AFGL-TR-79-0044

INVESTIGATION OF MAGNETIC FIELD
PHENOMENA IN THE IONOSPHERE

LEVEL $^{ \text{A} }$

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the work of Weston Observatory in assisting AFGL peronnel in maintaining a network of geomagnetic observatories designed to collect and digitally transmit variations of the geomagnetic field, to Hanscom AFB, MA. Lightning protection was designed and installed on the induction coil magnetometers. Power supplies of the fluxgate magnetometers were updated, scale changes modified, cooling capacity increased.

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New temperature control of trailers installed.   The changing
total field component is traced over the past five years and
a method of calibrating the fluxgate magnetometer is outlined.

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1. Introduction

The subject contract directs Weston Observatory personnel to support and assist AFGL personnel in establishing and maintaining and evaluating the MAGAF network of geomagnetic observatories. The location of the network and the observatory configuration have been fully described in a prior report (5). Now that the observatories are in operation, the current task is the maintenance of the network, of a magnetic observatory and a test coil facility at Weston, with the obligation to continually evaluate all the components in both the network and observatory in order to improve the reliability and accuracy of the data. This report very briefly summarizes the efforts to upgrade the instrumentation at the network stations and to develop a methodology for calibrating the network magnetometers.

2. The Magnetic Observatory and the Test Coil Facility

There has been little change in the operation of the magnetic observatory from the conditions reported in a prior report (5). We consider the Rubidium total field magnetometer to be the principal observatory instrument since its visual recorder gives an instantaneous picture of the varying magnetic field. The output of the Rubidium total field magnetometer is the Larmor precessional frequency of the Rb^{85} atom which is proportional to the magnitude of the existing magnetic field. For the past

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12 years we have been printing this frequency every ten minutes or every minute during magnetically disturbed periods. As a result of the modification detailed in Fig. 1, the actual value of the field in gammas is now printed. Without calculation the field change in gammas is immediately available.

In an effort to reduce expenses, the speed of the stripchart recorder to the total field magnetometer was reduced by 75%. This speed is still adequate to give a good visual picture of the changing field.

A decrease in the magnitude of the total magnetic field was previously reported (5). 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. Since December 1976, the gradient between Pier A (a proton precession magnetometer) and Pier B (the Rubidium sensor) has remained constant at 96 ± 1 gammas. Thus the changing field is not due to instrumental drift of the Rubidium sensor.

This decrease has now been documented for the past five 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 and Fig. 2 display the average magnetic midnight value for each month in the period

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1974-1978. In constructing Table 1, the value of the
recording Rubidium 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; Fredricks-
burg, Va.; and San Juan, Puerto Rico. Between 1970 and
1975 the decrease has been 120 gammas/year at Puerto Rico
and nearly 110 gammas/year at Fredricksburg. At Weston,
the average decrease in the vertical component is being
offset by a slow increase in the horizontal component of
about 40 gammas/year. It is Alldredge's contention that
we are observing a regional and rapid change feature of the
secular variation.

AFGL personnel continue to use the Test Coil Facility,
but there has been neither time nor funds to do more than
maintain the facility.

3. Support of Project MAGAF

The installation of the MAGAF magnetic observatories
in Florida and California was completed in the early stages
of this contract. Now the contractual obligations are to
assist AFGL personnel in maintaining the observatories in

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operating condition and to upgrade, where possible, the instrumentation in order to insure a continuous flow of high quality data to the computer facility at AFGL. If a failure at any observatory occurs, the normal operational 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. When repair is complete the unit is tested at the Sudbury site and is then available as a replacement unit. Rather than detail the operational problems at each site, we will discuss the basic problems which have arisen and the measures taken to forestall their recurrances.

3.1 Generic Station Improvements

The trailers in Michigan, Wisconsin and California were tied down to prevent movement in high winds. Initially only the trailers in South Dakota and Florida were so anchored. Screw-in guy anchors and 1/4" aluminum guy wires were attached to each corner of the trailer.

The original cables from the fluxgate sensors to the trailers attracted rodents and additionally may not have been fully waterproofed. All these cables have been replaced with new and heavier waterproofed cables. The ports where the cables enter the trailer and the sensor shelter were provided with screening to keep out rodents. There has been no rodent or water seepage problem.

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The new cable because of its different impedance necessitated phasing adjustments. The second harmonic frequency output of the magnetometer must be matched in frequency with the square wave generator which triggers the measurement time. If this synchronization is not exact, there will be an error in the measurement of the magnetic field component. This notion of synchronization is shown in Fig. 3, and the error produced by lack of phasing (lag or lead of signal with square wave) is shown in Fig. 4. The reason why the vertical component is so different from the horizontals is simply not known.

Initially the attempt was made to control the temperature in the trailers by means of an air-conditioner which had both cooling and heating capability. This was unsuccessful particularly in the winter. 1500 watt space heaters have been installed and these are barely adequate, but they are the maxima that can be used with the present voltage inputs to the trailers. Temperature sensors, both external and internal to the trailers have been added and these temperatures are transmitted to AFGL as part of the normal station data frame.

