U.S.DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

AN AUTOMATIC, QUASI-ABSOLUTE, GEOMAGNETIC CALIBRATION SYSTEM.

by

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Open File Report 91-350

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INTRODUCTION

This paper describes a system which automatically performs periodic baseline calibrations at U.S. geomagnetic observatories. This instrument is known as "DIDD" (Delta Inclination, Delta Declination) system, after it's manner of operation.The "DIDD" system consists of a proton magnetometer located within a set of mutually orthogonal Helmholtz coils deflection coils, plus a current generator and sequencer (known as the "DIDD generator").

TECHNIQUE AND ALGORITHMS

The Helmholtz coils, called the I and D bias coils, are mutually perpendicular to each other and to an axis which is aligned along the mean local magnetic field direction. The axis of the D coil is horizontal and in the local mean magnetic E-W direction. The I coil axis lies in the local mean magnetic meridian plane. A proton magnetometer sensing head is placed at the center of the coil system. In operation, bias fields of about one-third the local field value are sequentially applied in the +I, -I, +D, and -D directions.The modulus of the resultant total field vector is measured and recorded for each bias field and for the unbiased condition.These measurements provide enough information to determine the instantaneous angular deviation of the Earth field vector from the previously determined direction of the axis of the coil system, as well as the modulus of the instantaneous, unbiased Earth field vector. The angular deviations are obtained in the I direction (in the mean magnetic meridian plane) and in the D direction (perpendicular to the mean meridian plane). From trigonometry, utilizing the original inclination and declination angles of the coil system axis, one may compute H, D, Z, or X,Y, Z as well as instantaneous inclination and declination angles. Exact knowledge of the magnitude of the bias field is not needed, since it can also be determined from the measurements. It _is_ required that the bias field not change during either the +I and -I sequence or during the +D and -D sequence. (It may change between sequences, however.)

The algorithms needed to compute the elements of the magnetic field from the measurement sequence are summarized below.

The total inclination angle, α_{IT} is given by:

$$\alpha_{IT} = \alpha_I + \frac{(I^+)^2 - (I^-)^2}{4AF}$$

where: α_{IT} is the inclination angle of the system axis determined independently with a Declination Inclination Magnetometer (DIM).

I^+ is the modulus of the total field vector when a bias field, A, is introduced in the +I direction (toward the Earth, in the northern hemisphere) by means of the I coil.

I^- is the modulus when the bias field, A, is reversed.

F is the unbiased modulus of the total field vector.

Likewise, the total declination angle, α_{DT}, may be found by:

$$\alpha_{DT} = \alpha_D + \frac{(D^+)^2 - (D^-)^2}{4AF\cos\alpha_{IT}}$$

where: α_D is the declination angle of the system axis, measured in the horizontal plane, determined independently by a DIM.

D^+ and D^-, in this case, refer to the modulus of the total field vector when the bias field, A, is introduced in the +D and -D directions (+D is in the magnetic east direction).

In the expressions for α_{IT} and α_{DT} the last term represents the instantaneous angular deviations from the previously determined axis direction.

The field, A, is given by:

$$A = \frac{1}{\sqrt{2}}\sqrt{(I^+)^2 + (I^-)^2 - 2F^2}$$

for the inclination sequence, and

for the declination sequence.

$$A = \frac{1}{\sqrt{2}} \sqrt{(D^+)^2 + (D^-)^2 - 2F^2}$$

The quasi-absolute DIDD sequence is depicted in Figure 1.

HELMHOLTZ COIL SYSTEM

The coil system consists of mutually orthogonal square Helmholtz coils. Each of the 4 coils is 25 in. x 25 in., has 54 turns of # 22 solid copper wire, and each Helmholtz pair has a scale factor of 150 nanoteslas (gammas) per milliamp. Deflection currents are usually about 107 milliamps for deflection fields of about 16,000 nanoteslas. The coil system is constructed of aluminum angle, flat, and "U" stock, requiring only a bandsaw, drill press, and common hand tools. The coil axis is easily adjusted for worldwide inclination angles. The coil system is shown in Figure 2 and 3. Mechanical design and construction of the coil was by the author (electrical design by A.W. Green,Jr.).

