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INVESTIGATION OF MAGNETIC FIELD PHENOMENA IN THE IONOSPHERE.(U)

JAN 80 J F DEVANE, E A JOHNSON F19628-76-C-0291

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INVESTIGATION OF MAGNETIC FIELD
PHENOMENA IN THE IONOSPHERE

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Weston Observatory (Boston College) has maintained a geomagnetic observatory to continuously monitor changes in the geomagnetic field and to provide standards for magnetic instrumentation and to maintain a coil system in which a wide variety of magnetic instrumentation can be tested and calibrated to support AFGL RESEARCH. The observatories in Project MAGAF have been installed and maintained. The secular change in the geomagnetic field at Weston is detailed for the past six years. Modifications have

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) been made in the network instrumentation to insure reliability and accuracy of the data digitally transmitted to Hanscom AFB. A three component magnetic observatory has been designed around the total field sensor. The reliability of the principal components of the network has been investigated and changes proposed for the remote observatories.

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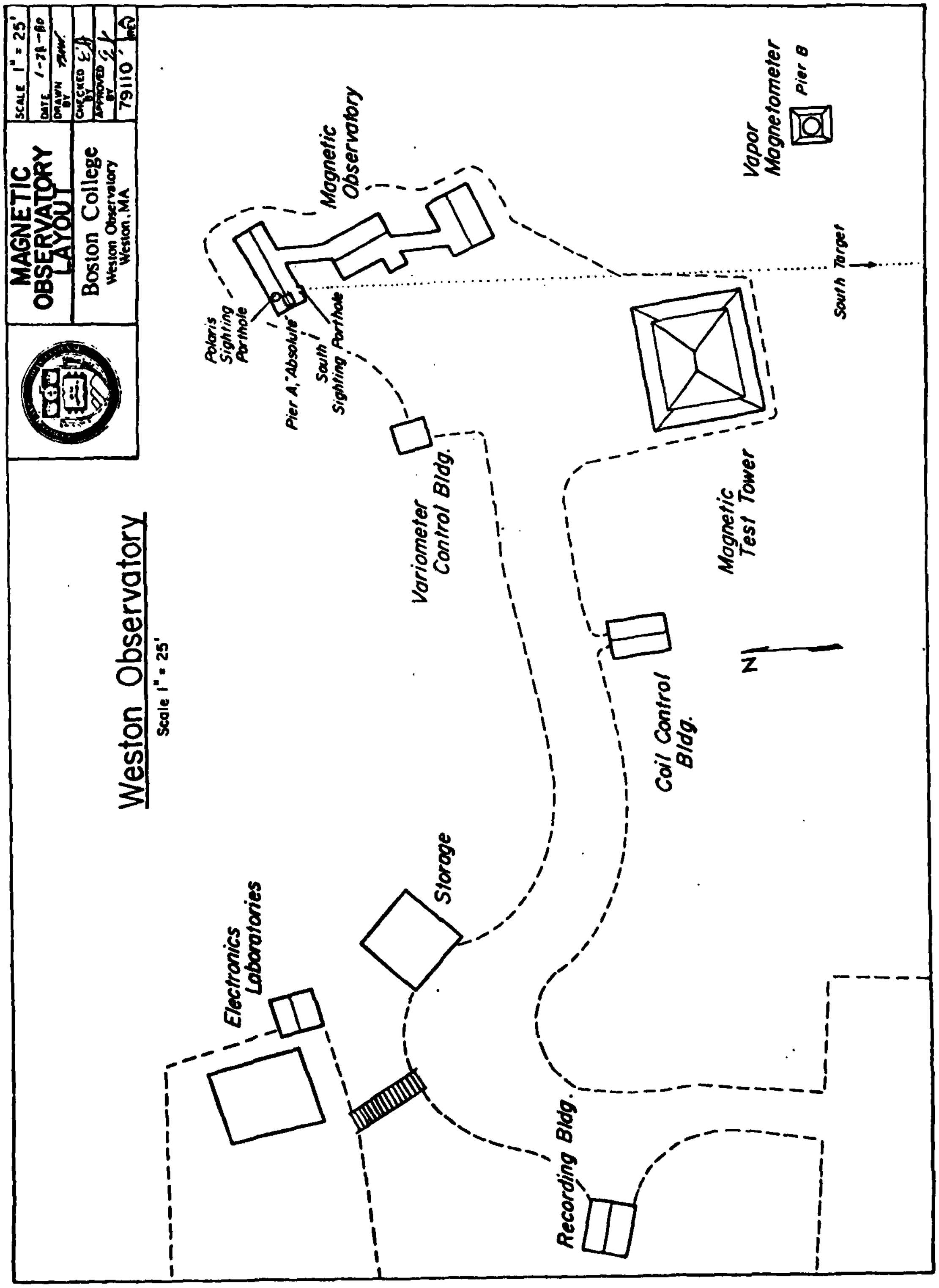
Introduction

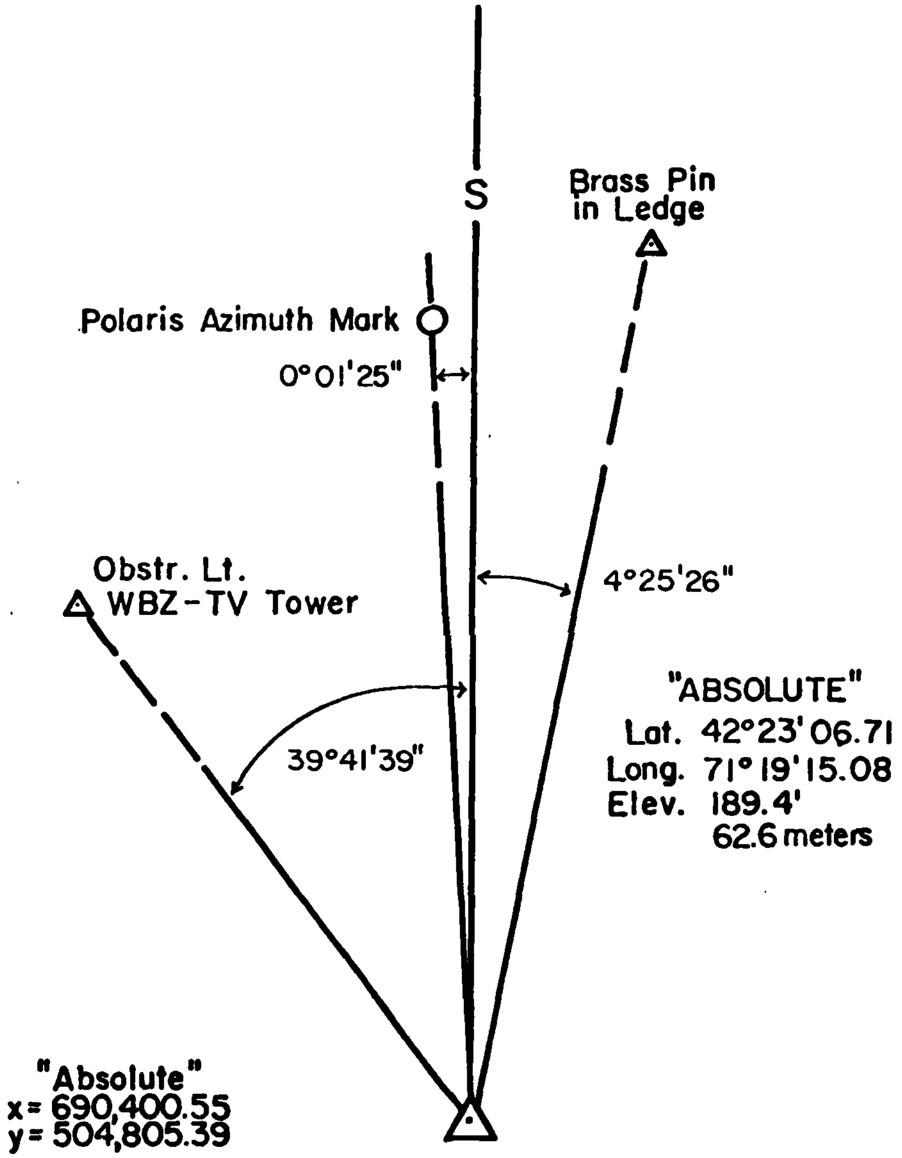
Since 1957 Boston College (Weston Observatory) has, with continuing support from AFGL, operated the only geomagnetic observatory in Northeast United States. The observatory and all its facilities have been developed to support Air Force Programs investigating the magnetic environment of the earth. Late in 1973 the thrust of the Air Force research changed from the use of ionospheric sounding rockets to the development of a system of geomagnetic observatories to investigate micropulsations. Weston Observatory personnel have assisted and supported AFGL personnel in establishing the MAGAF network of geomagnetic observatories. After the observatories were installed the prime obligation of this contract was to continually maintain the network in operation, evaluating all the components in both the network and at Weston Observatory in order to improve the reliability and accuracy of the data.

This report will briefly discuss the magnetic observatory at Weston, then in turn will discuss some generic problems encountered at the remote observatories and detail some of the modifications made to the instrumentation of the MAGAF stations.

The Weston Magnetic Observatory

The plan map of the magnetic observatory at Weston is shown in Figure 1 and 1A. A description of the instrumentation has been given in a prior report (1). The variometers are the standard Ruska instruments recording at two levels of sensitivity on photographic paper. The output of the total


MAGNETIC OBSERVATORY LAYOUT
Boston College
Weston Observatory
Weston, MA
SCALE 1" = 25'
DATE 1-28-80
DRAWN BY
CHECKED BY
APPROVED BY
79110'
Weston Observatory
Scale 1" = 25'
Magnetic Observatory
Polaris Sighting Porthole
Pier A, "Absolute"
South Sighting Porthole
Variometer Control Bldg.
Vapor Magnetometer
Pier B
South Target
Magnetic Test Tower
N
Coil Control Bldg.
Storage
Electronics Laboratories
Recording Bldg.



Location of South Target from Absolute Pier magnetometer is recorded on both strip chart and on a printed tape (Figure 2).

The photographic recording of the variometers was suspended in January 1979 following the sudden death of our faithful record changer, for whom a replacement has not been found. In July 1979 the horizontal and declination components were realigned and considerable effort, unsuccessful, was expended trying to align the vertical component. One more effort to align the vertical component is planned. Even if unsuccessful, we will resume recording the horizontal and declination components having the assurance that the records will be changed at least six days per week.

In June 1979 the Rubidium vapor magnetometer, in continuous operation since February 1976, failed. Its replacement, a Cesium vapor magnetometer did not perform satisfactorily and was returned to the manufacturer, Varian Associates Ltd., Canada. After many delays, the repaired magnetometer was put into operation in October 1979.

We consider the total field magnetometer to be the principal observatory instrument since its visual recorder gives an instantaneous picture of the magnitude of the total magnetic field. The output of a vapor magnetometer is the Larmor precessional frequency which is proportional to the magnitude of the existing magnetic field. For the past ten years we have been printing this frequency value every ten minutes. As a result of modifications (2), the actual value of the field in gammas is now printed, so that without

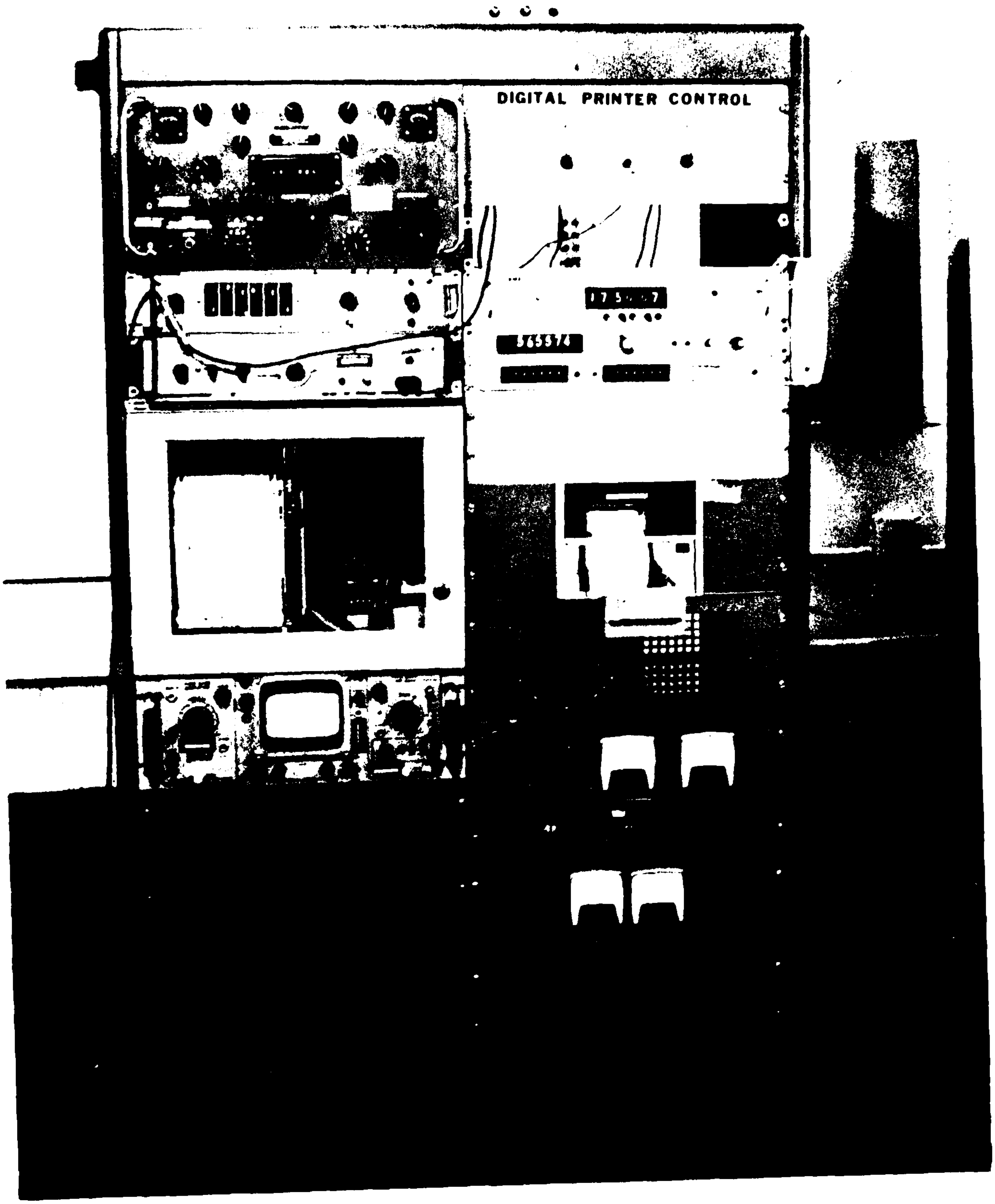


Figure 2

calculation the field change in gammas is immediately available. In an effort to reduce expenses, the speed of the stripchart record of the total field magnetometer was reduced by 75%. This speed is adequate to give a good visual picture of the changing field. A frequency gate is set on the output of the total field magnetometer. If the preset frequency values are exceeded the printer is activated each minute so that a very detailed record of the magnetic disturbance is produced. In the early stage of the contract, both an audio and visual signal (blinking light) was sent to the workshop so that AFGL personnel at Bedford could be warned of increasing magnetic activity.

A decrease in the magnitude of the total magnetic field was previously reported (1). At that time we were not sure that the effect was not due to instrumental effects combined with changes in the location of the sensor. The decrease in the magnitude of the total field is real. From December 1976 to June 1979, the gradient between Pier A (a proton precession magnetometer) and Pier B (the Rubidium sensor) remained constant at 96 $\pm$ 1 gammas. Thus the apparent change in the magnitude of the field was not due to any problems associated with the Rubidium sensor.