High quality shipping packages have been procured for the instruments and their associated electronics. The original wooden boxes rapidly deteriorated with constant useage. The new packaging is made of fiberglass with foam interiors.

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3.2 The Fluxgate Magnetometers

Inadequate cooling capacity in the electronics package led to instabilities due to overheating. More powerful fans were installed and additional holes drilled in the metal case to insure adequate air circulation.

A 5 volt power supply capacitor deteriorated with long useage. This element has been replaced by a more reliable unit with a life expectancy of 10 years (according to the manufacturer). The entire power supply is being evaluated with the prospect of eventual replacement.

The DAC (digital to analog converter) is perhaps the most important element in the fluxgate system because it determines the flow of current which corresponds to the value of the prevailing magnetic field. The signal from a fluxgate sensor is a DC level which is proportional to the external magnetic field along the axis of the sensor and is fedback to null this external field. This may be termed the coarse section. The fine section nulls out a field of only ±64 gammas. If the field rises (or falls) above (or below) this level (±64 gammas) a comparator circuit detects an offscale condition. The DAC uses the sign of the comparator and delivers feedback current in the form of 64 gamma increments to the coarse winding. The up-down counter will stop when output of the fine section is within its linear dynamic range of 64 gammas. The analog fine voltage is read out on the front panel and also delivered to the

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DCP control and storage unit. The coarse reading (an 11 bit digital word) is delivered to the DCP and is also converted to digital display on the front panel. The changes in scale were not smooth. In the plotted output, this has led to steplike jumps in the field values. Two problems were detected, one in the wire-wound potentiometer which controls the coarse section current and hence the baseline about which the variations of the magnetic field are measured. With time the potentiometer became unreliable due to wear or even due to rough handling in transit. When the potentiometer was replaced with a new cermet potentiometer the settings were stable and the transitions through scale changes were far smoother. There was a second steplike change introduced during the zero to minus one coarse step (coarse reading 0, fine reading -64). The problem was traced to the DAC and may be caused by the two's complement logic used in the DAC and its adjacent circuitry. The original Burr Brown DAC45CB1 is no longer on the market. An equivalent DAC with identical pin positions is the DAC1136K from Analog Devices, Inc. This has proved to be more reliable and is being installed in all components of the network. A comparative test is described in Appendix A. The combined change of potentiometer and DAC has reduced the problems associated with scale changes.

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3.3 Leveling the Fluxgate Magnetometers

In the processing of testing the fluxgate magnetometers before they were deployed, it became evident that there were problems with very exact leveling of the sensors and possibly with departures from orthogonality. There were relatively insensitive levels on the instrument platforms, but when the instrument was rotated 180°, the field values were not the same. To study the problem of leveling, two Berger vials (model 1800-30) were installed. The bubble levels are made of non-magnetic materials and have an alcohol base fluid. The calibration marks on the glass vials represent an increment of 30 seconds of arc. The orientation of the levels is shown in Figure 5.

The purpose of the leveling procedure is to make the X sensor (north-south) and the Y sensor (East-West) level in the horizontal plane. The sensor is placed in its normal orientation (+X in N-S and Y=0) on pier "A". The X field value is recorded. A pencil line is drawn on the surface of the pier using a side of the platform as a straightedge. The sensor is then rotated 180° so that the opposite edge of the sensor is aligned with the pencil line. The Y field value is recorded. (It is now a negative value). The absolute values of the two readings are averaged. The N-S thumb screws are adjusted until the X reading is close to this averaged value. The level bubble is then adjusted by means of the adjustment on the vial assembly to indicate

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a 'level' condition. This procedure of 180° rotation, averaging and level calibration is repeated until the positive X value and the negative X value are with 1 to 2 gammas of each other. The procedure for Y level adjustment is the same except that the Y axis is placed N-S and the X axis E-W. It is generally possible to achieve satisfactory (within 2 gammas) agreement between positive and negative magnitude in 4 to 6 rotations.

The procedure is carried out in the existing magnetic field which is continuously changing. A two component horizontal Schonstedt fluxgate magnetometer operates continuously on a nearby pier so that the changing field is monitored during the leveling process. Ideally the output of both the Schonstedt and the sensor being tested should be recorded on the same graph, but we do not as yet have a suitable recorder. Once leveled, the sensors were considered calibrated if they gave the same values as the Schoenstedt, apart from pier differences.

The vertical component of the fluxgate magnetometer was checked by calculating the total field value from the three components and comparing this value with the magnitude of the total field as recorded by a proton precession magnetometer. In general, the results were comparable, but by no means exact. This led to consideration of orthogonality since the calculation of the total field value is based on that assumption.