DIDD Generator

The currents necessary for quasi-absolute "DIDD" observations need to be as stable as practically possible. To accomplish this task a low power stable current source was designed to work from a single ended supply. Operation of the "DIDD" generator may be initiated manually, by toggling an advance button, or automatically from the microprocessor in the observatory Data Collection Platform (DCP). The software menu in the DCP permits selection of 2, 4, 6, or 12, "DIDD" sequences per day. Refer to Figure 4 for reference designations used in text below.

The "DIDD" generator consists of 6 sub-circuits as follows;

1) Power conditioning
2) Current generator
3) Digital interface
4) Manual interface
5) Logic
6) Switching

The 12 vdc power is conditioned by transient surge suppressor (SP-1) to clip incoming power transients at 18 volts, and an electrolytic capacitor (C-1) to filter out high frequency interference.

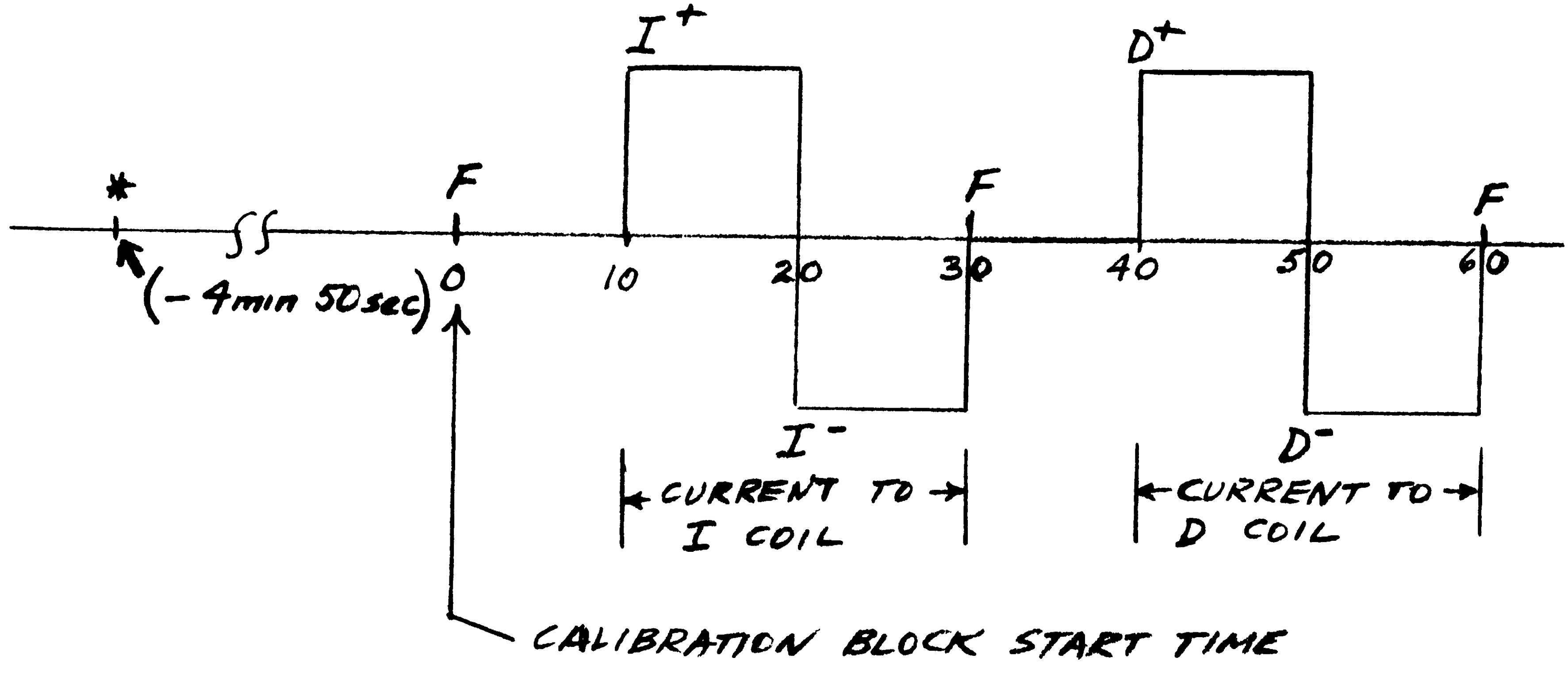
The current generator uses a Motorola, MC1403 for a reference. It's 2.5 vdc output is divided down to a range of 1 volt to 1.5 volts through resistors R-1, R-2, and R-3. This voltage is applied to the positive input of an operational amplifier (LM258), and is used as the reference voltage for the generator. The output of the op-amp is used to control the equivalent series resistance of the field effect transistor (FET) Q-6. The current to the coils is thus controlled by the FET. The current from the coils is returned through resistors R-4 and R-5. The voltage created by the current through these resistors is applied to the negative input to the op-amp for feedback to keep the circuit in balance. If the generator is required to output 100 milliamperes, it would create a voltage of 1.43 volts as feedback to the op-amp. If the reference voltage is adjusted to this same voltage, the output current of the generator will remain constant.