The decrease has been documented for the past six years. Each day, seven values of the total field, centered on magnetic midnight, are averaged. Apart from magnetic storm time, magnetic midnight is the least disturbed time of day. Table 1 displays the average magnetic midnight value for each month in

	1974	1975	1976	1977	1978	1979
Jan	57200	57136	57064	56976	56870	56772
Feb	196	128	062	968	863	762
Mar	193	120	059	958	853	762
Apr	186	114	047	952	847	746
May	182	110	042	940	843	732
Jun	180	104	035	931	832	
Jul	176	095	028	913	827	
Aug	172	091	016	910	813	
Spt	166	089	005	56899	808	
Oct	158	081	003	894	56796	
Nov	150	077	56993	894	788	676
Dec	57144	57072	56985	56879	56775	56669

TABLE 1

Change in the Total Field at Weston Observatory

1974 - 1979

the period 1974-1979. In constructing Table 1, the value of recording total field magnetometer has been reduced to Pier A since this is the pier on which absolute values are measured.

The decrease was discussed with Dr. Leroy Alldredge of the U.S. Geological Survey during the IAGA meeting in Seattle, August 1977. Subsequently he forwarded a preprint of a research note in which he has documented decreases in the vertical field component at Agincourt, Canada, Fredricksburg Va. and San Juan, Puerto Rico. Between 1970 and 1975 the decrease has been nearly 110 gammas/year at Fredricksburg. At Weston the decrease in the vertical component is seen in the decreasing magnitude of the total field but the decrease in the vertical field is somewhat compensated by a slow increase in the horizontal component. It is Alldredge's contention that we are observing a regional and rapid change feature of the secular variation.

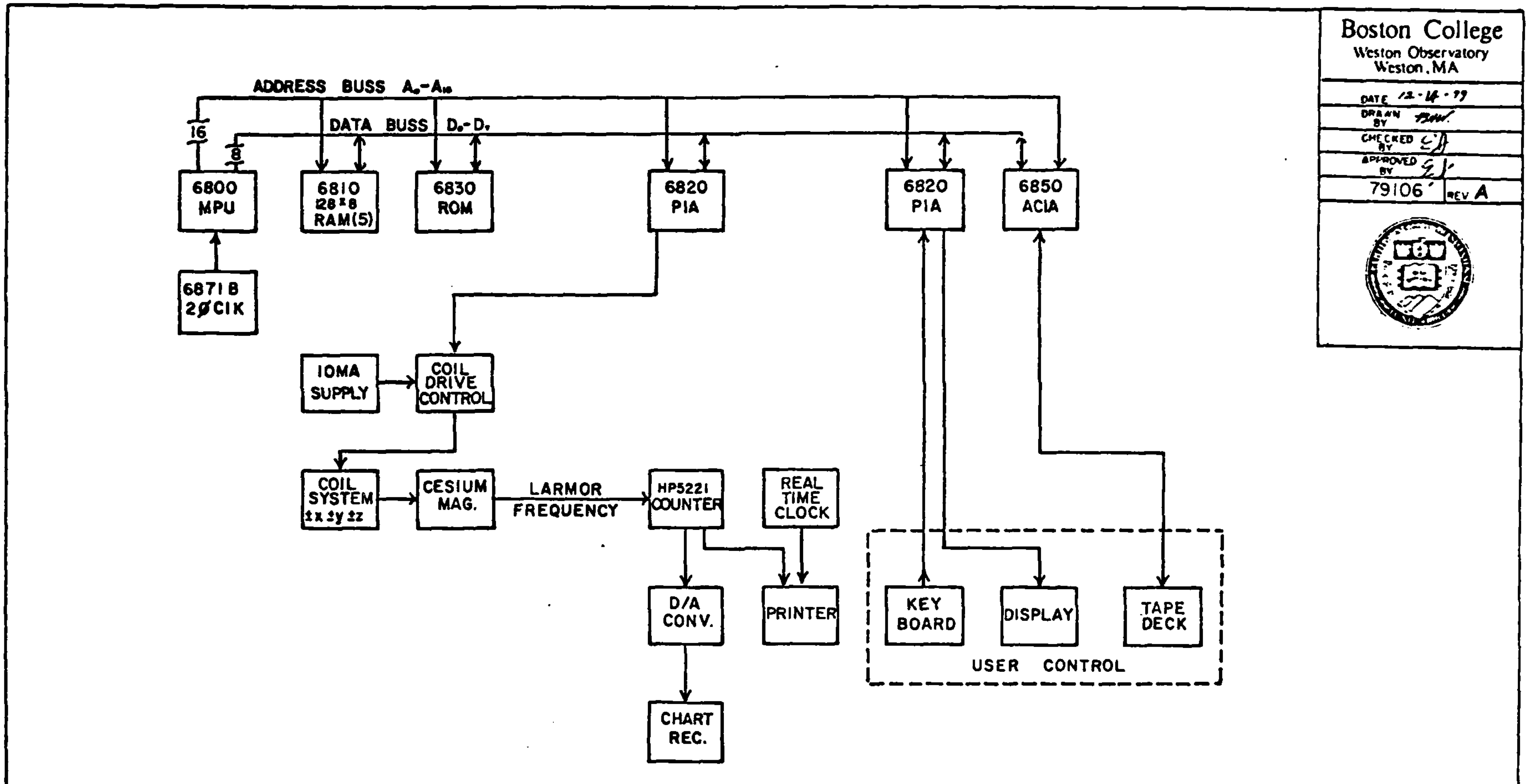
There is an additional problem. When the Rubidium magnetometer was replaced with a Cesium magnetometer, the gradient between Pier A and Pier B became 72 gammas. When replacing the magnetometer, the orientation of the coil system in which the magnetometer is mounted was rotated into geographic coordinates. Thus a prior suspicion (1) that the value of the field actually measured by the sensor depends on its orientation is confirmed. The real change in the field can still be determined by a regular program of monitoring the field with a proton precession magnetometer on Pier A.

Dating back to 1974 plans have existed for the conversion of a Republic Baseline magnetometer to a system which would produce, in suitable output form, values of the total intensity and of the three orthogonal components of the vector magnetic field at predetermined intervals. The operative elements are a total field magnetometer and a set of orthogonal McKeehan coils. By sequentially adding and subtracting a known magnetic field along each axis of the coils, the vector components can be calculated as follows.

$$F_x = \frac{F^2_{B_{x+}} - F^2_{B_{x-}}}{4\ B_x}$$

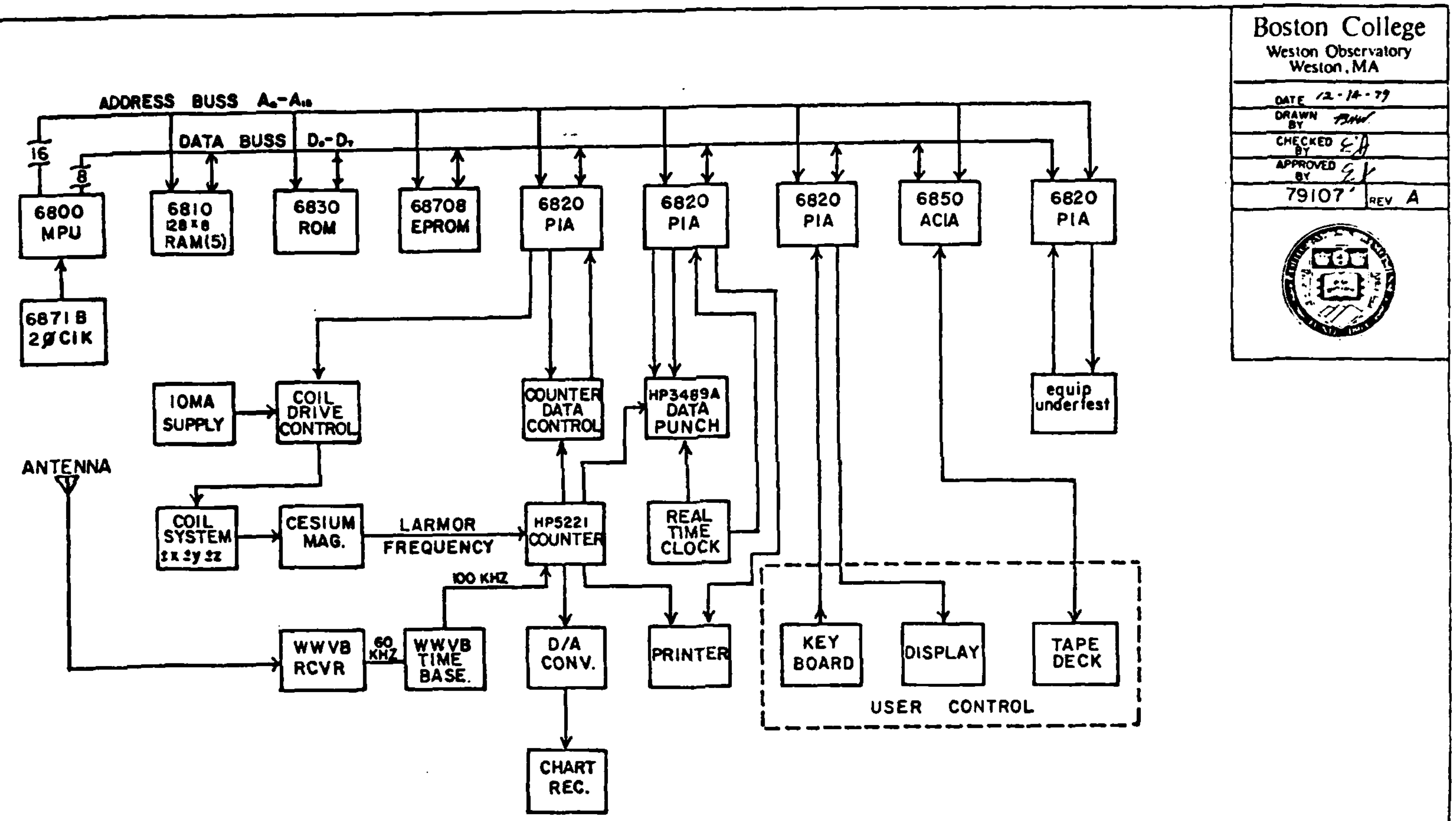
Where F_x is the magnetic field component in the north direction, B_x is the field produced by the current in the coil with its axis in the north-south direction and $B_{x\pm}$ is the values of the recorded field when a positive or negative bias current is applied to the coils. The process is repeated for the F_y and F_z, the east-west and vertical coil systems respectively. In the original system a mechanical sequential contactor regulated the flow of current to the coils. The mechanical contacts deteriorated with use, so that the coil factors varied. Our plans for the modification of this system are detailed in Figures 3 and 3A.

The heart of the system is a microprocessor. The sequence and duration of current to the coils is controlled by programmed logic rather than mechanical contact. At present, the plan is to sample the magnetic field every ten minutes, and store the data on paper tape. Magnetograms, hourly



Weston Observatory Automatic 3 Axis Vapor Magnetometer System (Present)

Figure 3A



Weston Observatory Automatic 3 Axis Vapor Magnetometer System (Under development)

Figure 3B

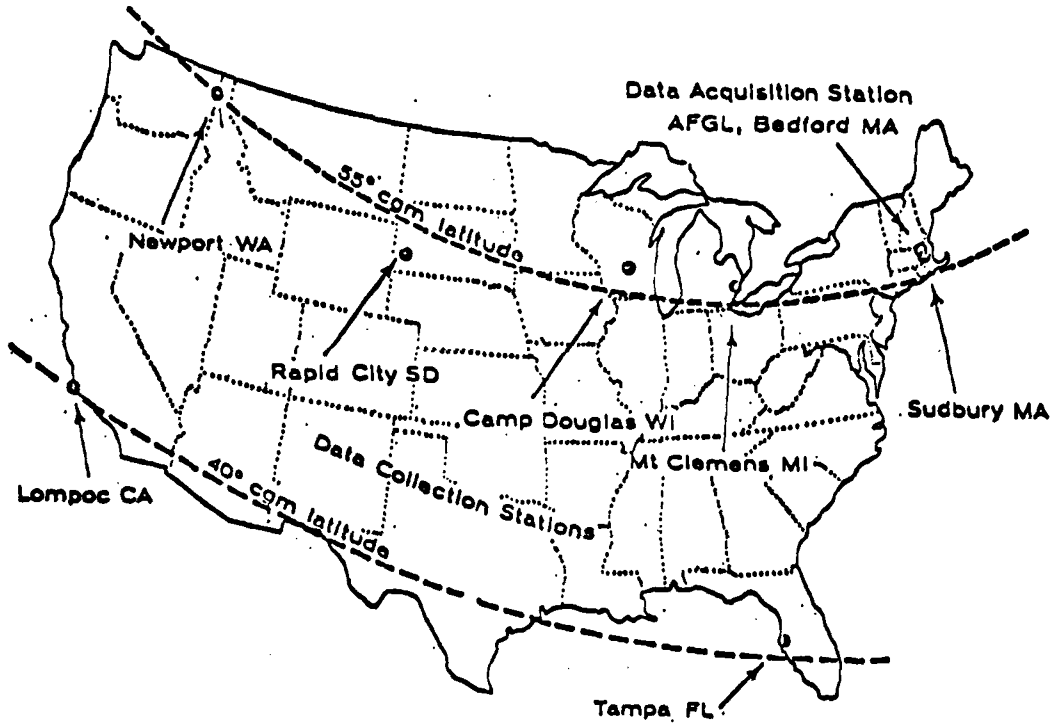
averages and many other data presentations can be extracted from the tape. Appropriate data will be filed with the World Data Center A, Boulder Colorado. The unique properties of the microprocessor (MPU) provide versatility and flexibility for the observatory system. For example, the MPU can control several different outputs. The same data can be used to print ASCll characters on paper tape, present two's complement binary numbers to a digital to analog converter to draw magnetograms or to convert to serial data signals for magnetic tape storage, or transmission over telephone lines. Software changes are all that are needed to control the data format and all system timing and sequencing. Rapid changes in the field can be noted by the MPU and sampling of the field can be done at more frequent intervals--whatever the user programs into the system. System functions can be added, deleted or changed by programming. Future needs can be met by changing instructions to the machine, instead of by redesign, constructions of new circuits, or other hardware modifications. The MPU can handle additional inputs as well. For example, in a test for orthogonality, digitized output from a MAGAF Fluxgate magnetometer can be handled by the MPU and directly compared to the Cesium magnetometer data, or to another fluxgate, or to both. There are many exciting possibilities, but efforts now are directed <u>only</u> towards recording the three vector components on tape in an appropriate format. The system, however, has been planned realizing that designing flexibility at this time will allow changes to be made easily in the future.

Various groups who were conducting magnetic surveys in this area have used the printed output of the total field magnetometer to remove the daily variation from their survey data. They include students from University of Massachusetts, Amherst, The University of Rhode Island, and Woods Hole and Weston Geophysical Engineers, Inc. A group of scientists from Sylvania ESD of Needham, MA made several visits to the Observatory. They were formulating a proposal to investigate the effects of large scale magnetic activity on sensitive power systems. Initially they proposed to the use the Sudbury station as source of magnetic activity data. However, College, Alaska was suggested as the experimental site because there is almost constant large scale magnetic activity in the auroral zone.

Because of restrictions on funds and manpower there has been no opportunity to update the Test Coil Facility. AFGL personnel continued to use the facility to test magnetometers destined for space flights.

The Magnetometer Network

The Magnetometer Network has been described in an AFGL publication (3). A prior report (1) gives detailed drawings of a typical observatory. The geographical location of the observatories is shown in Figure 5. In September 1976, the stations on the northern latitude line were installed and operational. The Florida station was in operation in December



Geographic Locations of the Network Stations

Figure 5

1976. The installation of the California station was not completed until October 1977. To save the cost of transportation, the trailer was purchased in California. However, there were delays in the delivery of electronic components. Once the installation of the network was completed the contractual obligations were to assist AFGL personnel in maintaining the observatories in operating condition and to upgrade, where possible, the instrumentation in order to insure a continuous flow of high quality data to the AFGL.

