TAD I CLEAR      /JMS CLEAR; STADD; N
01551  3365            DCA STADD
01552  2346            ISZ CLEAR
01553  1746            TAD I CLEAR
01554  7041            CIA
01555  3366            DCA COUNTC
01556  3765            DCA I STADD
01557  2365            ISZ STADD
01560  2366            ISZ COUNTC
01561  5356            JMP .-3
01562  2346            ISZ CLEAR
01563  7300            CLA CLL
01564  5746            JMP I CLEAR
01565  0000  STADD,    0
01566  0000  COUNTC,   0

01570  0520  /DISPLAY ROUTINE FOR TIME OF FLIGHT.
01571  1456  /AUTOMATICALLY SCALES BOTH AXES.  TAKES SUM OF N BINS.
01572  1454  /TAKES S+N-N, LOOKS AT ORIGINAL DATA FIELD (SING PREC)
01573  1451  /OR AT DOUBLE PRECISION STORAGE LOCATIONS.
01574  1647
```

```
01575  1704
01576  1756
01577  0400
              *1600
01600  7300  DISPLA,  CLA CLL
01601  3355           DCA NDIS
01602  3362           DCA ROTF
01603  3365           DCA NA
01604  1354           TAD NBINA
01605  2355           ISZ NOIS
01606  7004           RAL
01607  4720           SNL
01610  5205           JMP .-3
01611  7300           CLA CLL
01612  3365           DCA NA
01613  7200  STAR,    CLA
01614  7000           NOP
01615  7000           NOP
01616  5222           JMP .+4
01617  7240           CLA CMA
01620  1362           TAD ROTF
01621  3362           DCA ROTF       /SETS ROTF=ROTF-1 IF NO VALUE >
01622  1362           TAD ROTF       /TWO OF FULL SCALE
01623  1377           TAD (+6)
01624  7500           SMA
01625  5231           JMP .+4
01626  7200           CLA
01627  1376           TAD (-5)       /WON'T ROTATE ANY MORE THAN 5
01630  3362           DCA ROTF
01631  7240           CLA CMA
01632  1353           TAD START2
01633  3356           DCA XN         /XN=START2-1
01634  4775  RET,     JMS CLEAR
01635  1451           ALSDSN
01636  0006           6
01637  1364           TAD NBIND
01640  7041           CIA
01641  3360           DCA NBIN2
01642  2356           ISZ XN
01643  4774           JMS DPDADD
01644  2360           ISZ NBIN2
01645  5242           JMP .-3        /ADDS UP N BINS TO TRIPLE PRE
01646  5773           JMP CHECKD
01647  1362  SROT,    TAD ROTF
01650  7500           SMA
01651  7041           CIA            /MAKES ROTF2=-ABS(ROTF)
01652  7450           SNA            /SKIPS ALL ROTATING IF ROTF=0
01653  5260           JMP .+5
01654  3363           DCA ROTF2
01655  4320           JMS TROT       /ROTATES TRIPLE PRECISION
01656  2363           ISZ ROTF2      /RIGHT (OR LEFT IF ROTF<0
01657  5255           JMP .-2
01660  7200           CLA;
01661  1772    TAD MSDH
01662  7440           SZA
01663  5350           JMP BIG
01664  1771           TAD HSDH
01665  7440           SZA            /IF ANYTHING LEFT IN HSDH OR MSB
01666  5350           JMP BIG        /THEN DIDN'T ROTATE RIGHT ENOUGH
01667  1770           TAD LSDH
01670  7510           SPA
01671  7000           NOP            /IF ANY VALUE IS WITHIN 2 OF FS
01672  6063           DYL            /FLAGD IS SET NON-ZERO
```

```
01673  7300            CLA CLL          /PREVIOUS STEP LOADS Y-AXIS
01674  1355            TAD NDIS
01675  7041            CIA
01676  3357            DCA NN
01677  1365            TAD NA
01700  2357            ISZ NN
01701  5315            JMP ROT
01702  6053            DXL
01703  6054            DIX
01704  7300            CLA CLL
01705  1354            TAD NBINA
01706  7041            CIA
01707  1365            TAD NA
01710  2365            ISZ NA
01711  7710            SPA CLA
01712  5234            JMP RET
01713  5211            JMP 1611
01714  7000            NOP
01715  7100   ROT,     CLL
01716  7004            RAL
01717  5300            JMP SKIP
01720  0000   TROT,    0
01721  7200            CLA
01722  1362            TAD ROTF
01723  7500            SMA
01724  5326            JMP TRR
01725  5341            JMP TRL
01726  7300   TRR,     CLA CLL
01727  1771            TAD HSDH
01730  7010            RAR
01731  3771            DCA HSDH
01732  1772            TAD MSDH
01733  7010            RAR
01734  3772            DCA MSDH
01735  1770            TAD LSDH
01736  7010            RAR
01737  3770            DCA LSDH
01740  5720            JMP I TROT
01741  7300   TRL,     CLA CLL
01742  1770            TAD LSDH
01743  7004            RAL
01744  7430            SZL
01745  5350            JMP BIG
01746  3770            DCA LSDH
01747  5720            JMP I TROT
01750  2362   BIG,     ISZ ROTF
01751  7000            NOP
01752  5213            JMP STAR
01753  2001   START2,  2001
01754  0062            0062
01755  0000   NDIS,    0000
01756  0000   XN,      0000
01757  0000   NN,      0000