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3.4 Orthogonality of the Fluxgate Sensors

When the instruments were manufactured, tests of
orthogonality were performed in the precision coil facility
at the NASA Ames Research Center (6). There were departures
from orthogonality, but well with the specification: "the
3 sensors shall be aligned to within ±.5 degree of ortho-
gonal" (6). Our tests indicated that larger departures
may exist. It is impossible to test optically the ortho-
gonality of the sensors because they are encased in a
potting compound. Differential stresses due to the aging
of the compound may have changed the orientation of the
sensors. Rough handling in transit could also alter the
original orientation of the sensors.

Departures from orthogonality can cause large errors
in measurement of the components. For example, an error
in the alignment of the vertical sensor may be estimated
by (4) $\Delta H = \Delta F \cos I - \Delta I \; F \sin I$

$$\Delta Z = \Delta F \sin I + \Delta I \; F \cos I$$

If F is constant, the departure from vertical orthogonality
may be considered a variation of the inclination, ΔI. Then

$$\Delta H = -\Delta I \; F \sin I$$

$$\Delta Z = \Delta I \; F \cos I$$

Assuming a departure of 0.5° (8.73×10^{-3} radians), the
actual specifications of the manufacturer (6), $\Delta H = -448$ gam-
mas and $\Delta Z = 146$ gammas for a total field magnitude of 54000
gammas and an inclination of 72°. Small departures from

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orthogonality are a source of discrepancy between measured and standard values and of the variations of measurement by different instruments. The relationships which may be used to study the effects of non-orthogonality on all the components of the magnetic field are given by Wienert (7).

The evaluation of the non-orthogonality must be made in the existing magnetic field, hence the changes in the field must be accurately recorded during the test period. A two component Schonstedt horizontal fluxgate and the total field magnetometer recording at the same rate should be sufficient to detail the field changes. Then given a turn-table whose rotation can be known to 20 seconds of arc and on which the sensor may be mounted and accurately leveled, the table would be rotated through 360° and the component values read at five positions 90° apart. On the supposition that the sensors are not orthogonal, orthogonal North (X) and East (Y) components are calculated from the non-orthogonal measurements (A,B) by (Fig. 6)

$$X=(A\cos b - B\sin a)/\cos(a-b)$$

$$Y=(A\sin b - B\cos a)/\cos(a-b)$$

The four unknowns may be determined by a least squares solutions. The true horizontal component can then be determined for any measurement of X and Y from

$$H^2=X^2+Y^2-2XY\cos\theta$$

where $\theta=a+b$, θ expressing the departure from orthogonality in the horizontal plane. Note that the leveling procedure

previously described, only insures that the sensors are in the horizontal plane.

Similar equations may be used to determine the departure from orthogonality of the vertical sensor.

After the departures from orthogonality are known it is still possible that the measurements may not conform to the standard values on the Weston pier. The procedure presupposed that there is perfect alignment of the sensors with the external markings on the instrument case.

In summary we determine angles Θ and $\emptyset$ which allows us to calculate the actual horizontal component $H_a^2=X^2+Y^2-2XY\cos\Theta$, and then $Z_a^2=Z_r^2+H_a^2-2Z_rH_a\cos\emptyset$. Only with these values of H_a and Z_a can we calculate the magnitude of the total field from $F^2=H_a^2+Z_a^2$.

3.5 Calibration of the Fluxgate Magnetometer

By calibration we mean comparison with standards of magnetic field measurements. Once the orthogonality or departure from orthogonality is known, the total horizontal component measured by a fluxgate may be compared with the observatory standard of the horizontal component, the QHM. The QHM is used to determine the baseline of the horizontal Ruska variometer which records continuously and whose component value is referred to the pier on which the fluxgate is being run. Knowing the orthogonality condition of the vertical fluxgate sensor we can compare its value with that

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of the Ruska variometer. The fluxgate magnetometer should

be run for several days so that a statistical measure of

comparison may be developed, i.e. how well the fluxgate

magnetometer replicates the standard values

Because of inherent uncertainty in the variometer

readings, the rms value of the total field will be at least

±6 gammas. To improve the calibration of the fluxgate we

are attempting to convert the total field vapor magnetometer

to an automatic standard magnetic observatory (2). Then

a comparison could be made by means of digitized data and

thus reduce the uncertainty arising from scaling of the

Ruska magnetograms.

Fundamentally, the fluxgate magnetometers are not

designed to be 'absolute instruments' (1). There are two

factors presently unknown; the drift with time of the

sensor and associated electronics and the temperature re-

sponse of the sensors. The manufacturer's specification

of stability is .5 gammas/1000 hours. To our knowledge,

this drift has not been checked. After the fluxgate

instruments are calibrated at Weston, their stability at

a site may be checked by references to standards at the

site. The U.S.G.S. Geomagnetic Branch uses a proton

precession magnetometer in conjunction with a theodolite

magnetometer which simultaneously measures declination and

inclination. AFGL scientists are acquiring similar instru-

mentation. At each visit to a site these measurements

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can be made to check the stability of the fluxgate. But
there is the additional problem of the secular change of
the magnetic field. At Weston the total field is decreas-
ing rapidly (Table 1); the horizontal component is in-
creasing while the vertical component is decreasing. The
secular change is quite variable with location (3). It
will require considerable care to separate stability of
instrumentation from secular change.