If a failure at any station occurs, the normal procedure is to dispatch personnel to the station and to attempt to repair the failed unit at the site. If this cannot be done in reasonable time, the unit is replaced and shipped to Weston for repair.

Before discussing problems specifically related to the magnetometers, it might be well to recount some of the problems encountered. Many of the early problems associated with station failure were due to external influences. Animals, water, lightning, and human activity have produced disturbances or interruptions in the data. Mice seemed to be attracted to the cables from the fluxgate sensors to the instrument vans. Parts of cables were severed by gnawing rodents in Michigan, Wisconsin, and South Dakota. In no case were search coil cables ever damaged. The mice seemed to prefer the teflon jacketed fluxgate cables to the non-contaminating PVC jacket of the search coil cables. Systematically all the original fluxgate cables were replaced by new PVC jacketed cables. The new cables have not been damaged by rodents.

In California, mice found their way into the power supply compartment of a Geotronics (search coil) magnetometer, nested there, and proceeded to spread nesting material and general filth throughout, eventually damaging the instrument. The magnetometer was cleaned by the manufacturer by immersions in heated solvent, and then repaired, but the smell of the unit still betrays its former condition. Throughout the network screening has been installed at potential entry points in an attempt to thwart infestations by rodents and other pests.

In Michigan a burrowing animal caused collapse of one of the six sets of concrete blocks supporting the instrument van. This corner support has been repaired 3 times to date; the last time by E. Johnson and R.O. Hutchinson who re-adjusted all six supports, repositioned, and tied the trailer down with guy wires and anchors at each corner. All vans are guyed down except the one in Washington which is sheltered by trees.

The presence of dangerous snakes at the Florida site required extensive removal of vegetation, but this opened up the area and attracted people on motorcycles, in dune buggies, on horseback and in pleasure vehicles that were sometimes parked in the area. Some of this activity showed on magnetograms. This was reported to the security police, who stepped up their patrols through the area also disturbing the instruments. In response to the situation, after getting permission from Base Civil Engineers, Boston College placed a chain link fence with a locked gate across the most obvious access to the area. However, this did not stop vehicles capable of off-the-road travel. An additional section of fence was later added, blocking the next most obvious entry-way. Still, this does not prevent occasional disturbances in the data by grounds maintenance personnel who periodically clear the area, or by military personnel who, on an unscheduled basis, conduct "exercises" nearby, sometimes encroaching into the MAGAF area.

A similar situation has been observed in California, where hunters are attracted to the area for varmints, quail, and other game. C. Tsacoyeanes reported disturbances in California to E. Johnson who recalled seeing several hunters in the area while the site was under construction, and David Knecht had reported finding that a lock on one of the shelters had been shot off. E. Johnson contacted the game warden's office at Vandenberg A.F.B. and learned that at some of the times of disturbance the game warden had observed traffic in the area and considering the times involved thought it quite likely that our problems could be attributed to hunting activity in the area. This area cannot be easily fenced. It remains to be seen what can be dome about this kind of problem.

The Fluxgate Magnetometers

The three component fluxgate magnetometers were designed and constructed at U.C.L.A. and have been described in an AFCRL report (4) and in an AFGL publication (3). In the course of time a number of modifications have been made to insure greater reliability and durability. Some of these modifications are discussed in detail in a Scientific Report (2). The major modifications included installation of high precision bubble levels on the sensor platform, new fans, and better ventilation for the electronics package, power supply capacitors, a new digital to analog converter (DAC), and new cables.

The DAC ultimately controls the flow of current which corresponds to the value of the prevailing magnetic field along the axis of the sensor. Detection of the second harmonic of the driving frequency ultimately yields a D.C. current which is fed back to null the field. The nulling field has two components, a coarse and fine. The fine component nulls out a field of only ± 64 gammas. In the field rises (or falls) above (or below) this ± 64 gamma range a comparator circuit detects an out of range condition. The comparator activates a counter which counts up or down according to the direction of the out of range condition. This counter drives the DAC which in turn raises or lowers the current in the coarse offset sensor coil until the sum of coarse and fine components null the external field prevailing along the sensor axis. After some use, the scale changes were often not smooth, resulting in step-like increments in the plotted output. Two problems were detected, one in the wire-wound potentiometer which controls the coarse offset current. Wire-wound pots do not have infinite resolution, and are subject to changes merely through handling in transit, and wear poorly.

Calibration settings became unstable. When the original potentiometers were replaced with cermet potentiometers the settings became much more stable and repeatable. A second problem was associated with the zero to minus one coarse step (coarse reading 0.0, fine reading -64). The difficulty was traced to the DAC. The output of the DAC in this step was 50% or more in excess of normal output. This made it impossible to null out values of the field near zero, and since Y component is set near zero, the problem manifests itself as a "searching oscillation" of many coarse steps in channel Y. The original DAC was no longer on the market. An equivalent DAC with identical pinouts was suggested by Bob George of U.C.L.A. and has proved to be more accurate and stable and is being installed when the instruments are returned to Weston for repair.

In a Scientific Report (2) we detailed the problem of accurately leveling the sensors, the suspected departure from orothogonality of the sensors, and a method of determining the departures. Even if the sensors are within the specifications as to orthogonal conditions (0.5° between the horizontal and vertical sensors) this leads to an error of almost 475 gammas in the horizontal component, assuming a total field magnitude of 57,000 gammas and an inclination of 72°. Knowledge of possible non-orthogonal conditions is important in the process of determining the 'absolute' values of the components of the magnetic field at the observatories. The fluxgate magnetometer was not designed to be an 'absolute' instrument, it very accurately measures the variations of the field components around preset values. How well these values represent the 'absolute' values of the field is to be determined at each site by comparison with 'absolute' standards. The U.S.G.S. Geomagnetics Branch uses a proton precession magnetometer in conjunction with a theodolite magnetometer which simultaneously measures the declination and inclination, to establish standards for the horizontal and vertical field. AFGL scientists are acquiring similar instrumentation so that a survey may be made at each site and the baseline values of the fluxgate set to match these established values. Unless the departure from orthogonality is known, interpretation of the data may be misleading.

THE INDUCTION COIL MAGNETOMETERS

The sensors and associated electronics are the product of Geotronics, Inc. of Austin, Texas. The most serious problems have occurred during thunderstorms. Apart from one incident, the failures have not been catastrophic. The failures of various components have been due to transients associated with lightning. A number of changes have been made to protect the equipment (2). The following is a brief summary.

Transients in the sensor to amplifier lines have been suspected of causing failure of the switches in the chopper amplifier. Back to back high speed switching diodes were installed to limit these surges, but failures still occurred, without damage to the diodes. The precise means by which switch failure occurs is still not known. On the work bench, failure of the original 709A operational amplifiers could be induced by nearby static discharges. An inexpensive Fairchild 741 operational amplifier proved to be able to withstand higher levels of static discharge. All of the 48 original amplifiers have been replaced by this unit.

All AC inputs are now guarded by a GE VSP-1 voltage spike protector to prevent entrance of transients through the power lines. The ±17 volt power supply outputs are protected by 18 volt varistors which limit power supply surges. Previously 20 volt zener diodes had protected the electronics but as a result of absorbing surges, shorted out, leaving the magnetometer out of service. The varistors offer non-destructive protection.

Power supply failure due to transients had been a problem, but so far, no protected supply has failed.

Another problem has been master oscillator lockup caused by short duration power drop-outs. The original oscillator "locked up" when A.C. line voltage dipped below 55 VAC. First, a power drop-out, time delay relay was installed in the A.C. line. Improvement was made, but the relay was not catching the faster (less than 50 ms) power drops. Finally, we selected a commercially produced oscillator, which is easily retrofitted to replace the original circuit. Apart from lightning problems and power drop-out problems, the search coil magnetometers have performed well. One must remember that according to the manufacturer, these instruments were not designed with unmanned operation in mind. The manufacturer says that a more typical operating time might be 4 hours, and that since thunder storms would interfere with measurements, storms would preclude operation.

Reliability: a study of the fluxgate magnetometer power supply.

One of the objectives of this contract is to improve the reliability of the instrumentation in the magnetometer network. Experience points to weaknesses, components which have actually failed: air conditioners, fans, power supply capacitors, and DACs. These problems have received the most attention. However, a statistical likelihood of failure can also be investigated and related to influences such as vibration and temperature.

Components are often described by factors such as Mean Time Between Failure (MTBF), or failure rate λ. Failure rate information is sometimes published by manufacturers or by the government as part of its own reliability programs. With this information it is possible to mathematically predict areas of equipment weakness with fair accuracy. But failure, particularly of modern electronic components, can only be predicted on a statistical basis. The probability of no failure (P_o) over a time interval, T, is, assuming a Poisson distribution of failure,

$$P_o = \exp(-T/MTBF) = R$$

where R is called the reliability factor (5).

Through MTBF is the average time between failure, the probability of no failure (or the reliability) in a time period equal to the MTBF is only

$$R = \exp(-1) = .367,$$

a relatively low reliability.

The equation may be inverted to yield

$$-\ln(R) = T/MTBF$$

A 90% confidence, R = 0.9, yields

$$.105 = T/MTBF$$

Thus we can be 90% sure of operation without failure for 10.5% of the MTBF. Figure 6A is a plot of R vs T/MTBF.

Calculation of the MTBF for a system requires a knowledge of the failure rate, $\lambda = 1/MTBF$, of each component in the system. Under the assumption that the system will fail if any of its components fails, the failure rate of the system is the sum of the failure rates of its components. Thus

$$\lambda_s = \lambda_1 + \ldots\ldots\lambda_n$$

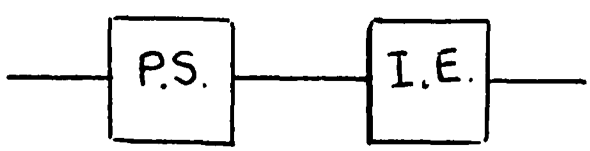
The failure rate is usually given as failures per million hours. For an MTBF of 50,000 hours, $\lambda = 20/10^6$ hrs.

If more than one system must work, the resulting reliability is the product of the reliabilities of each of the systems. Often, in the case of space missions, duplicate systems are provided to improve reliability. Then the system reliability R_s is

$$R_s = R_1 + R_2 - (R_1R_2)$$

The following three examples illustrate the gain in reliability through the use of backup components:

System success example 1, both systems (supply and electronics must work



CONFIDENCE LEVEL VS. T/MTBF

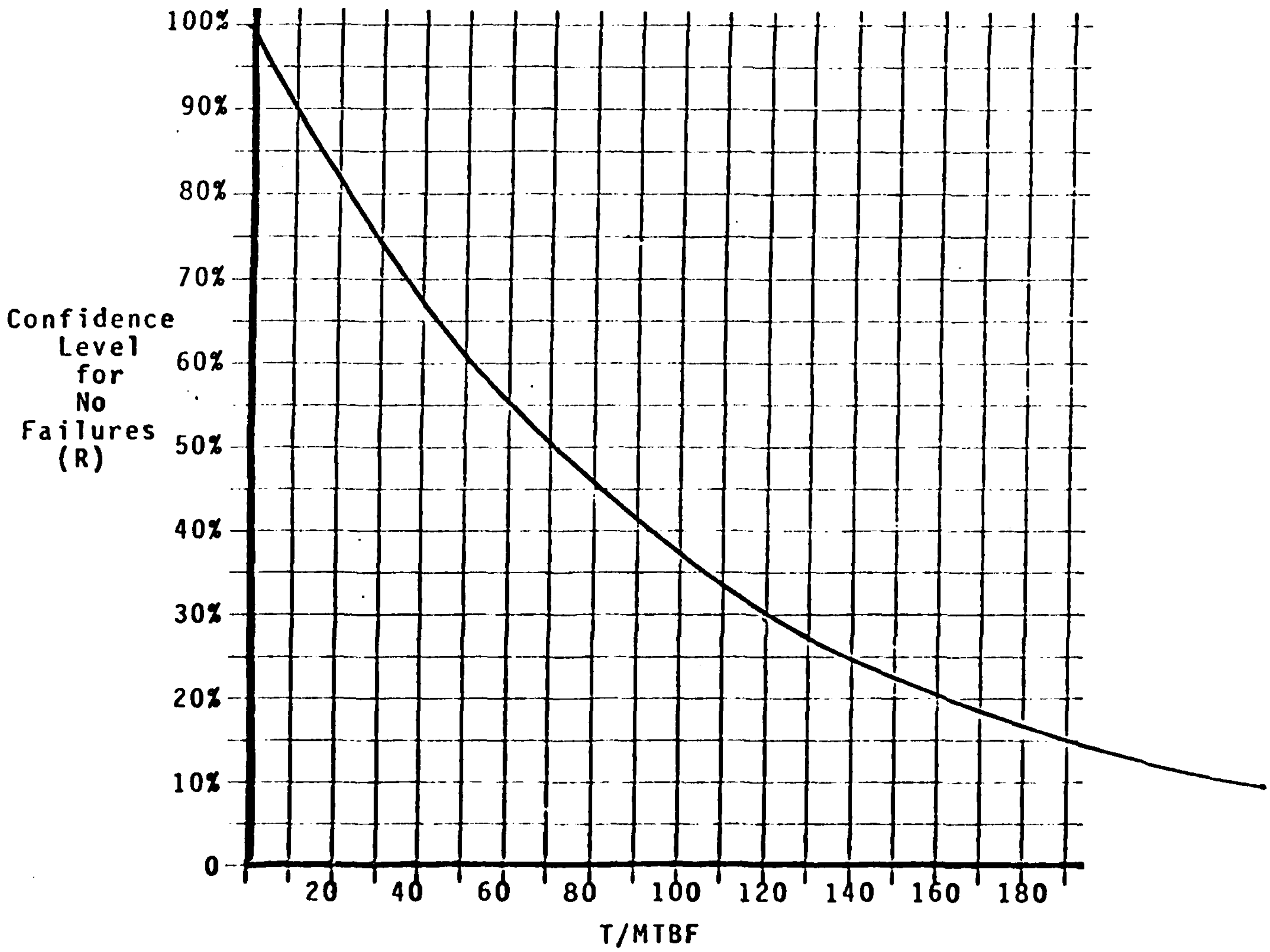


Figure 6A

P_s = Probability of system success

P_{ps} = Probability of power supply success

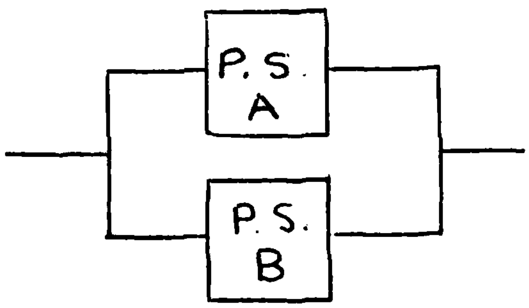
P_{ie} = Probability of instrument electronics success

$P_s = P_{ps}P_{ie}$

If, for example $P_{ps} = .3$ and $P_{ie} = .95$; $P_s = .28$

The system reliability is dominated by P_{ps}.

System success example 2, either system, Supply A or Supply B will provide system success



P_s = Probability of system success

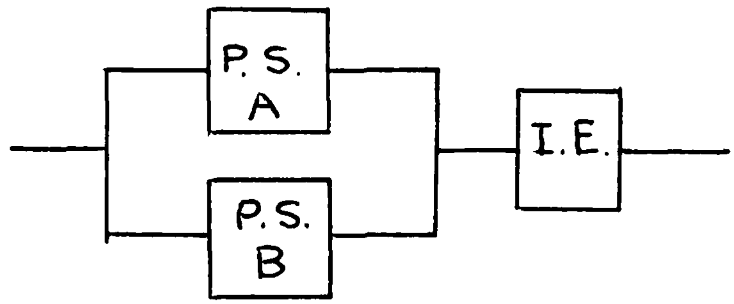
P_A = Probability of Supply A success

P_B = Probability of Supply B success

In this case, if $P_A = P_B$; $P_S = 2PA - (PA)^2$. If PA = .3

$P_S = .51$

System success example 3, effect of using hypothetical power supply back-up with instrument electronics



$P_S = (2P_A - P_A^2) \quad (P_{ie})$ If $P_A = .3$, $P_{ie} = .95$

$$P_S = (.51) \quad (.95) = .48$$

compared to .28 for a single supply.