The digital and manual interfaces will be described in unison as they are identical with the exception that the manual interface has de-bouncing capacitors (C-6 and C-7). This section buffers and inverts the signals from outside the generator. It does this through a hex inverting Schmitt trigger(IC-1). The Schmitt trigger gives high noise immunity because it will ignore incoming transients of less than 90% of the positive power supply and must return to within 10% of the common side of the supply to be reset. The interfacing consists of two inputs from each source (digital and manual), the advance triggers will advance the generator to the next phase (I+,I-,etc.), the reset triggers will reset the generator to the first phase (F) of the "DIDD" cycle. The pull-up resistors (R-6 through R-9) provide further suppression from open ended inputs.

The logic consists of two integrated circuits, IC-2 and IC-3. IC-2 (CD4075) is a triple 3-input OR gate. It is used to accept inputs from either the digital or the manual interfaces and pass it to IC-3. IC-3 (CD4017) is a decade divider with ten decoded outputs. It is ideally suited for this circuit as it will count input pulses and advance to the next output line without need for decoding. The input line is pin 14, and the reset is on pin 15. Only decoded output lines 0 through 5 are employed in this circuit, as there are only 6 different phases of the "DIDD" generator. They are found on pins 3, 2, 4, 7, 10, and 1, respectively.

The last section, the switching circuit, is used to combine the logic section and current generator to supply stable current to the inclination coils and the declination coils in both a forward and reversed direction. This section also allows the generator to be powered and current to be generated, but not flow through any of the coils, only through current sensing resistors, R-4 and R-5. This is the only section of the entire generator that needs a warm up period of longer than 45 seconds. With the application of current, the temperature inside the resistors changes very rapidly for the first few minutes, then falls off at an exponential rate. The change in temperature results in a change in resistance, thus changing the feedback voltage, which in turn changes the output current. It has been determined that after 4 minutes the current will hold to about one part in 50,000, therefore the first phase is started 5 minutes before any field altering currents are applied to the coils to allow for stabilizing. The current is routed to the resistors through relay, K-5, which is energized by FET, Q-5. This FET as well as FET's Q-1 through Q-4 are employed as switching transistors. If they are driven by a high state on their gate, they will conduct, thus energizing the relay in series. In phases 1 and 4 ("F"), Q5 is driven by OR gate IC-2B. This gate allows either pin 3 or pin 7 to energize K-5. It should be noted at this time, that unless relays, K-1 through K-4, are energized, the coils are shorted out and connected to the current return path. This keeps the 100 meter long connecting wires from picking up any stray currents. The second phase, "I+", is obtained by de-energizing K-5, and energizing K-1. This allows the positive side of the inclination coils to be connected to the current source. In this fashion an I+ deflection is achieved. The third phase "I-", is accomplished in a similar way. K-1 is relaxed and K-2 is excited, thus allowing current to flow through the inclination coils in the reverse direction as in phase 2. The fourth phase "F",is the same as the first, the current flows through only K-5. Phases 5,("D+") and 6,("D-") are similar to phases 2 and 3, except the current flows out through relays K-3 and K-4 and into the declination coils. At the end of the "D-" phase the generator power is stopped. This again shorts both coils and no power is consumed until 5 minutes before the next "DIDD" cycle is initiated. Refer to Figure 5, for the installation with the present DCP.