01760  0000   NBIN2,   0
01761  0000   FLAGD,   0
01762  0000   ROTF,    0
01763  0000   ROTF2,   0
01764  0004   NBIND,   0004
```

01770	1507
01771	1511
01772	1510
01773	1513
01774	1400
01775	1546
01776	7773
01777	0006

```
                  *5000
05000  4777  BTX,     JMS TYPX
05001  5357           CMBINT
05002  4134           JMS INPUT
05003  6174           6174
05004  4407           JMS I 7
05005  6776           FPUT FBINT
05006  0000           FEXT
05007  7300           CLA CLL
05010  5022           JMP RESTOR
05011  0000  NBTL,    0
05012  0000  CTL,     0
05013  7300           CLA CLL
05014  3340           DCA NCTL
05015  4134           JMS 134
05016  4407           JMS I 7
05017  6172           FPUT CTHOLD
05020  3264           FMPY MILL          /MILL=MILLION, 10↑6
05021  0000           FEXT
05022  4407  CTLRET,  JMS I 7
05023  4267           FDIV TEN           /TEN=10 (10)
05024  0000           FEXT
05025  2340           ISZ NCTL
05026  1375           TAD (-7)
05027  1044           TAD 44
05030  7510           SPA
05031  5272           JMP CTLERR
05032  1374           TAD (-4)
05033  7540           SMA SZA            / 7<=BIN EXP<=11 (10)
05034  5222           JMP CTLRET
05035  7450  CTLAGN,  SNA
05036  5247           JMP CTLYES
05037  2044           ISZ 44
05040  7300           CLA CLL
05041  1045           TAD 45
05042  7010           RAR
05043  3045           DCA 45
05044  1373           TAD (-13)
05045  1044           TAD 44
05046  5235           JMP CTLAGN
05047  1372  CTLYES,  TAD (-3)
05050  1340           TAD NCTL
05051  7510           SPA
05052  5272           JMP CTLERR
05053  1371           TAD (-5)           / 3<=NCTL<=8??  NO: ERROR MESS
05054  7540           SMA SZA
05055  5272           JMP CTLERR
05056  7200           CLA
05057  1045           TAD 45
05060  0370           AND (7760)         /THROW AWAY 4 LSB
05061  1340           TAD NCTL
05062  6173           6173
05063  5612           JMP I CTL
05064  0024  MILL,    FLTG +100.00E+04
05065  3641
05066  1000
05067  0004  TEN,     FLTG +100.00E-01
05070  2400
05071  0000
05072  4777  CTLERR,  JMS TYPX
05073  5365           CTERR
```

```
05075  0000  CTR,     0                  /COUNTING TIME READ
05076  7200           CLA
05077  1340           TAD NCTL
05100  7041           CIA
05101  3341           DCA NCTLL
05102  4407           JMS I 7
05103  5267           FGET TEN
05104  0000           FEXT
05105  2341  CTRRET,  ISZ NCTLL
05106  7410           SKP
05107  5315           JMP CTROUT
05110  4407           JMS I 7
05111  3267           FMPY TEN
05112  7000           FNOR
05113  0000           FEXT
05114  5305           JMP CTRRET
05115  4407  CTROUT,  JMS I 7
05116  6335           FPUT NCTLF
05117  0000           FEXT
05120  7300           CLA CLL
05121  6172           6172
05122  3045           DCA 45
05123  1367           TAD (13)
05124  3044           DCA 44
05125  3046           DCA 46
05126  4407           JMS I 7
05127  7000           FNOR
05130  4264           FDIV MILL
05131  3335           FMPY NCTLF
05132  7000           FNOR
05133  0000           FEXT
05134  5675           JMP I CTR
05135  0000  NCTLF,   0
05136  0000           0
05137  0000           0
05140  0000  NCTL,    0
05141  0000  NCTLL,   0