Example 3 assumes that both supplies are running in parallel. If a back up supply is used, which is connected and powered only upon failure of the primary supply MTBF for the system supply is doubled. That is, "two elements each with an exponential mean life of Θ, give a system mean life of $(3/2)\Theta$ when there is active redundancy and 2Θ when there is standby redundancy" (6).

Since many of the problems encountered appear to be thermal in origin we have done an analysis of the fluxgate magnetometer power supply. The failure rates have been taken from MIL-HDBK-217B, 7 Sept. 76.

While the handbook presents a straightforward approach to most discrete electronic components, the failure rate calculations for blowers and fans are more involved. To use the failure rate models accurately, quantities such as winding temperature, bearing temperature and temperature cycling characteristics must be known. From MIL-HDBK-217B, pg. 2.8.2.1 paragraph 2.8.2,

"The failure rates are strongly influenced by the thermal conditions of the application and particularly by thermal cycling. It is important, for this reason, that the thermal environment be accurately determined and the proper models of this section employed in developing the failure rate."

We, as an end user of a relatively small number of fans, have not the means to determine many of the parameters necessary for model definition, for instance, α_B, bearing characteristic life resulting from thermal cycling. A proper and accurate analysis of fan lifetime is most appropriately done by the manufacturer, who has the means to best accomplish detailed internal temperature studies of the product.

Nevertheless, certain generalizations can be gleaned from the text. Page 2.8.2-2, Notes 1, for UQG (Upper Quality Group) units use α_B = 120,000 hours if computed αB exceeds 120,000 hours. Note 2, for LQG units use α_B = 80,000 hours if computed αB exceeds 80,000 hours." Paragraph 2.8.2.1 states t_2 (MTBF) = $S\alpha_B$ and S is obtained from Figure 2.8.2-2. S in that figure does not exceed one if we assume that the winding diameter exceeds .005 inches (see note, pg. 2.8.2-4) then $t_2/\alpha w$ is assumed to be equal to 0, and the solution is given in paragraph 2.8.2.1.1 which states MTBF (t_2) is determined by t_2 = .885 (120,000) hours which is 106,200 hours, or about 12 years. For lower quality level (commercial) fans, t_2 = .885 (80,000) hours, which is 70,800 hours, or 8 years. These are the upper limits of lifetime; a more "real world" case might be half of that. Remember, for a confidence level of 90% for no failures, T = .105 MTBF. For upper quality level fans this is 10 1/2% of 12 years, or 1.2 years; and for "commercial" fans, 10 1/2% of 8 years, or about 9 1/2 months.

We consulted with the manufacturer of the original fan, and also the MIL. SPEC. fan, in order to get a "real world" point of view about their performance. Rotron manufacturers both fans.

According to Mr. Loorents, applications engineer, of Rotron's Custom Division, Woodstock, New York, the MIL-B23071/7-001 spec Spartan fan has an MTBF at 25°C, in a benign environment, of 60,000 hours (6 years, 10 months). The original muffin fan is of commercial quality, and, according to MIL-HDBK-217B pg. 2.8.2-5, table 2.8.2-2, should be regarded to have .26/.95, or .27 times the MTBF of the upper quality level device, about 2 years. This seems to us to be unrealistically low, and Mr. Loorents agreed, saying that 5 years might be closer to true. Mr. Loorents added, that it is not uncommon to find muffin fans still operating after as much as ten years of service. He pointed out that differences in bearings and lubricants between the two fans would account for greater MTBF variations under stressed conditions. That is, under the best conditions, there would be much less difference in MTBF between the two fans, than under conditions of stress, such as back pressure, higher temperature, and vibration. Under higher stress, the MIL spec. Spartan fan would clearly outlast the muffin fan. For our further calculations however, we will consider muffin fan MTBF to be 2 years, corresponding to 57 failures per 10^6 hours. (In the first three years of operation, with 5 fans in the field, we had 2 failures). We will consider the MTBF of the Spartan fan to be 7 years of 16 failures per 10^6 hours. These are very high failure rates compared to the other magnetometer system components. Figures 6B-6K illustrate the effect of temperature on power supply component failure rates.

Since fans are unreliable in comparison to the components which they cool, and overheating is a severe problem, we have considered a rearrangement of the components. The greatest source of heat in each instrument is the power supply. As originally received, the fluxgate magnetometers and the DCP, have within the same chasis, the instrument electronics, the power supply, and a fan. In both cases, ventilation, even with the fans, was inadequate. The fluxgate has its principal exhaust vents in the rear, cooling the power supply, but allowing heated air to accumulate in the instrument section. The situation is even worse in the DCP; there are no exhaust vents. If it is desirable to have to have power supply, instrument electronics and a cooling fan in the same chassis, there must be adequate ventilation; some vents must be placed <u>above</u> the power supply so that, when the fan fails, heat can be removed by convection. The electronics should be designed to be reliable <u>even if the fan fails</u>. However, it is difficult to design around a fan failure since the internal instrument temperature may rise drastically. In a van with a working air conditioner temperatures in excess of 110 degrees are expected, and in excess of 130 degrees with defective air conditioning.

In the case of remote stations, it is better to design an instrument that is separate from the power supply and which does not depend on a fan to maintain ventilation. Those areas which are most sensitive to temperature change should be identified and evaluated for possible hardware precautions such as temperature compensation. When hardware may be limited, temperature compensation can be accomplished by software, after temperature dependent performance is analyzed. In particular, the fluxgate magnetometer electronics could be mounted in a closed insulated chassis, heated internally by self-regulating heaters capable of maintaining temperature about 90 degrees F. The power supply could be mounted separately, and be rated heavily, and vented to be cooled only by convection. The power supply chassis could also contain one or two fans controlled by thermostatically operated switches which could operate the fans only if more ventilation be needed. A spare power supply at each site would provide an immediate replacement for the least reliable circuit. With separate power supplies and keyed plug systems, a supply could easily be changed by untrained personnel. A new remote observatory design ought to share as many components in common as possible. The advantage of having on-site interchangeable spares is clear: quick, locally available service.

Fluxgate sensors and electronics are not readily interchangeable. Power supplies can easily be standardized to be interchangeable. We want to insure that the same sensor and electronics remain at a site for an extended period of time to monitor the secular variation. A detailed magnetic survey is planned at each observatory, to determine the absolute values of the components of the magnetic field and thus to calibrate the fluxgate magnetometers. Replacement of a sensor would upset the continuity of the data and would require repetition of the survey.

By far, the system component least reliable and most troublesome, has been the air conditioner. It was poor engineering to link air conditioners to the reliability of the state-of-the-art observatory system. Each air conditioner has two motors. Failure of either results in extensive damage to the air conditioner and overheating inside the van causing data deterioration and instrument damage. Piping joints and the pipes in the air conditioner condenser deteriorate under normal conditions. To design temperature stabilized equipment within its own local environment is certainly a worthwhile goal, using air conditioners only as an emergency back-up is a possibility.

The station at Newport, Washington, has been without air conditioning for nearly two years and there has been no overheating problem. No elaborate ventilating scheme has been used and the equipment is as it was delivered. The windows in the van are opened in the summer and closed in the winter.

It is not advisable to use this scheme for other stations, but we do emphasize that, with the proposed equipment refinements and a single ventilating plan, the instruments can be run reliably without energy-wasteful and costly airconditioning.

The modifications discussed and in particular the comments concerning reliability should in no way be construed as criticism of the original design of the fluxgate magnetometer nor of the van housing the equipment. In 1973 the design of the fluxgate magnetometer embodied the best state-of-the-art electronics. For example, the Burr-Brown DAC 45CB1 was the best available; within three years it was off the market. Under the ideal conditions, at Weston, the temperature control system operated well with new equipment. Age of equipment and different external conditions now show that it was not the best possible design. In six years, there has been great progress in electronics, and in temperature control techniques. It is part of this contract's purpose to make use of that progress to provide greater reliability for the entire MAGAF network.

3.5 On Site Assistance

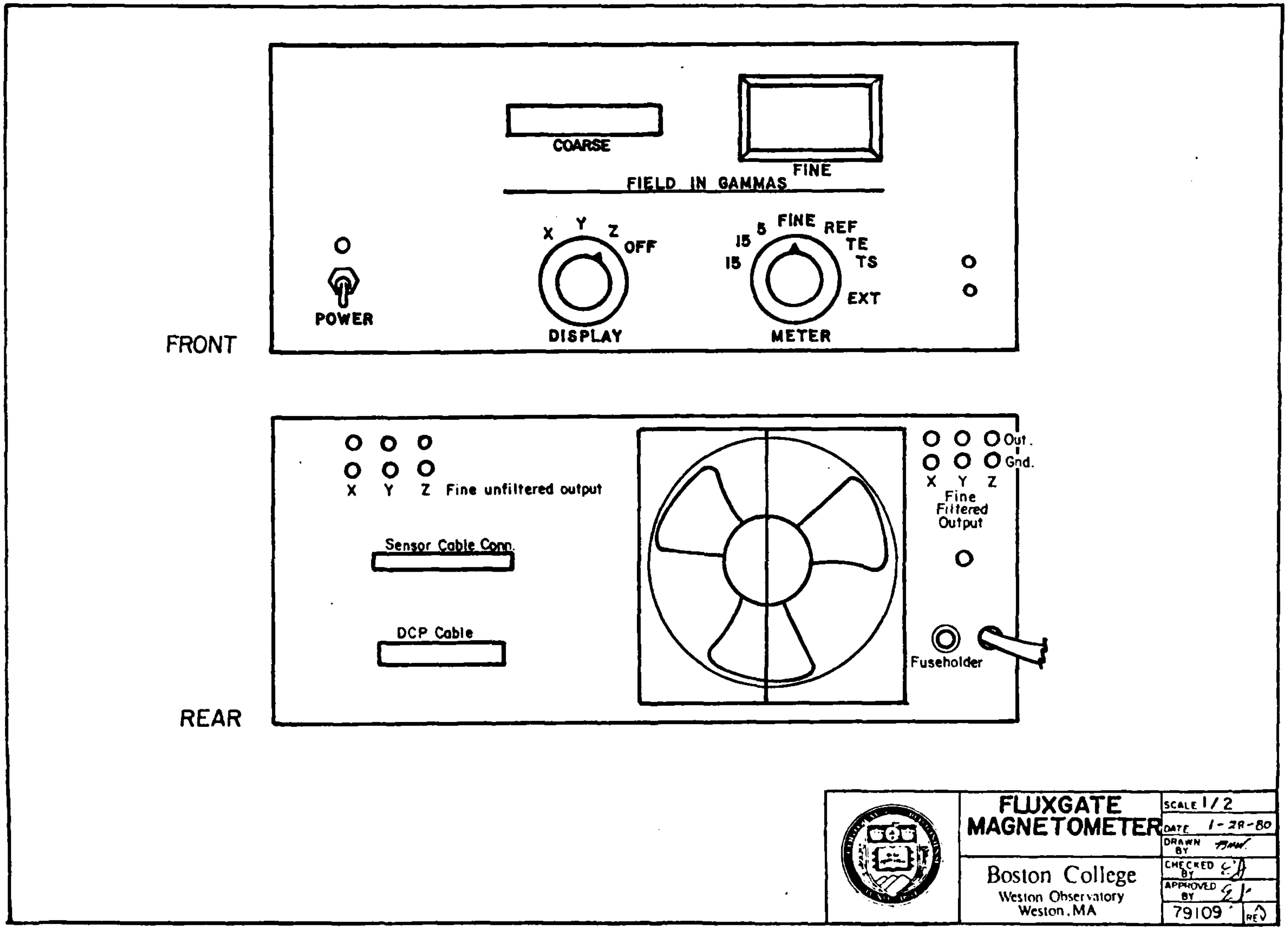
For some time (since April 1979) a plan to use the services of individuals, employed by the government at observatory sites, for simple service tasks has been in development. Dr. Knecht of AFGL has visited the sites and has conferred with the individuals who would be involved. Dr. Knecht has also investigated the legal aspects of temporary employment by an outside contractor with the legal personnel at Hanscom AFB. As a result he has begun to prepare the necessary documentation so that Boston College may, on short notice and for a very brief period, employ individuals to perform simple repair or inspection service.

Often a problem at a station can be identified from the data stream. Sometimes the solution is simple: press a restart switch; change a circuit board; reset a zeroing potentiometer. In anticipation of this program we have prepared drawings (Figures 4A-4G) to be used by these personnel. The diagrams provide a means to quickly locate replacement components. The assumption is that any service or replacement would be made while in telephone communication with Weston Observatory. The procedure is designed to maintain or rapidly restore the production of data without necessitating costly travel and the delays of travel by Weston and AFGL personnel to the remote observatories.

Conclusion

The MAGAF network of seven geomagnetic observatories has operated with relative success for two years. For the most part, failure knowledge of the individual components has grown, and complete replacement of failure prone parts has proceeded as far as financially possible. The reliability of components has been investigated with a view to improving long term stability, and design changes have been developed for the same purpose.

The calibration of the fluxgate magnetometers is an unfinished task, as is a full understanding of the temperature variation and mechanical differences between individual sensors. Additional equipment and time for experimentation should lead to solutions of these problems.