QUASI-ABSOLUTE (DIDD) SEQUENCE



PROTON POLARIZATIONS BEGIN AT 0,10,20,30,40,50, & 60 SECS

* CURRENT GENERATOR TURNED ON FOR WARM-UP (INTO LOAD RESISTOR)

Figure 1.

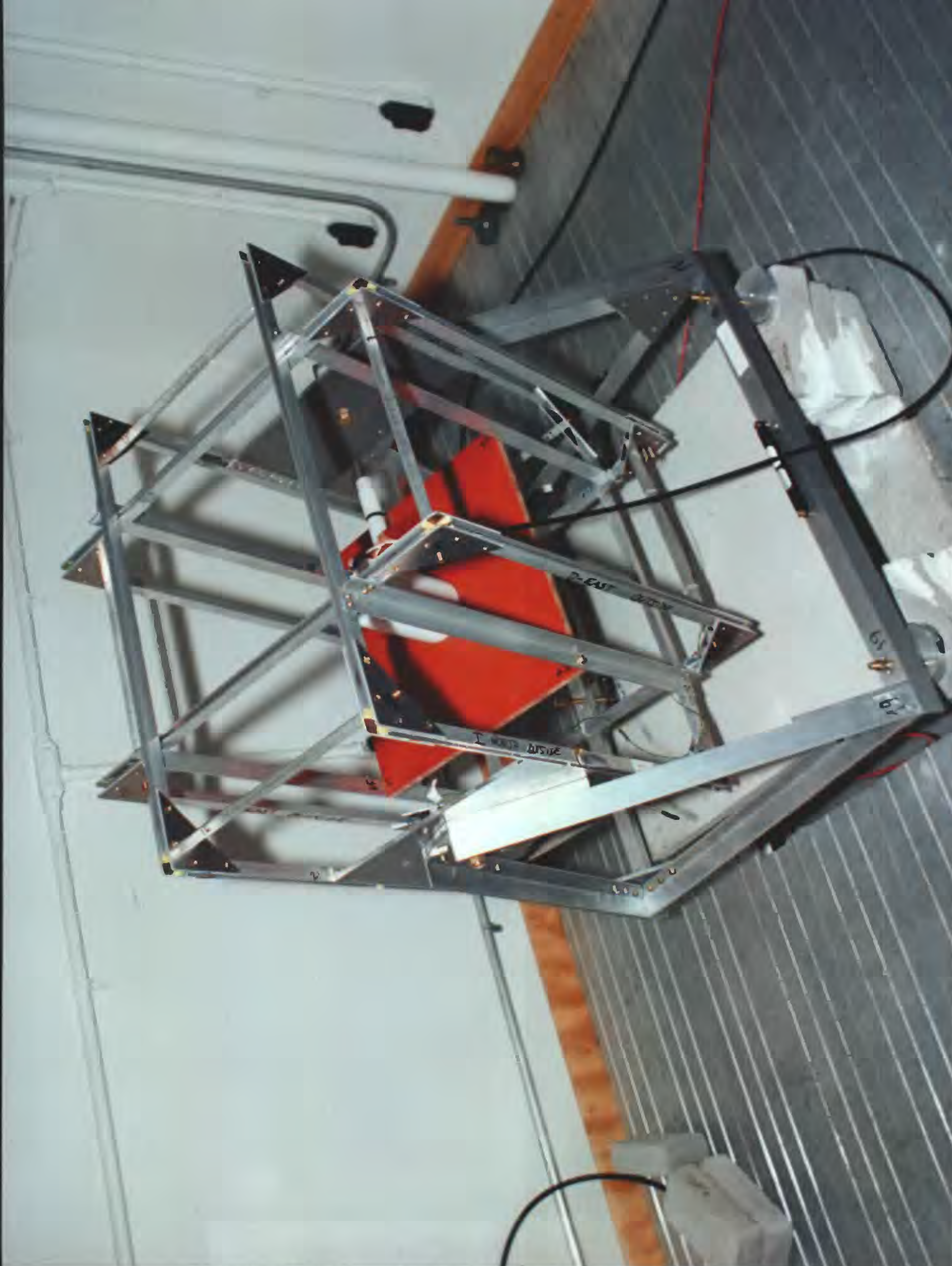


Figure 2


D-WEST OUTSIDE
D-WEST OUTSIDE