The manufacturer describes 'a wide range of temperature
sensitivity in scale factors,... the exact cause of the
temperature variance was not found' (6). John Wood, U.S.G.S.
Geomagnetics Branch, Denver, has compared the fluxgate
records at Newport, WA., with the U.S.G.S. variometers at
that site. He detects variations which, he says, are
typically due to temperature variation at the sensor. At
present there is excellent control of and a continuous
record of the temperature within the trailers. But the
temperature within the sensor shelter is unknown. Addition-
al insulation and thermostatic control of the temperature
is planned for the instrument shelters. Continued compari-
son at Newport and Sudbury of fluxgates and variometers
may lead to knowledge and control of the variation of the
sensors with temperature.

3.6 The Induction Coil Magnetometers

The sensors and associated electronics are the product

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of Geotronics, Inc., of Austin, Texas. The most serious
problem was failure during the occurrence of thunderstorms.
Apart from one incident, the failure has not been catastro-
phic. In general, the failures of various components have
been due to voltage surges or voltage dropouts, most pro-
bably secondary ones, but certainly associated with light-
ning. A number of changes have been made to protect the
equipment.

1) The original 709A operational amplifiers were re-
placed with a premium Burr Brown 3522 unit. However these
new units cost about $25 apiece. It was then found that
continual operation and lightning protection was as good
with an inexpensive Fairchild 741 operational amplifier at
a cost of $0.60 per unit. All of the 48 original amplifiers
have been replaced with this unit.

2) All AC inputs are now guarded by a GE VSP-1 volt-
age spike protector to prevent entrance of transients which
had been causing power supply failures. Since the instal-
lation of the VSP-1 units, there have been no supply fail-
ures.

3) The ±17 volt power supply outputs are now protected
by 18 volt varistors which limit power supply surges. Pre-
viously 20 volt zener diodes had given protection to the
electronics, but as a result of absorbing the surge, shorted
out, leaving the entire circuit inoperable. The varistors
offer non-destructive protection. Fig. 7 schematically

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shows these changes.

4) Transients in the sensor to amplifier lines have caused failures of the chopper transitor. Back to back high quality zener diodes are being installed to block the surges.

5) An associated problem was the failure of the low voltage chopper driver when the AC voltage fell to less than 55 volts. The driver requires full voltage to re- start and when the line voltage gradually returned, the driver failed to operate. We have installed time delay relays which prevent line voltage being applied to the driver until one minute after power drop out. A weakness of this method is that the drop out must be longer than 100 ms. However, drop outs of durations shorter than this are statistically very small.

4. Conclusion

The MAGAF network of seven geomagnetic observatories has operated successfully during the year. The Sudbury site has often been used for the testing of repaired magneto- meters.

For the most part failures have been promptly cor- rected, since the common modes of failure are known. Know- ledge of the individual components has grown with each failure and complete replacement of failure-prone parts has proceeded as far as financially possible.

In the final year of this contract we view the up-grading of the instrumentation as the prime task. But there is, as well, the problem of the calibration of the fluxgate magnetometers so that there may be a substantial contribution from the MAGAF network to the MAGSAT program. In September of 1979 NASA will launch a low orbital satellite with the express purpose of determining a better model of the earth's magnetic field. NASA has requested the cooperation of all magnetic observatories in contributing the absolute values of the magnetic field components at as many sites as possible on the earth's surface. Properly calibrated, the MAGAF network can make a considerable contribution since there are now so few geomagnetic observatories within the continental United States.

Appendix A

The procedure to check the performance of the DAC is as follows. A meter, a Keithley model 610B electrometer with a Hewlett-Packard 3467B DVM, is placed in series with the offset coil. The LH2311D up-down comparator is removed from the offset board. An external clock control is added, allowing the operator to stop, start or speed up the clock. The operator sets the DAC to the desired levels by manipulating these external clock controls. Table A-1 shows a set of test values for fluxgate 005 with different DACs in each channel.