FRONT
COARSE
FINE
FIELD IN GAMMAS
POWER
X Y Z OFF
DISPLAY
15 15 5 FINE REF TE TS EXT
METER
REAR
X Y Z Fine unfiltered output
Sensor Cable Conn.
DCP Cable
Out.
Gnd.
X Y Z
Fine
Filtered
Output
Fuseholder
FLUXGATE
MAGNETOMETER
Boston College
Weston Observatory
Weston, MA
SCALE 1/2
DATE 1-28-80
DRAWN BY
CHECKED BY
APPROVED BY
79109
REV

Figure 4A

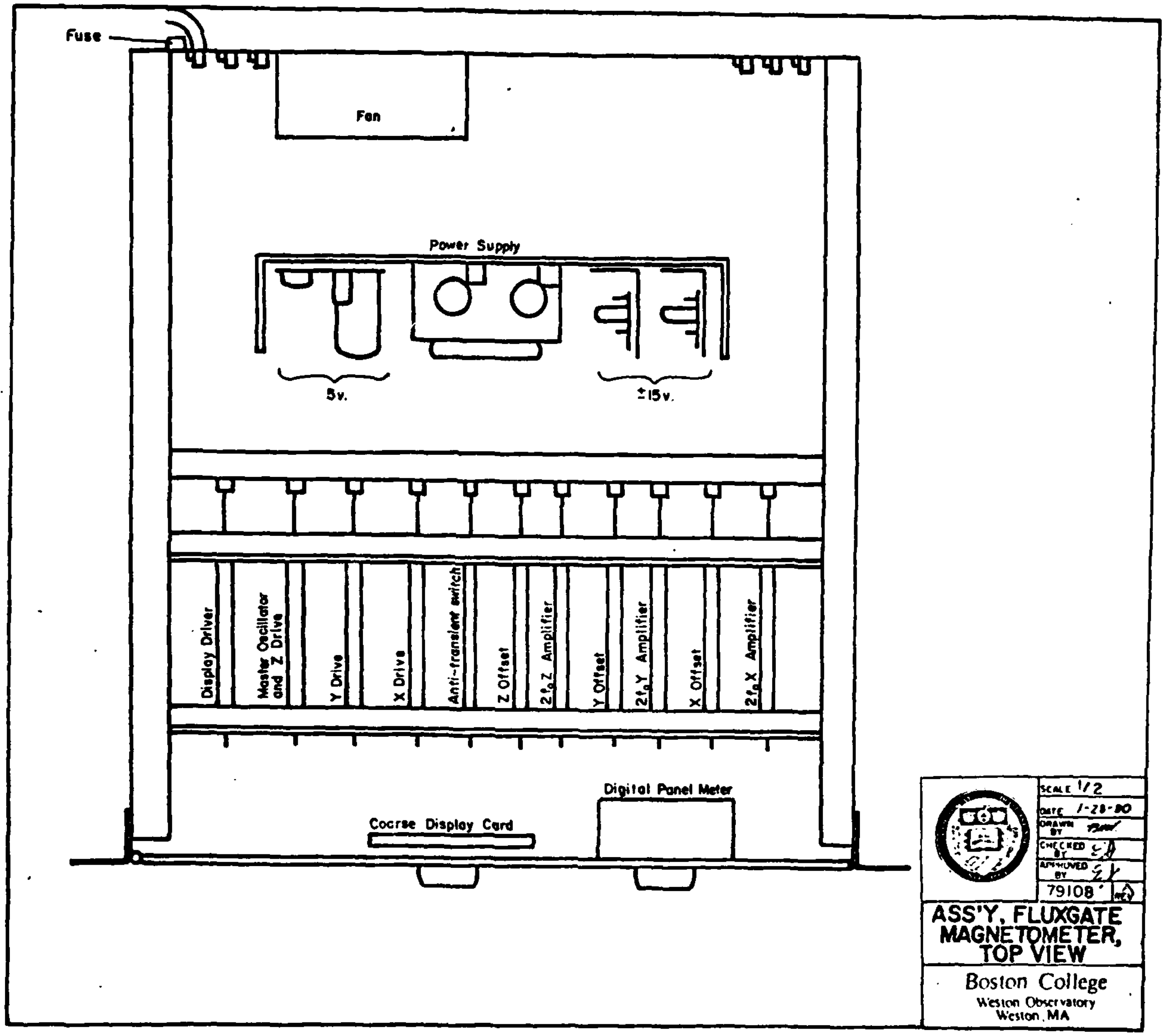

Fuse
Fan
Power Supply
5v.
±15v.
Display Driver
Master Oscillator and Z Drive
Y Drive
X Drive
Anti-transient switch
Z Offset
$2f_0$ Z Amplifier
Y Offset
$2f_0$ Y Amplifier
X Offset
$2f_0$ X Amplifier
Cocrse Display Card
Digital Panel Meter
SCALE 1/2
DATE 1-28-80
DRAWN BY
CHECKED BY
APPROVED BY
79108
ASS'Y, FLUXGATE MAGNETOMETER, TOP VIEW
Boston College
Weston Observatory
Weston, MA

Figure 4B

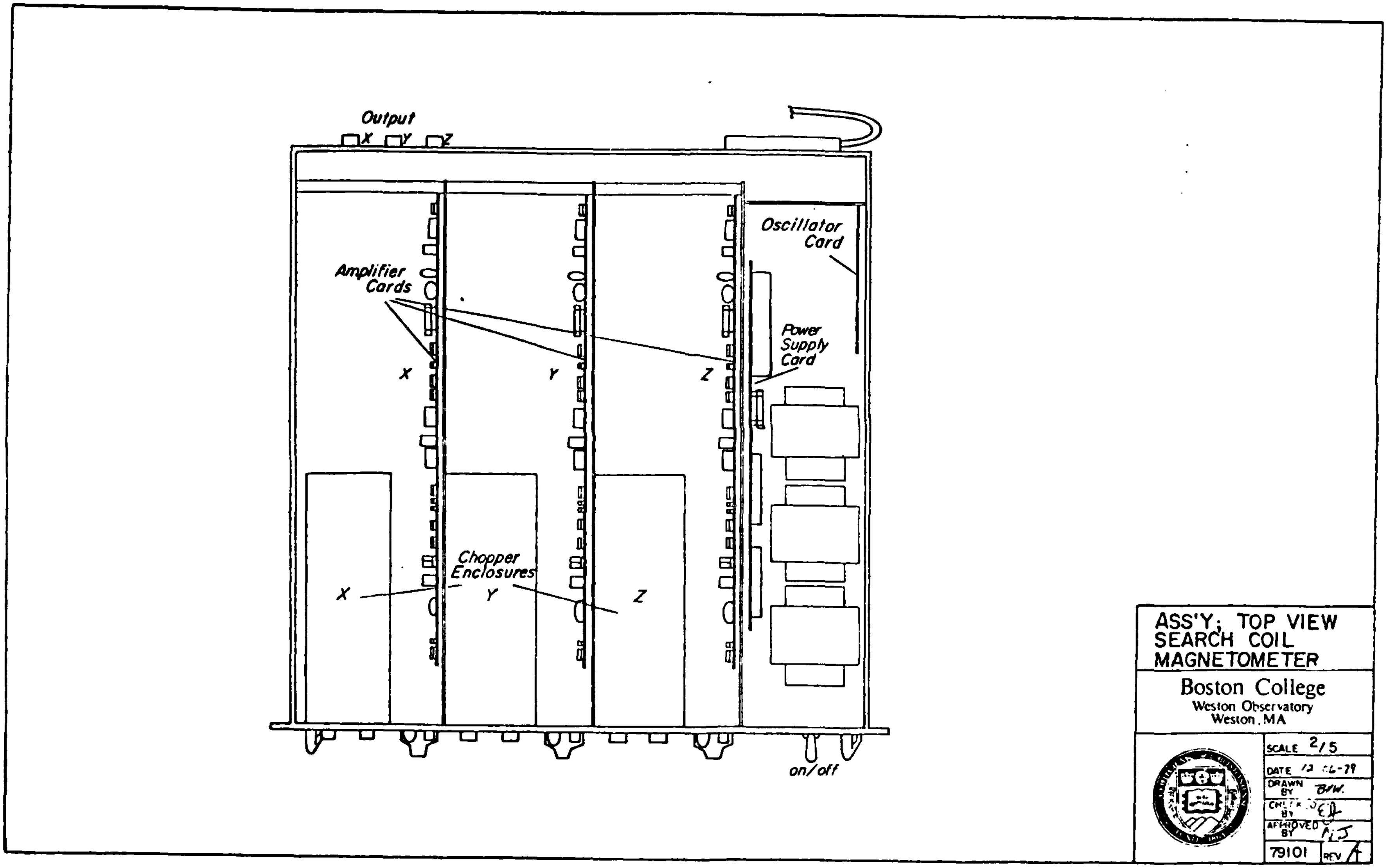
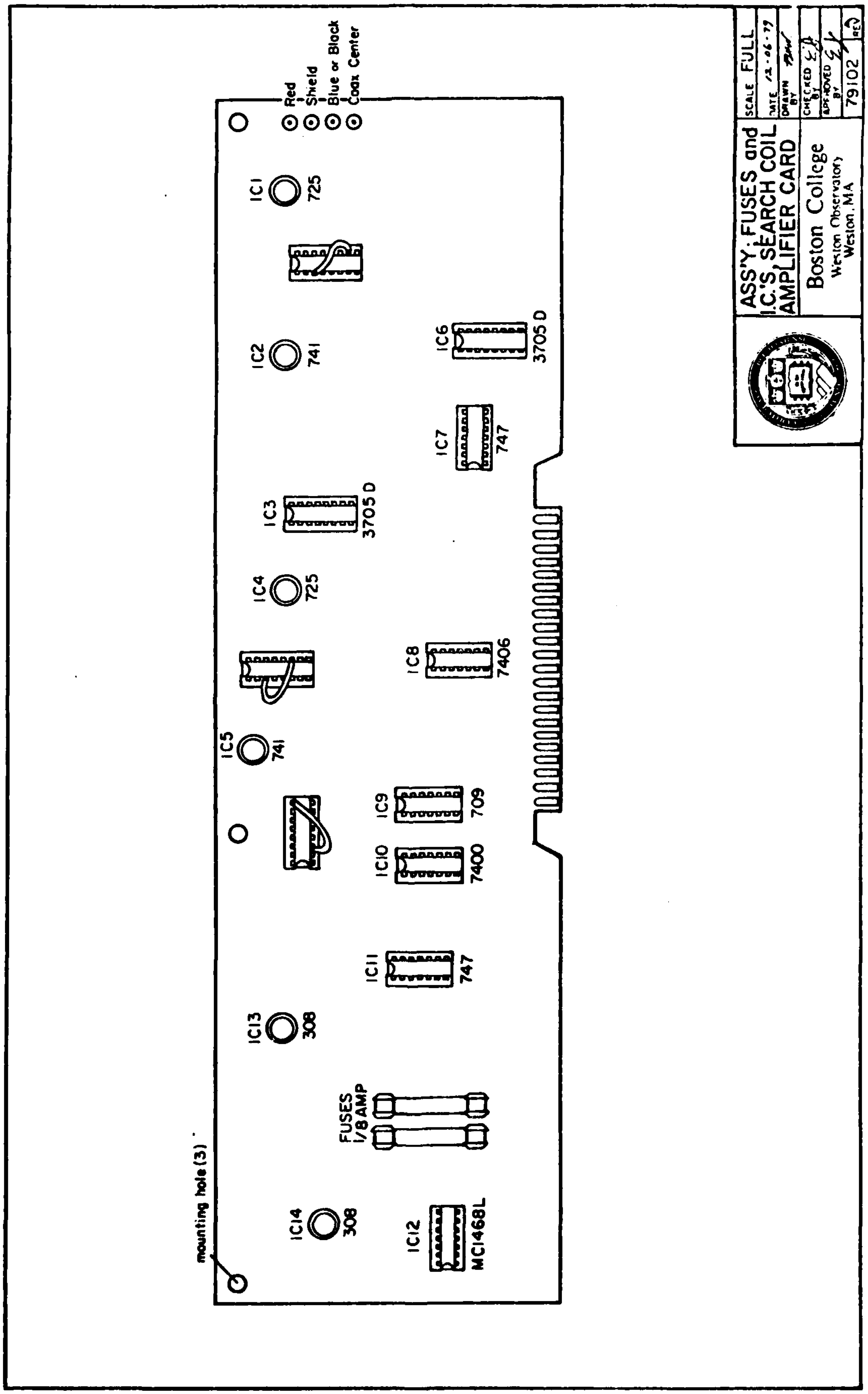

Output
X
Y
Z
Amplifier Cards
X
Y
Z
Oscillator Card
Power Supply Card
Chopper Enclosures
X
Y
Z
on/off
ASS'Y; TOP VIEW SEARCH COIL MAGNETOMETER
Boston College
Weston Observatory
Weston, MA
SCALE 2/5
DATE
DRAWN BY B/W.
CHECKED BY
APPROVED BY
79101
REV A

Figure 4C



ASS'Y. FUSES and I.C.'S, SEARCH COIL AMPLIFIER CARD
Boston College
Weston Observatory
Weston, MA
SCALE FULL
DATE 12-06-79
DRAWN BY
CHECKED BY
APPROVED BY
79102
Red
Shield
Blue or Black
Coax Center
IC1 725
IC2 741
IC3 3705 D
IC4 725
IC5 741
IC6 3705 D
IC7 747
IC8 7406
IC9 709
IC10 7400
IC11 747
IC12 MC1468L
IC13 308
IC14 308
FUSES 1/8 AMP
mounting hole (3)

Figure 4D

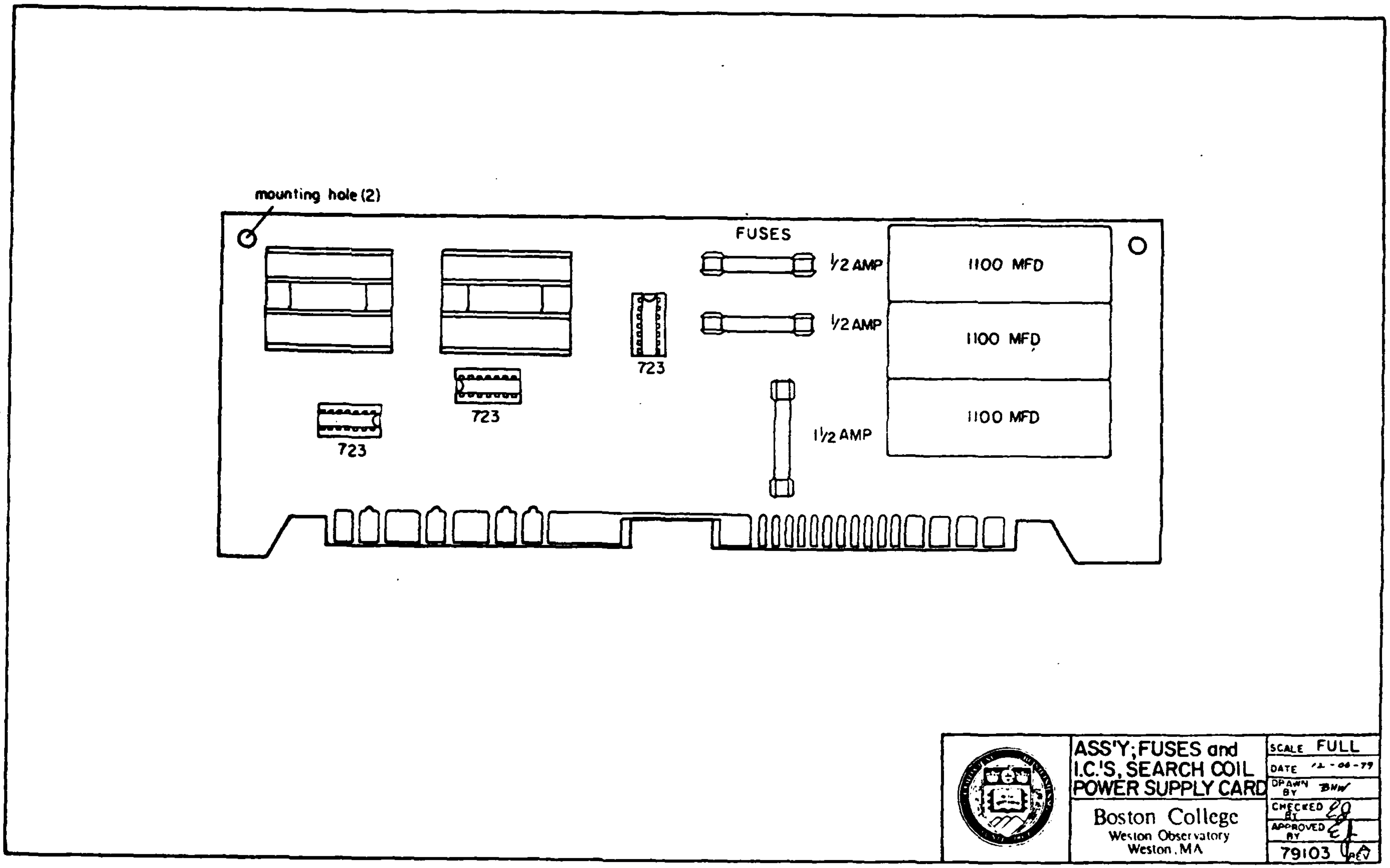

mounting hole (2)
FUSES
1/2 AMP
1/2 AMP
1 1/2 AMP
1100 MFD
1100 MFD
1100 MFD
723
723
723
ASS'Y; FUSES and I.C.'S, SEARCH COIL POWER SUPPLY CARD
Boston College
Weston Observatory
Weston, MA
SCALE FULL
DATE
DRAWN BY
CHECKED BY
APPROVED BY
79103