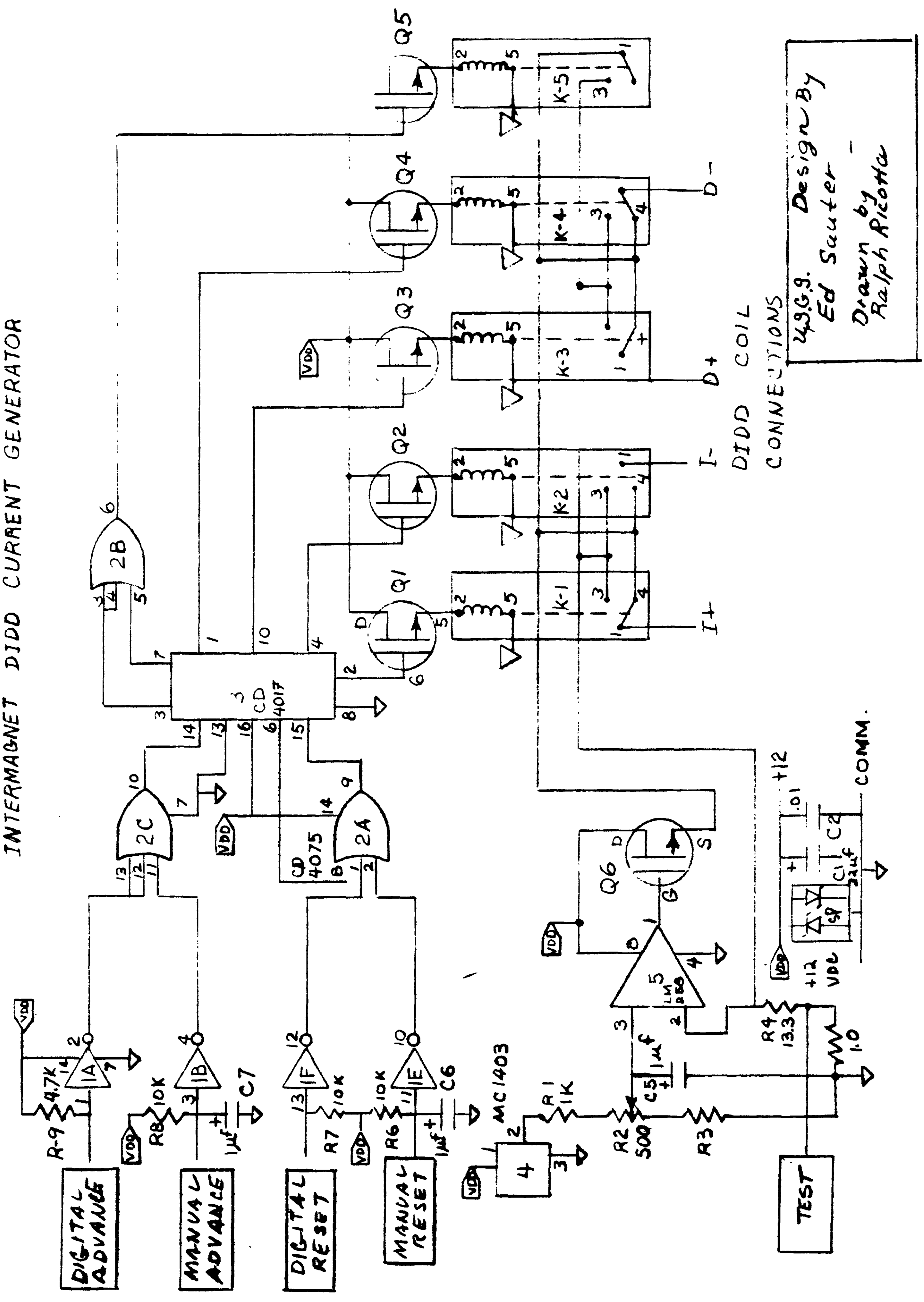

INTERMAGNET DIDD CURRENT GENERATOR
DIGITAL ADVANCE
MANUAL ADVANCE
DIGITAL RESET
MANUAL RESET
TEST
DIDD COIL CONNECTIONS
CD 4017
CD 4075
MC1403
COMM.
Design By
Ed Sauter
Drawn by

Figure 4.

TEST
ADVANCE
OUTPUT