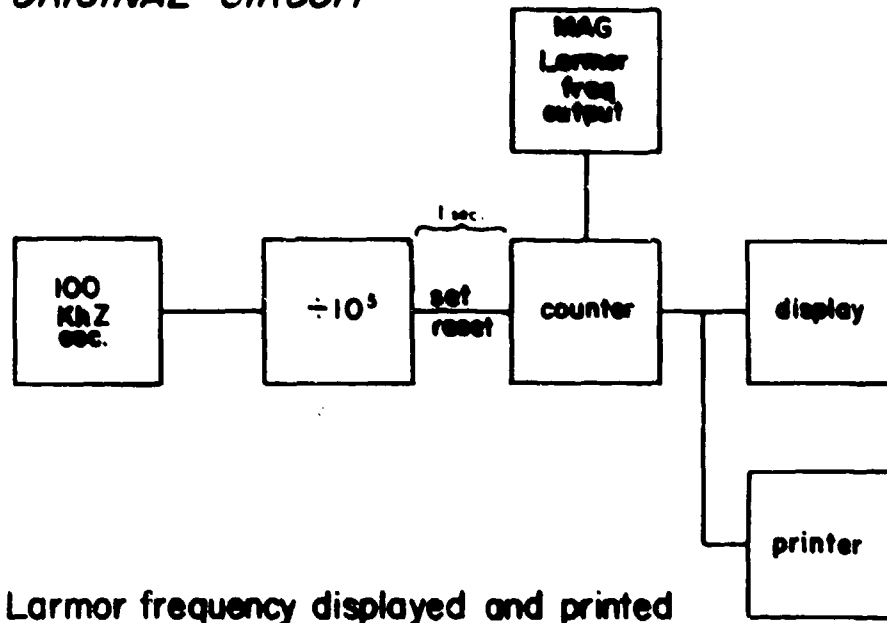| V	Z	X	Y
640	1.05×10^{-5}	1.01×10^{-5}	1.03×10^{-5}
576	9.47×10^{-6}	9.12×10^{-6}	9.30×10^{-6}
512	8.43	8.10	8.27
448	7.37	7.08	7.23
384	6.33	6.07	6.20
320	5.27	5.05	5.17
256	4.22	4.03	4.13
192	3.16	3.02	3.10
128	2.11	2.01	2.06
64	1.05×10^{-6}	1.00×10^{-6}	1.04×10^{-6}
0	0	0	0
-64	-1.58×10^{-6}	-1.09×10^{-6}	-1.03×10^{-6}
-128	-2.64	-2.11	-2.07
-192	-3.70	-3.12	-3.10
-256	-4.75	-4.13	-4.13
-320	-5.80	-5.15	-5.17
-384	-6.87	-6.16	-6.20
-448	-7.93	-7.16	-7.23
-512	-8.99	-8.19	-8.28
-576	-9.99×10^{-6}	-9.22×10^{-6}	-9.32×10^{-6}
-640	-1.10×10^{-5}	-1.02×10^{-5}	-1.03×10^{-5}

Table A-1

V is the gamma value read on the front panel coarse setting.

Z is the current in amperes in the Z channel controlled by
a used DAC45 and wire-wound potentiometer.

X is the current in amperes in the X channel controlled by
a previously unused DAC45 and wire-wound potentiometer.

Y is the current in amperes in the Y channel controlled by
a new DAC1136 with a new cermet potentiometer.

References

1) Alldredge, L., Instruments and Geomagnetic Stations
   in Physics of Geomagnetic Phenomena, ed.
   Matsushita, S. and W.L. Campbell, Academic, 1967.

2) Alldredge, L., I. Salducas, An Automatic Standard
   Magnetic Observatory, J. Geophys. Res., vol. 69,
   1964.

3) Annual Mean Values of Geomagnetic Components for Se-
   lected Observatories, World Data Center A for
   Solid Earth Geophysics, Boulder, CO., 1979.

4) Chapman, S. and J. Bartels, Geomagnetism, 2vol., Oxford,
   1951.

5) Devane, J.F., E.A. Johnson, R. Dalrymple. Final Report
   on Contract AF19628-74-C-0003, AFGL-TR-71-0230,
   1976.

6) Snare, R.C. A Geomagnetic Data Collection Network,
   AFCRL-TR-75-0593, 1975.

7) Wienert, K.A. Notes on Geomagnetic Observatory and
   Survey Practice, UNESCO, Brussels, 1970.