Figure 4E

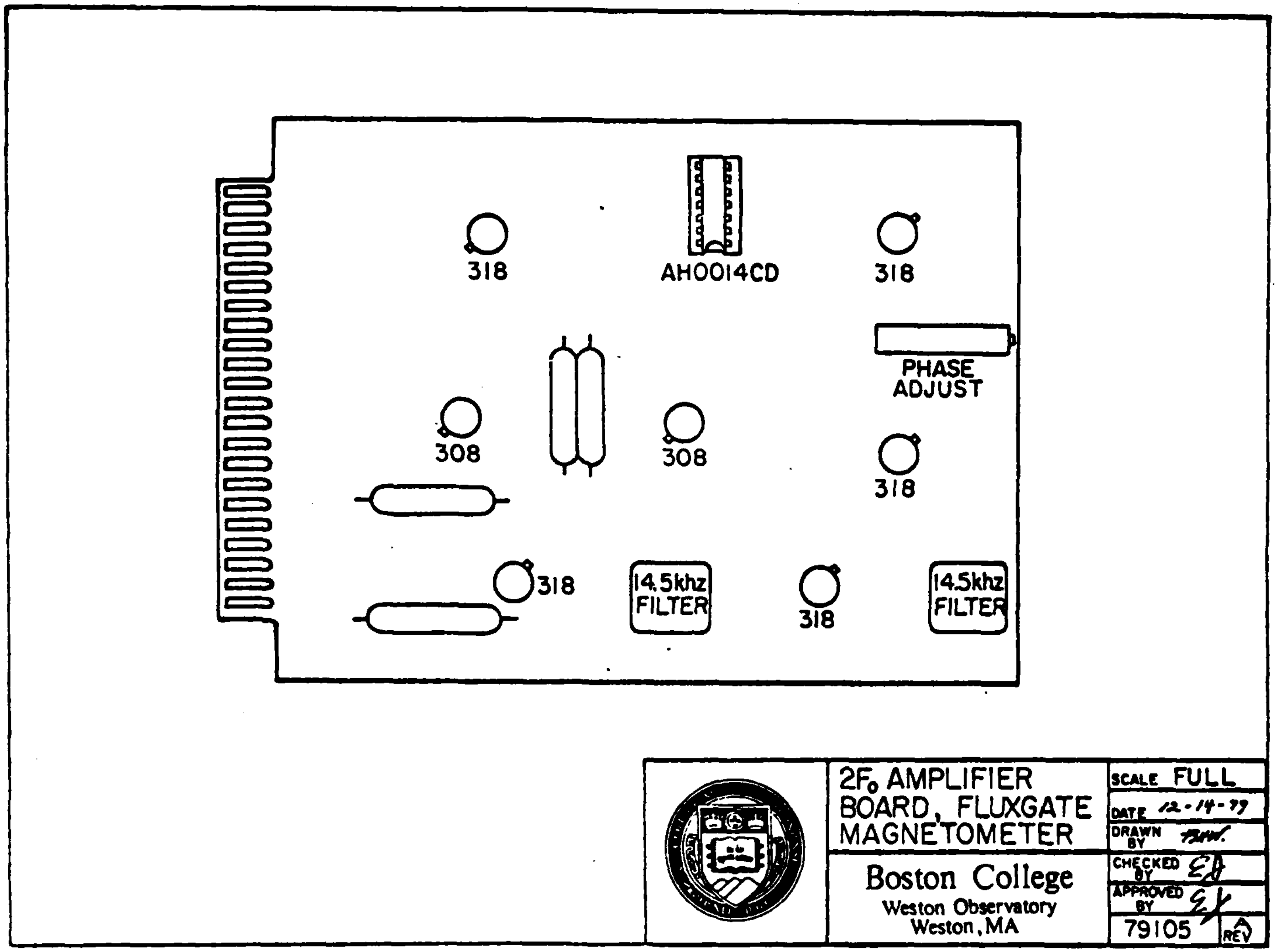

318
AH0014CD
318
PHASE
ADJUST
308
308
318
318
14.5khz
FILTER
318
14.5khz
FILTER
$2F_0$ AMPLIFIER
BOARD, FLUXGATE
MAGNETOMETER
Boston College
Weston Observatory
Weston, MA
SCALE FULL
DATE 12-14-79
CHECKED BY
APPROVED BY
79105
REV A

Figure 4F

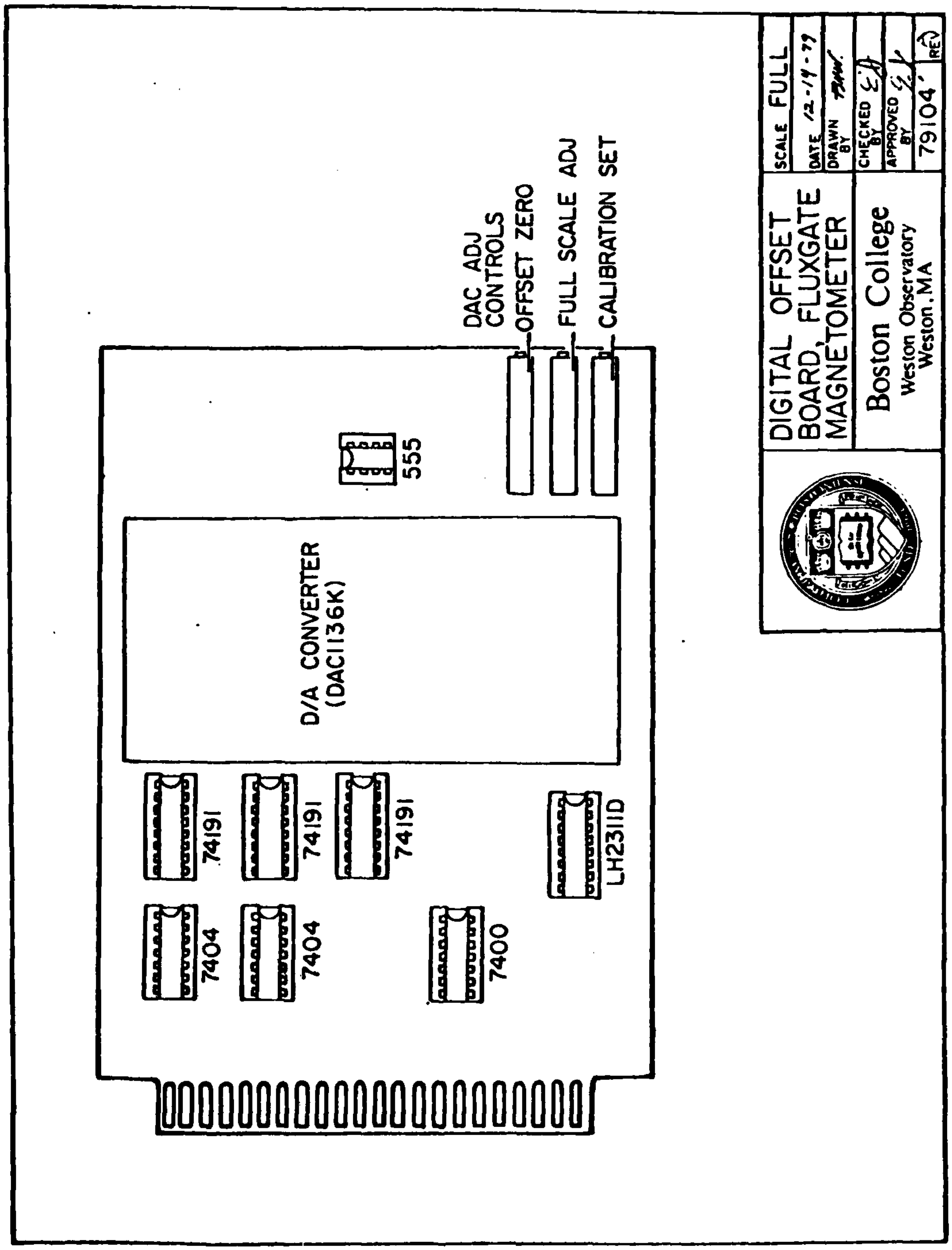
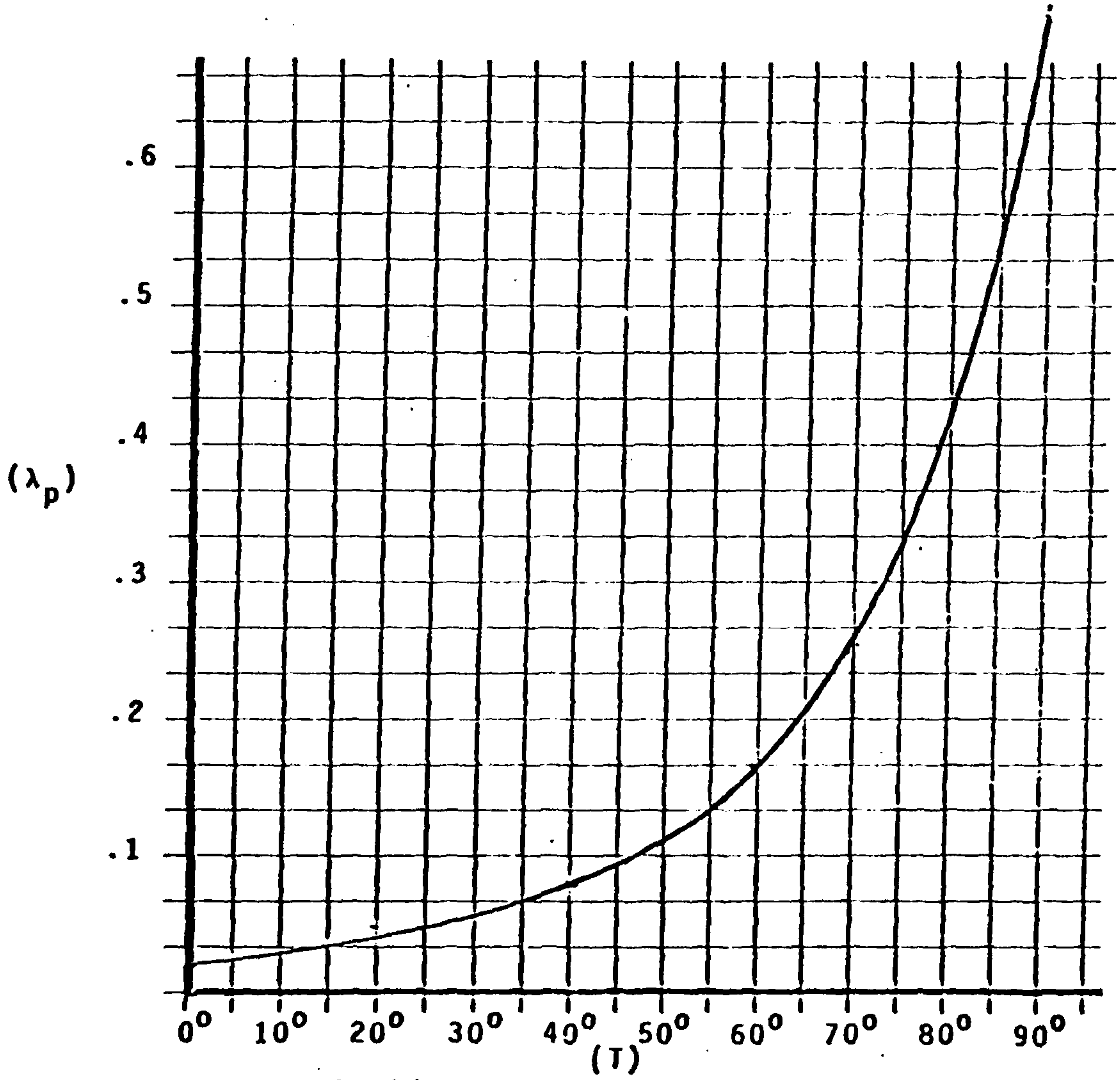

DAC ADJ
CONTROLS
OFFSET ZERO
FULL SCALE ADJ
CALIBRATION SET
555
D/A CONVERTER
(DAC1136K)
74191
74191
74191
7404
7404
7400
LH2311D
DIGITAL OFFSET
BOARD, FLUXGATE
MAGNETOMETER
Boston College
Weston Observatory
Weston, MA
SCALE FULL
DATE 12-19-79
DRAWN BY
CHECKED BY
APPROVED BY
79104'

Figure 4G

(1) ALUMINUM CAPACITORS, DRY ELECTROLYTIC FAILURE RATE (λ_p IN FAILURE/10^6 HOURS) (OPERATING VOLTAGE 40% OF RATED VOLTAGE: UPPER QUALITY LEVEL, FIXED GROUND ENVIRONMENT)



$\lambda_p = \lambda_b (\pi_E)(\pi_Q)$ (EQ. 1: notes 1.2)

$\pi_E = 2$; fixed ground environment

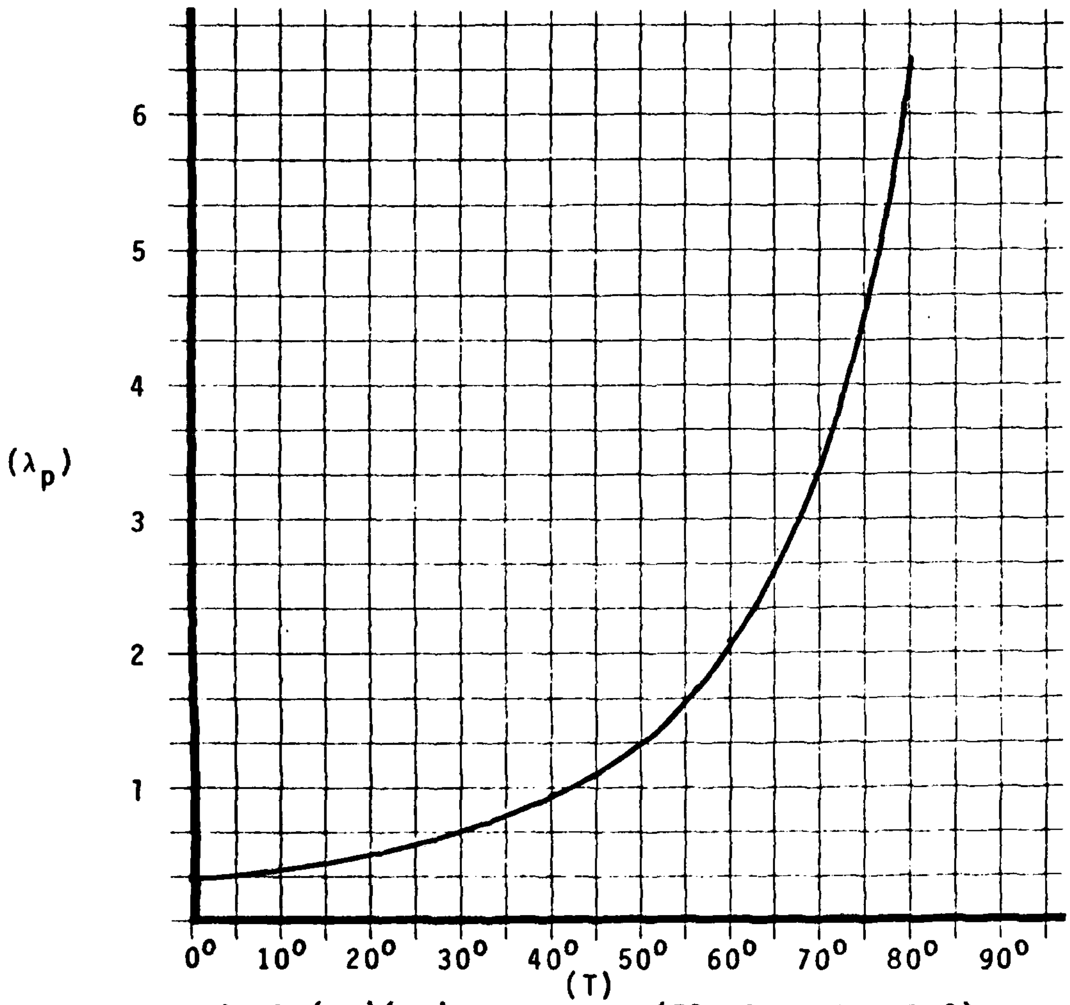
$\pi_Q = 1$; upper quality level

$\lambda_p = 2(\lambda_b)$ λ_b = base failure rate

1. Based on data from MIL-HDBK-217B 20Sept74, unrevised to 17March78, pp. 2.6, 6-3, 2.6, 6-4.
2. λ_b from MIL-HDBK-217B, table 2.6, 6-6, pg. 2.6, 6-4.