05142  4777  CTLX,    JMS TYPX
05143  5372           CMCT
05144  4212           JMS CTL
05145  5022           JMP RESTOR
05146  4777  CTRX,    JMS TYPX
05147  5375           CMCTR
05150  4275           JMS CTR
05151  1366           TAD (6)
05152  3062           DCA 62
05153  1365           TAD (3)
05154  4147           JMS OUTPUT
05155  5022           JMP RESTOR
05156  4777  SHIFTK,  JMS TYPX
05157  1314           CMNS
05160  4134           JMS INPUT
05161  3764           DCA NBIND
05162  5144           JMP 144
```

```
                NBIND=1764
                TYPX=1200
                FBINT=346
                RESTOR=22
                CTHOLD=172

05163   1070
05164   1764
05165   0003
05166   0006
05167   0013
05170   7760
05171   7773
05172   7775
05173   7765
05174   7774
05175   7771
05176   0346
05177   1200
                *5357
05357   0211    CMBINT,                 TEXT "BI
05360   1640    N
05361   2411    TI
05362   1505    ME
05363   7540    =
05364   4000     "

05365   2422    CTERR,                  TEXT "TR
05366   3140    Y
05367   0107    AG
05370   1641    N!
05371   3700    ←"

05372   0324    CMCT,                   TEXT "CT
05373   7540    =
05374   4000     "

05375   2411    CMCTR,                  TEXT "TI
05376   1505    ME
05377   7500    ="
```

```
                    *1300
01300   4705                    4705
01301   2000                    2000
01302   3000                    3000
01303   6001                    ION
01304   5706                    5706
01305   1546                    1546
01306   1600                    1600
01307   7300                    CLA CLL
01310   1313                    TAD KCONTI
01311   5712                    JMP I 1312
01312   0432                    0432
01313   7600                    -200
01314   1623    CMNS,
01315   7500    ="                          TEXT "NS
                *1316
01316   4134    NBINX,          JMS INPUT
01317   3724                    DCA I NBINAX
01320   4407                    JMS I 7
01321   6576                    FPUT I FNBINX
01322   0000                    FEXT
01323   5144                    JMP 144
01324   1754    NBINAX,         1754


01325   4134    PARALD,         JMS INPUT
01326   4407                    JMS I 7
01327   6736                    FPUT I FDISTX
01330   0000                    FEXT
01331   4134                    JMS INPUT
01332   4407                    JMS I 7
01333   6737                    FPUT I FDTX
01334   0000                    FEXT
01335   5740                    JMP I TOT
01336   0354    FDISTX,         354
01337   0351    FDTX,           351
01340   0203    TOT,            203
01341   7201    SPN,            CLA IAC
01342   3752                    DCA I SORNX
01343   5144                    JMP 144
01344   7240    NOISE,          CLA CMA
01345   3752                    DCA I SORNX
01346   5144                    JMP 144
01347   7300    SIGNAL,         CLA CLL
01350   3752                    DCA I SORNX
01351   5144                    JMP 144
01352   1544    SORNX,          1544
01353   7201    SP,             CLA IAC
01354   3765                    DCA I SORDX
01355   1367                    TAD T000
01356   3766                    DCA I STARTX
01357   5144                    JMP 144
01360   7240    DP,             CLA CMA
01361   3765                    DCA I SORDX
01362   1370                    TAD TOOT
01363   3766                    DCA I STARTX
01364   5144                    JMP 144
01365   1545    SORDX,          1545
01366   1753    STARTX,         1753
01367   2001    TOOO,           2001
01370   3002    TOOT,           3002
```

```
                *5200
05200   0401    CMFULL, TEXT /DA
05201   2401    TA
05202   4010     H
05203   0123    AS
05204   4022     R
05205   0501    EA
05206   0310    CH
05207   0504    ED
05210   4006     F
05211   2514    UL
05212   1440    L
05213   0417    DO
05214   2502    UB
05215   1405    LE
05216   4020     P
05217   2205    RE
05220   0311    CI
05221   2311    SI
05222   1716    ON
05223   7340    ;
05224   0417    DO
05225   1624    NT
05226   4003     C
05227   1716    ON
05230   2411    TI
05231   1625    NU
05232   0500    E/

05233   1726    CMOVER, TEXT /OV
05234   0522    ER
05235   0614    FL
05236   1727    OW
05237   3700    ←
05240   4340    #
05241   0331    CY
05242   0315    CL
05243   0523    ES
05244   7500    =

                RSW=6171
                LCW=6170
```