ORIGINAL CIRCUIT

Larmor frequency displayed and printed

MODIFIED CIRCUIT
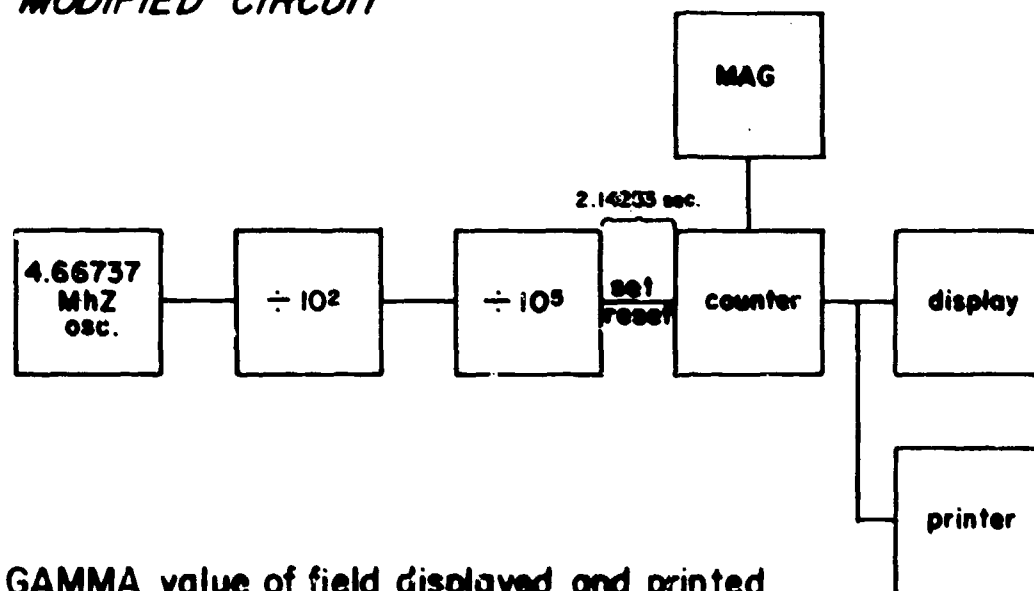

GAMMA value of field displayed and printed
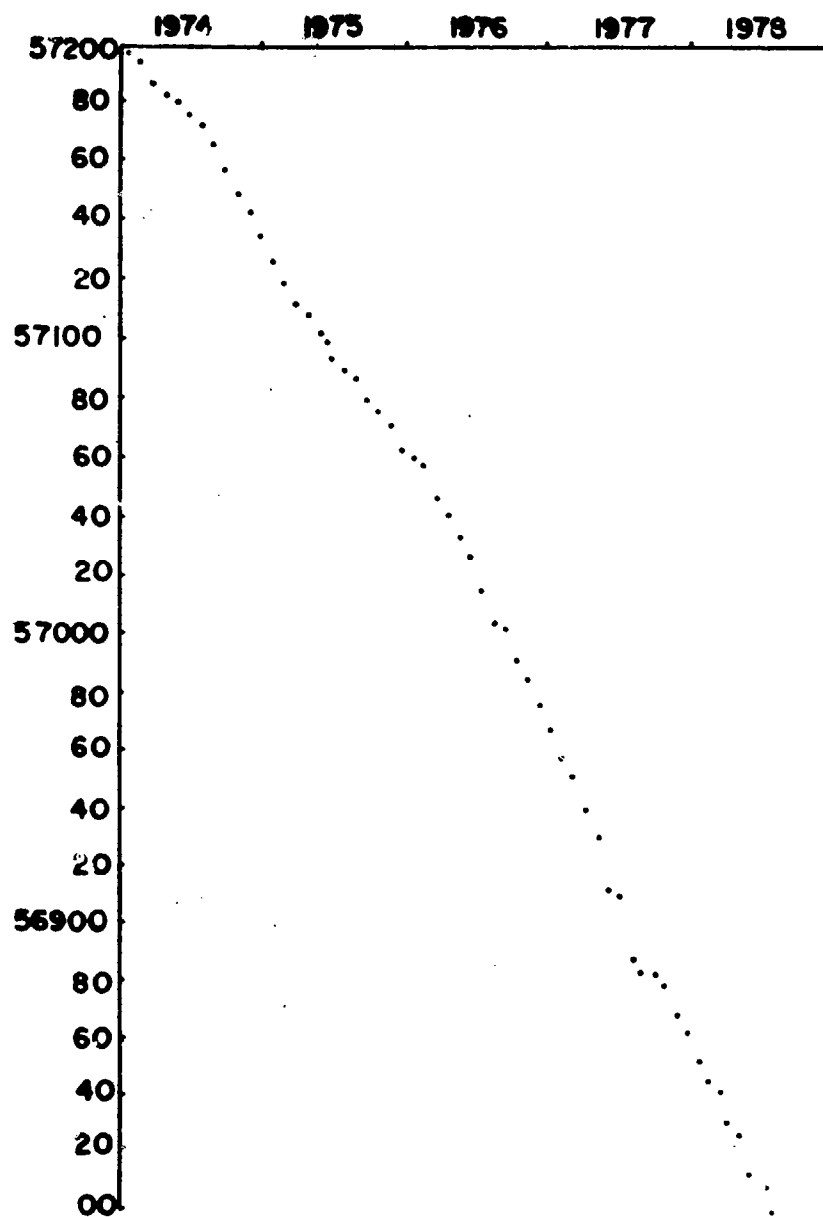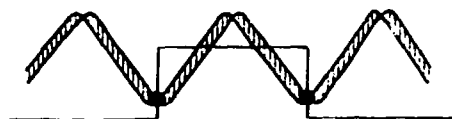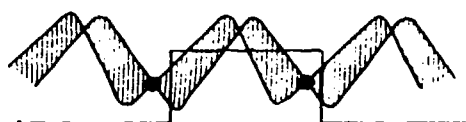
Fig. 1