Figure 6B

(1) ALUMINUM CAPACITORS, DRY ELECTROLYTIC
FAILURE RATE (λ_p IN FAILURES/10^6 HOURS)
(OPERATING VOLTAGE 50% OF RATED VOLTAGE:
COMMERICAL QUALITY IN FIXED GROUND
ENVIRONMENT)



$\lambda_p = \lambda_p(\pi_E)(\pi_Q)$ (EQ. 1; notes 1.2)

$\pi_E = 2$; fixed ground environment

$\pi_Q = 10$; lower quality level (commercial)

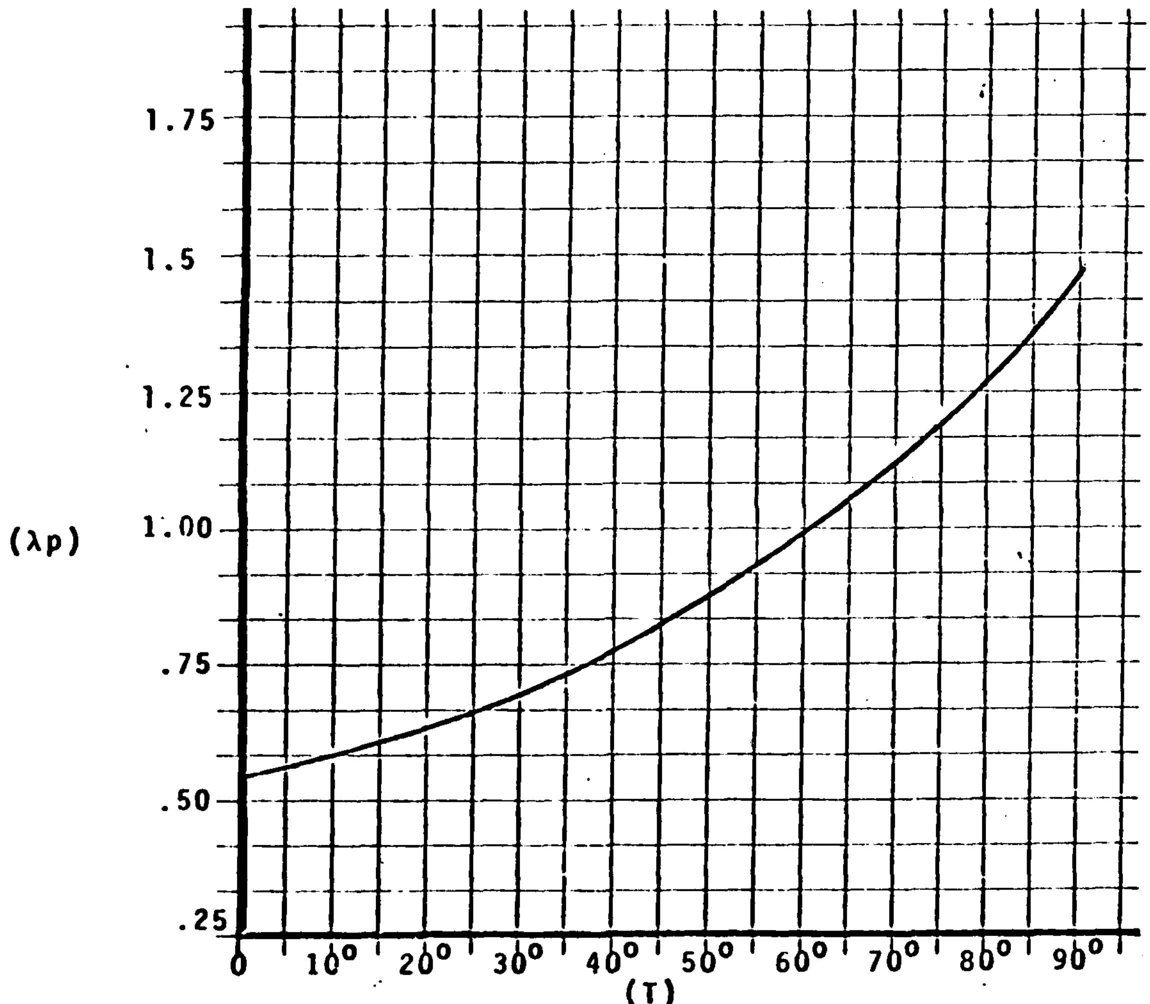
$\lambda_p = 2(\lambda_b)$ λ_b=base failure rate

1. Based on data from MIL-HDBK-217B, 20Sept 74, unrevised to 17March78, pp. 2.6, 6-3, 2.6, 6-4.
2. λ_b from MIL-HDBK-217B, table 2.6, 6-6, pg. 2,6, 6-4.

Figure 6C

SILICON DIODE, GENERAL PURPOSE FAILURE RATE
λ_p IN FAILURES/10^6 HOURS AT 20% RATINGS

$$\lambda_p = \lambda_b(\pi_E \times \pi_Q \times \pi_A \times \pi_{S2} \times \pi_C) = \lambda_p(\pi_K)$$

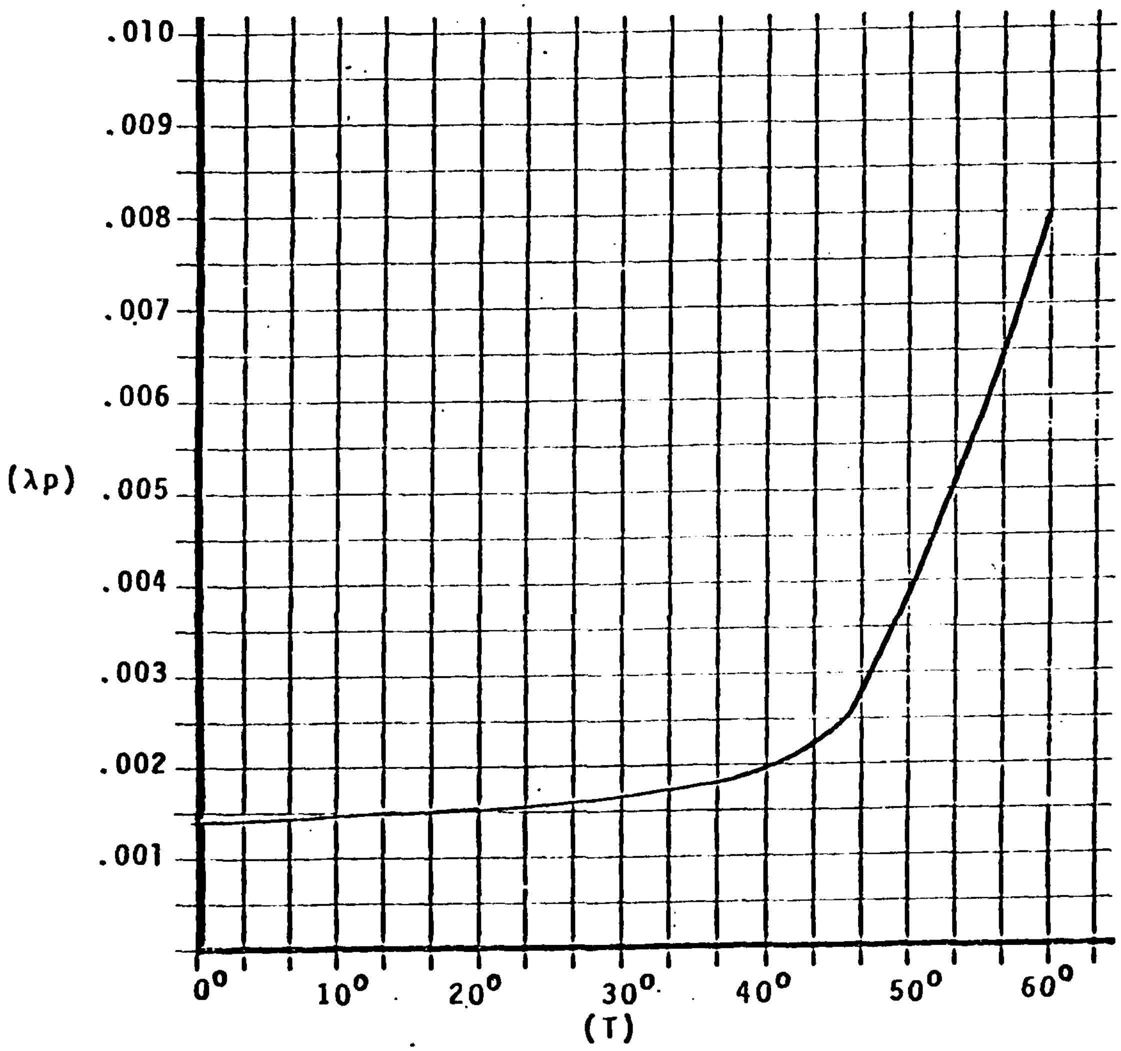


π_Q = 25 (lower or commercial quality)
π_E = 5 (ground fixed environment)
π_A = 1.5 (power rectifier, I_F>500ma)
π_C = 1 (mettalurgically bonded contact)
π_{S2} = .7 (voltage stress <60%)
π_K = (.7)(1)(1.5)(5)(25) = 131.25
π_K =131

Data from: MHB217B pp. 2.2.1-1, -4.

Figure 6D

[1]CAPACITORS, PAPER OR PLASTIC FILM, FAILURE RATE IN 10^6 HOURS AT 30% VOLTAGE RATING (T=65°C MAX RATING)



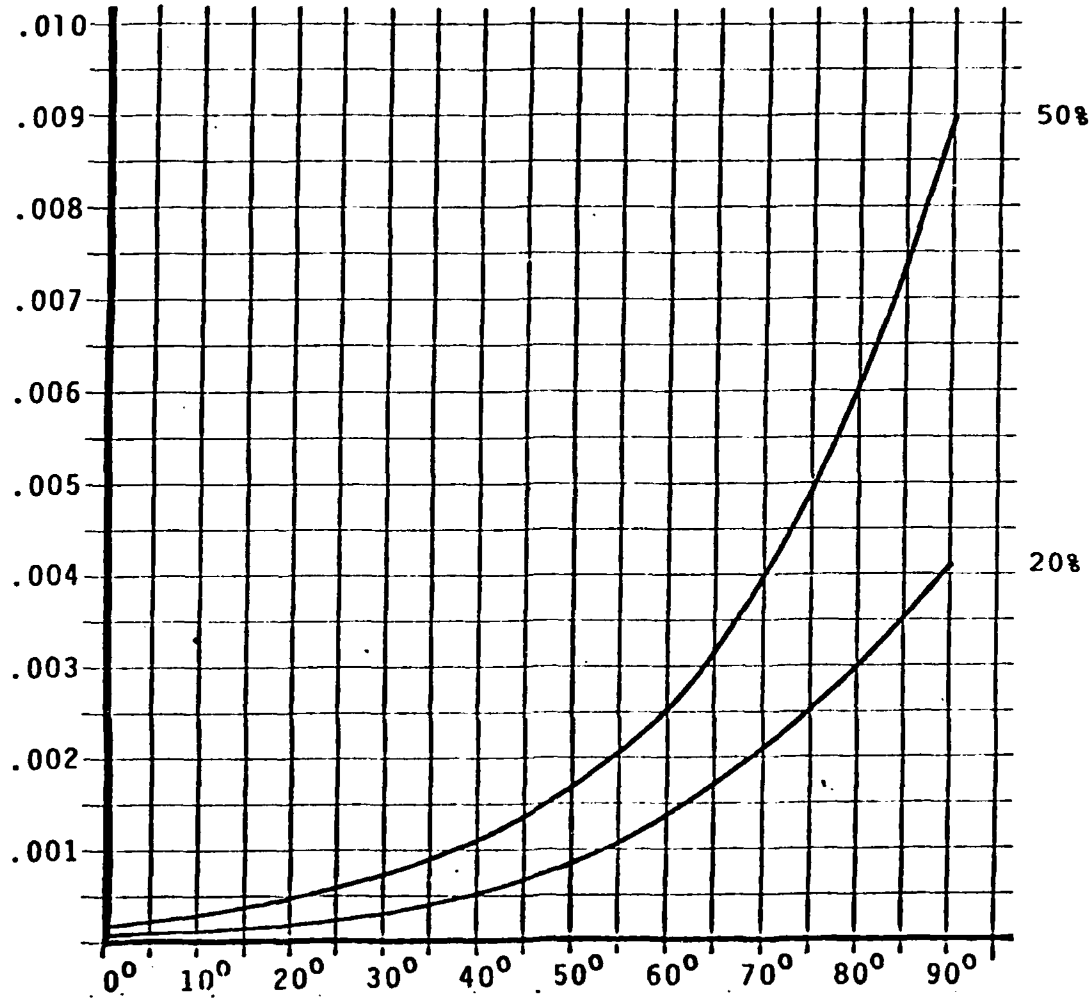
$$\lambda_p = \lambda_b(\pi_E)(\pi_Q) = \lambda_b(\pi_K) = 20\lambda_b$$

$\pi_E = 2$ (fixed ground environment)
$\pi_Q = 10$ (commercial quality)
$\pi_K = 20$

1. Data from MIL-HDBK-217B, 20Sept74, pp. 2.6.1-1,2.

Figure 6E

[1]Composition Resistors; Failure Rate
10^6 Hours at 20% and 50% Rated Loads



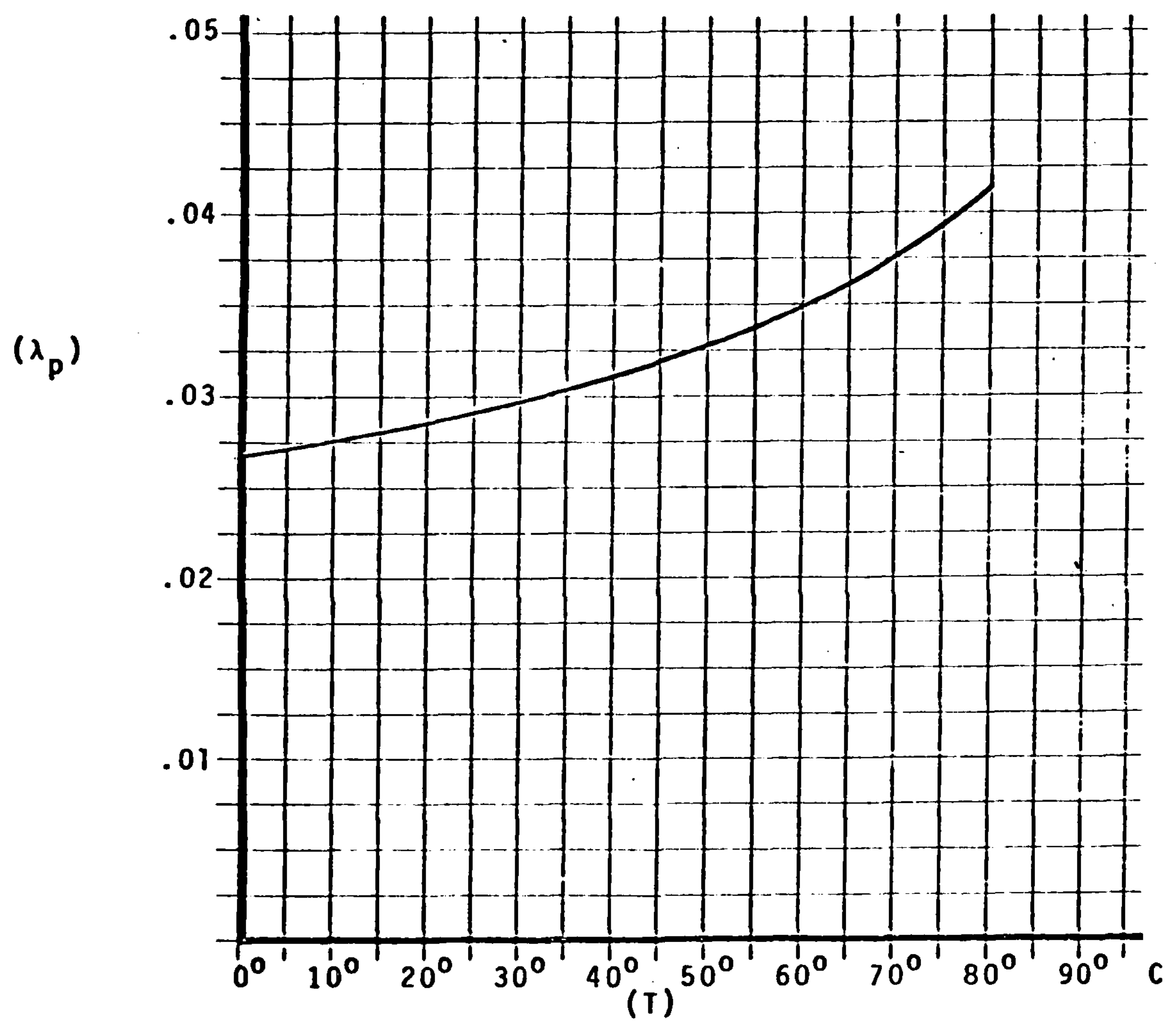
$$\lambda_p = \lambda_b(\pi_E \times \pi_R \times \pi_Q) = \lambda_b(\pi_K) = \lambda_b(2)$$

$\pi_E = 2$ (ground, fixed environment)
$\pi_R = 1$ (resistance range <100K)
$\pi_Q = 1.0$ (commerical quality)
$\pi_K = 2$

[1]Data from MIL-HDBK217B, 20SEPT74, pp. 25.1-1, -2.

Figure 6F

[1]RESISTORS, FIXED, WIREWOUND, (ACCURATE)
FAILURES/10^6 HOURS AT 50% POWER RATING



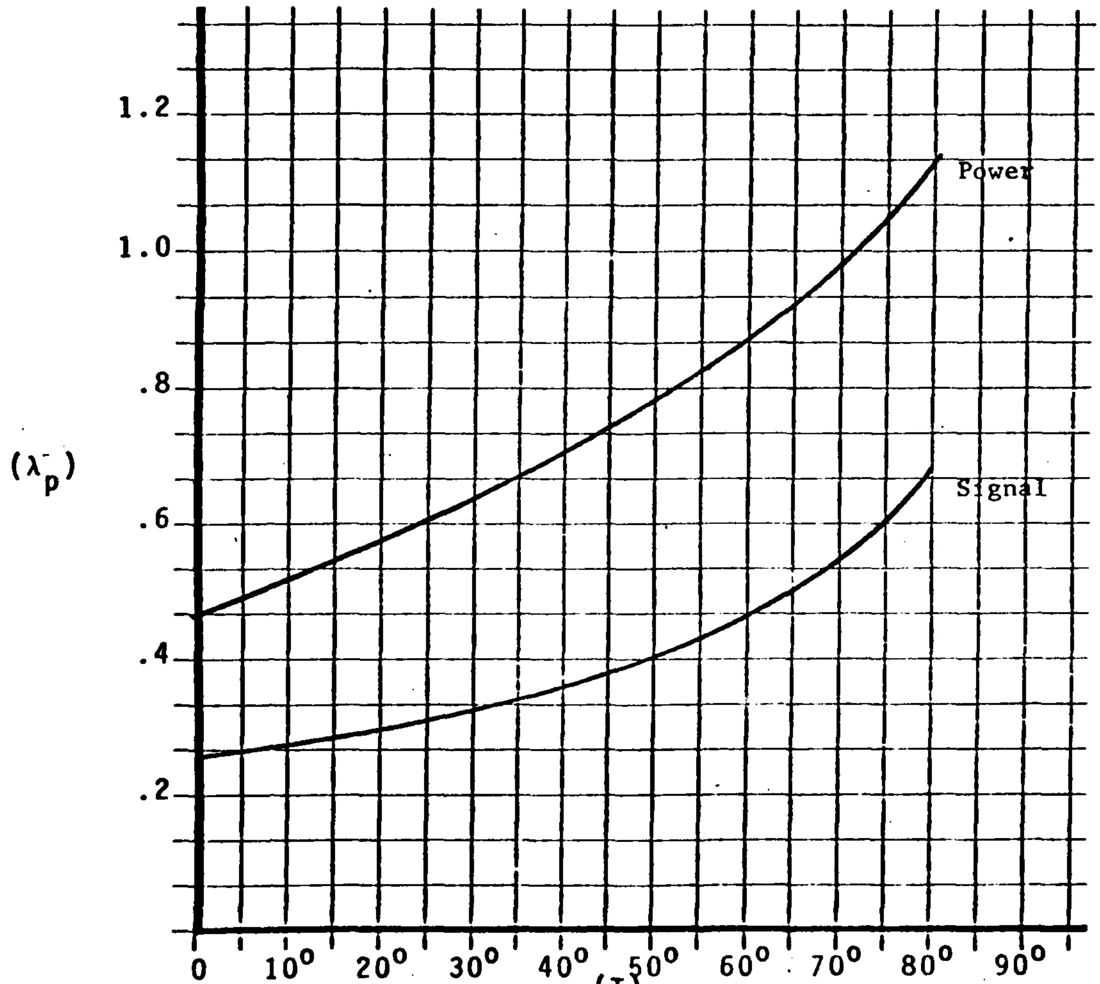
$$\lambda_p = \lambda_b(\pi_E)(\pi_R)(\pi_Q) = \lambda_b(\pi_K) = 6\lambda_b$$

$\pi_E = 6$ (fixed ground environment)
$\pi_R = 1$ ($R \leq 10K\Omega$)
$\pi_Q = 1$ (commercial quality)
$\pi_K = 6$

Note: 1, Data from MIL-HDBK-217B, 20Sept74, pg. 2.5.3-1; 7Sept76, pg. 2.5.3-2.

Figure 6G

[1]TRANSISTORS, SILICON NPN, POWER, AND SIGNAL TYPES, FAILURES IN 10^6 HOURS ASSUMING 20% POWER RATING STRESS



$$\lambda_p = \lambda_b(\pi_E)(\pi_A)(\pi_Q)(\pi_R)(\pi_{S2})(\pi_C) = \lambda_b(\pi_K)$$

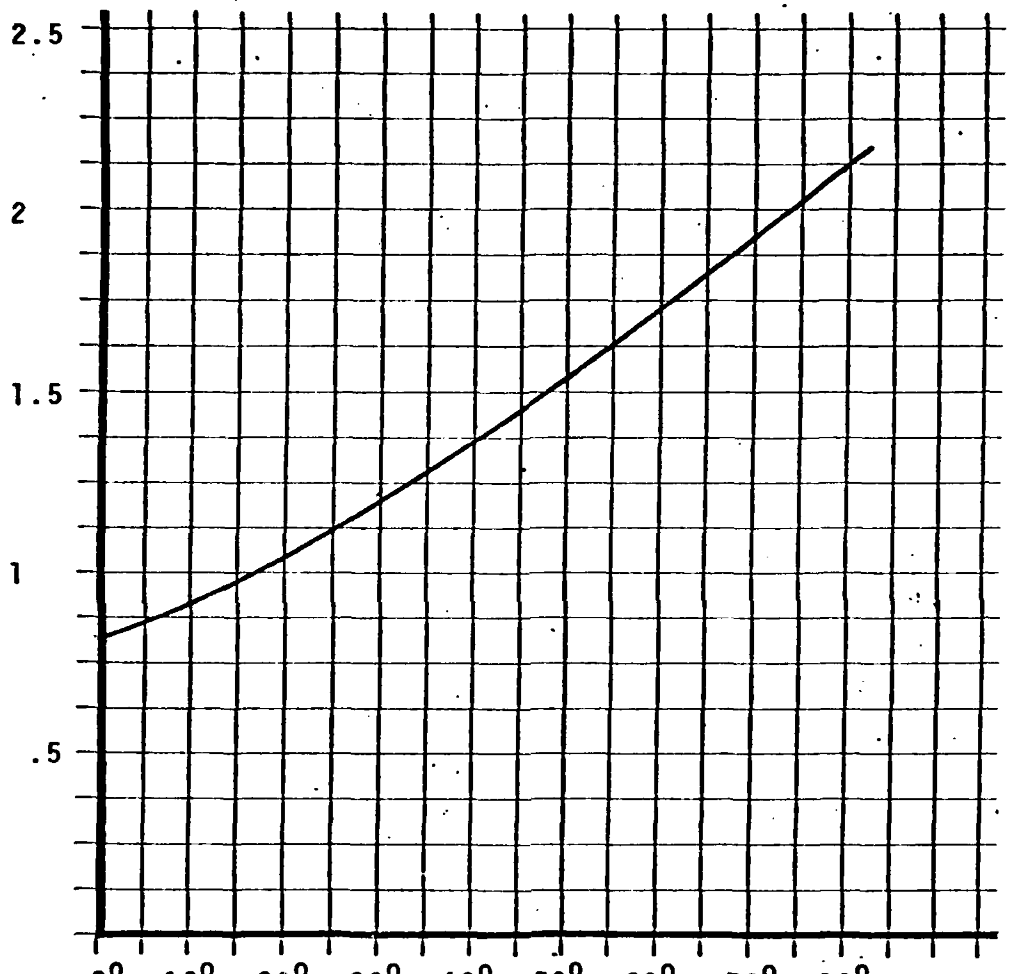
$\pi_E = 5$ (Fixed ground environment)
$\pi_A = 1.5$ (linear service)
$\pi_Q = 10$ (non-plastic, hermetic packaged)
$\pi_{RP} = 2$ (rating 5-20 watts - power type)
$\pi_{RS} = 1$ (rating 1 watt or less - signal type)
$\pi_{S2} = .75$ (50% voltage stress assumed)
$\pi_C = 1$ (single transistor in package)

$\pi_{kp} = 112$; $\pi_{ks} = 56$

[1]Data from MIL-HDBK-217B 20Sept74, 17March78, pp. 2.2.1-1 to 2.2.1-:

Figure 6H

Transistors, Silicon, PNP, Failure rate in failures per 10^6 hours[1]



$\lambda_p = \lambda b(\pi_E)(\pi_A)(\pi_Q)(\pi_r)(\pi_{S2})(\pi_C)$

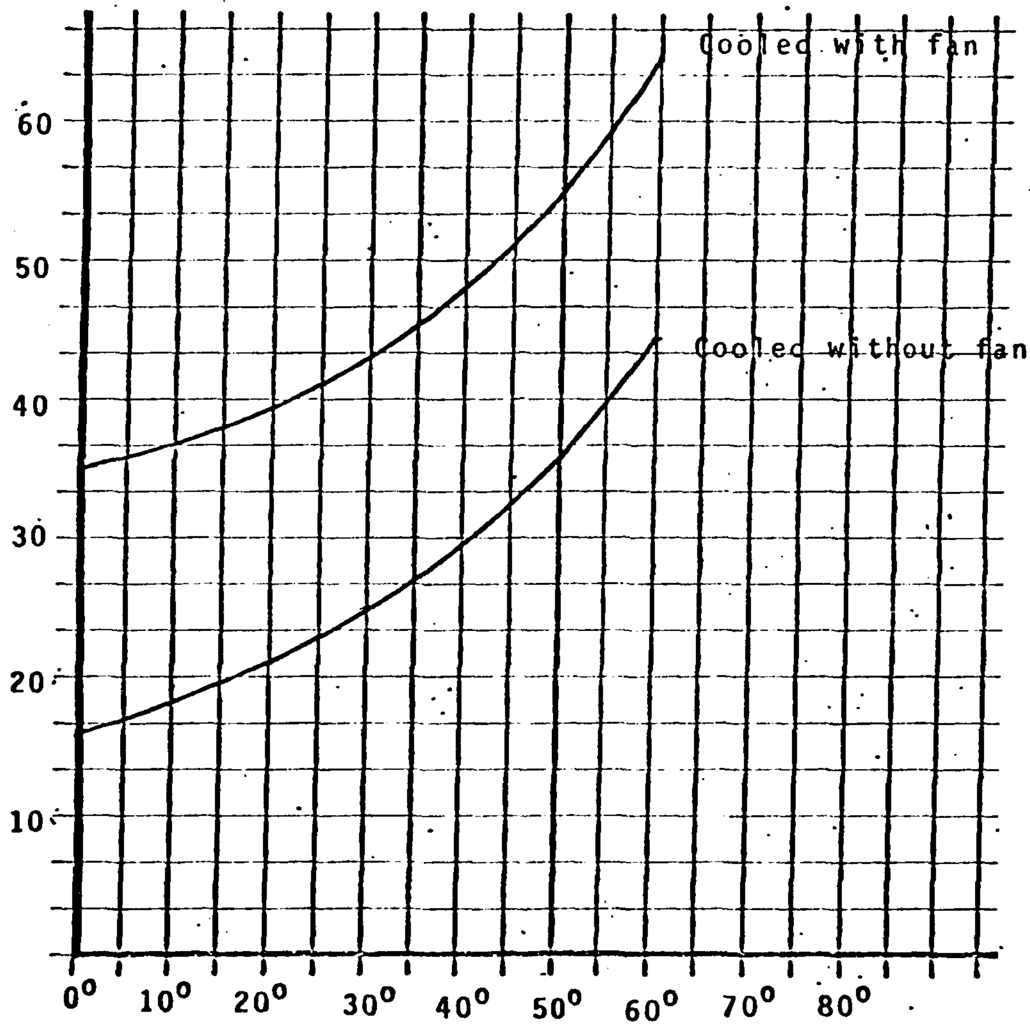
$\pi_E = 5$ Fixed ground environment
$\pi_A = 1.5$ Linear application
$\pi_Q = 10.0$ Commercial Quality
$\pi_r = 1.0$ Power rating less than 1 watt
$\pi_{S2} = 0.64$ 50% Stress factor
$\pi_C = 1.0$ Single transistor complexity

$\lambda_p = (\lambda_b)(\quad) = (\lambda_b)$

[1]Data from MIL-HDBK-217B,7SEPT 76, pp. 2.2.1-1, 2.2.1-2 and 20 SEPT 74, pg. 2.2.1-4.

Figure 6I

Power Supply failure rate in 10^6 hours with and without dependence on 50,000 hour fan for cooling. Fan life held constant



Failure rate of power supply is the sum of the power supply component failure rates.

Figure 6J

Contract Personnel

J.F. Devane, S.J.	Project Supervisor
E.A. Johnson	Project Scientist
R. Dalrymple	Technician
Janet Reach	Secretary

TABLE 2

Previous Contracts

AF19 (604) 3504	April 1, 1957 - March 31, 1959
AF19 (604) 5569	April 1, 1959 - Sept. 30, 1961
AF19 (628) 236	Oct. 1, 1961 - Oct. 31, 1964
AF19 (628) 4793	Nov. 1, 1964 - Oct, 31, 1967
F19 (628)-68-C-0094	Nov. 1, 1967 - Oct. 31, 1970
F19 (628)-68-C-0100	Nov. 1, 1967 - Oct. 31, 1970
F19 (628)-71-C-0083	Nov. 1, 1970 - July 31, 1973
F19 (628)-74-C-0003	Aug. 1, 1973 - June 30, 1976

TABLE 3

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