Fig. 2

voltage node IN PHASE with $2f_o$

voltage node LEADING $2f_o$

voltage node LAGGING $2f_o$

Sketches of Oscilloscope Waveforms
Showing the Alignment of the Phase
Shift Network Output Voltage Nodes
with the $2f_o$ Reference Signal
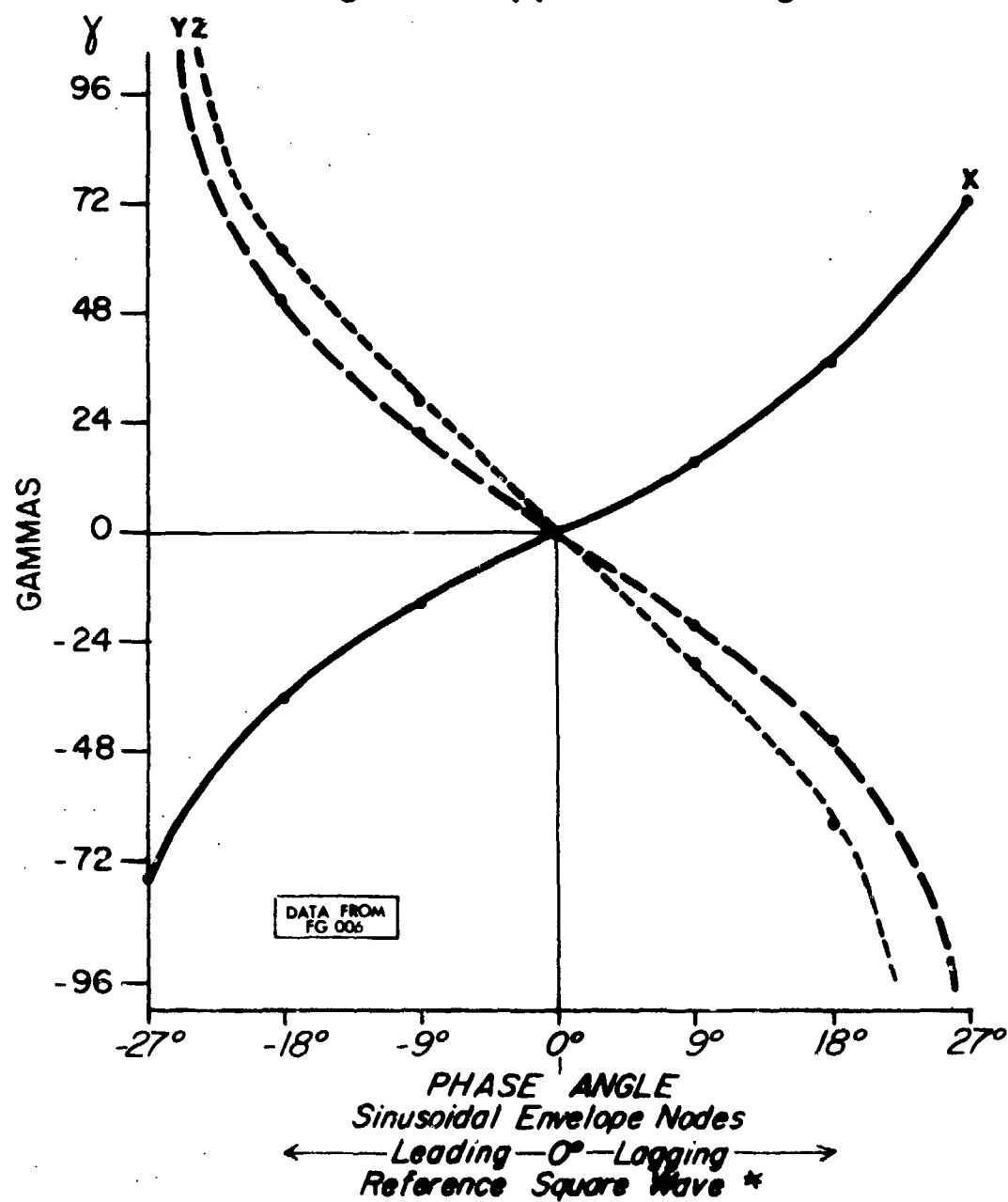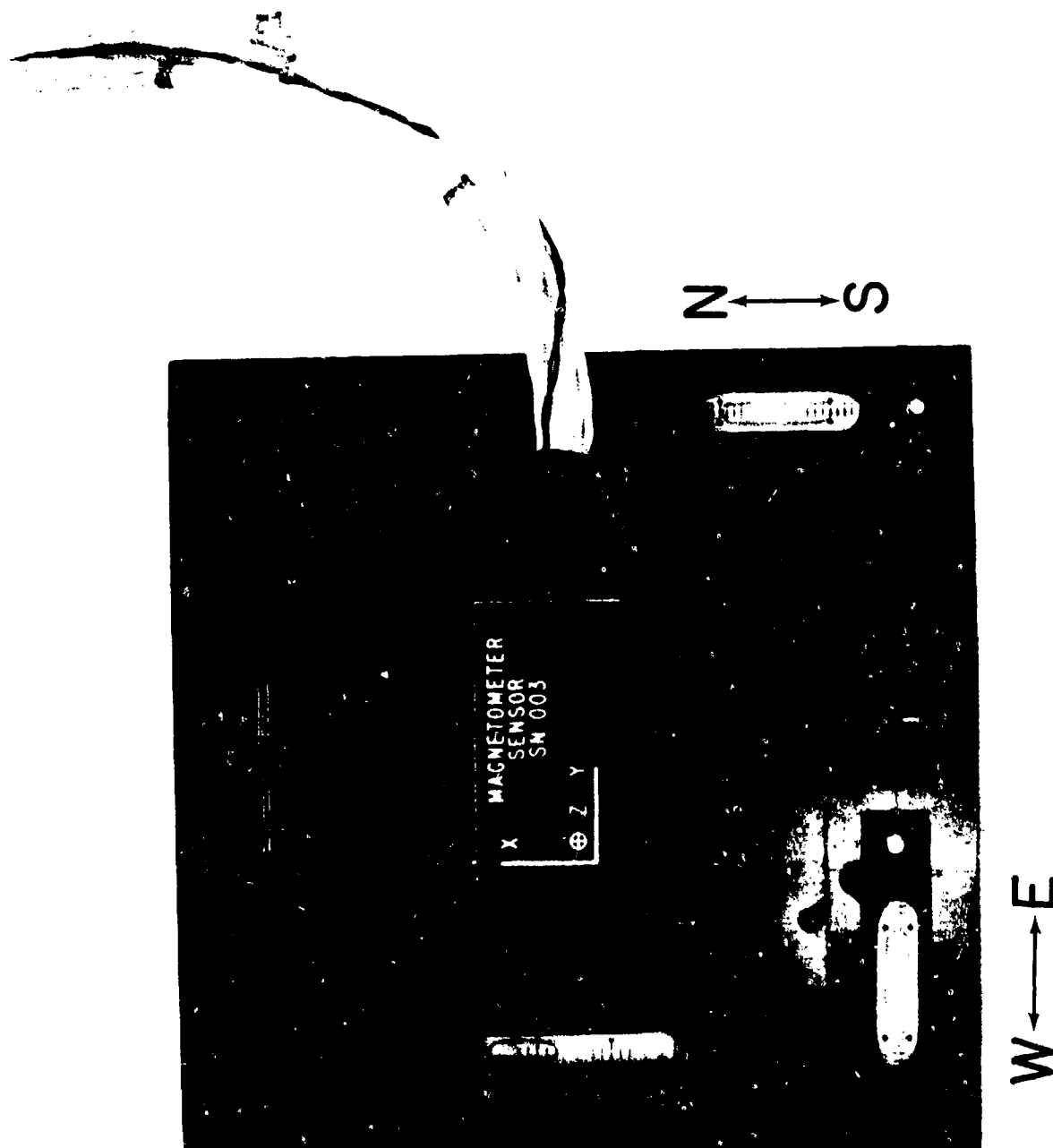
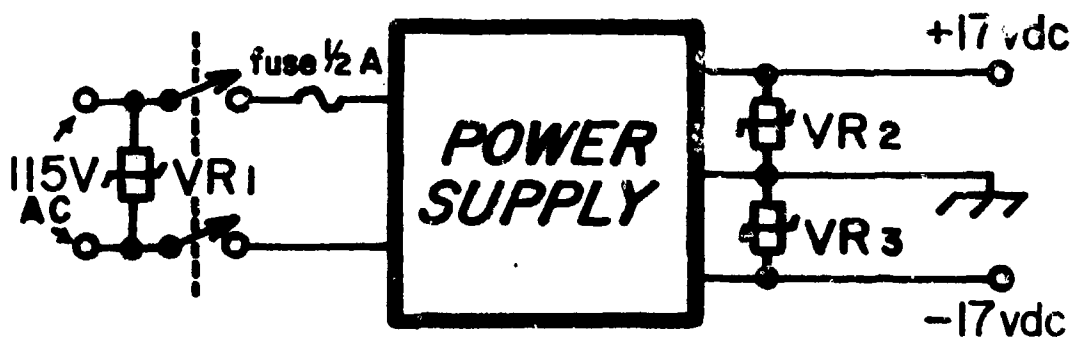Fig. 3

Phase Angle vs. Apparent Change in Gammas

Fig. 4

Fig. 5

TRANSIENT PROTECTION OF GEOTRONICS POWER SUPPLY

VR1 – GE-MOV-VSP-1 transient suppressor
VR2, VR3 – GE 18ZA3 Varistors

Fig. 7

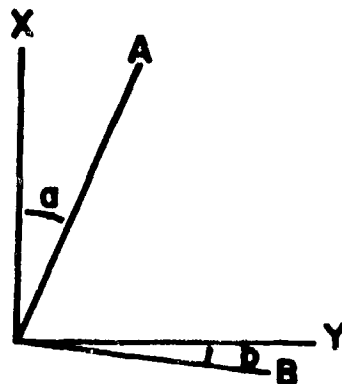## Relationship of Nonorthogonal to Orthogonal Components

Fig. 6

	1974	1975	1976	1977	1978
Jan	57200	57136	57064	56976	56870
Feb	57196	128	062	968	863
Mar	193	120	059	958	853
Apr	186	114	047	952	847
May	182	110	042	940	843
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
Dec	144	072	56985	879	775

TABLE 1

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