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U.S.G.S. TILTMETER NETWORKS,

OPERATION AND MAINTENANCE

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INTRODUCTION

Two networks of tiltmeters have been established by the U. S. Geological Survey. The central California tiltmeter network extends from Gold Hill, just north of Cholame, California, to Oroville. The most dense concentration of instruments within the central California network occurs in the Hollister region, along the San Andreas and Calaveras faults. The disposition of tiltmeter sites in central and northern California is shown in Figure 1, and latitude and longitude are listed in Table 1.

The southern California tiltmeter network extends from Borrego Badlands in the Anza-Borrego Desert, north to Cherry Creek, northwest of Gorman, California. The instruments are roughly located in arrays along the Big Pine, San Andreas, Cucamonga, San Jacinto and associated faults. The disposition of tiltmeter sites in southern California is shown in Figure 2 and latitude and longitude are listed in Table II. Both the central and southern California tiltmeter networks are undergoing a continous evaluation process to establish the validity of the results and therefore the locations and total numbers of stations within the networks can be expected to change from time to time.

The purpose of the U. S. G. S. tiltmeter networks is to monitor crustal deformation associated with earthquakes. Preliminary results from portions of the tiltmeter networks have been described by Johnston and Mortensen (1974), Mortensen and Johnston (1975), and Myren and Johnston (1976). The purpose of this report is to describe, in detail, the designs of the tiltmeter site and equipment, and the methods and procedures used to install and maintain the tiltmeter and its associated systems, with the exception of the low-frequency digital telemetry system which is being described in a separate report by Roger et. al. (1977).

SITE SELECTION AND PREPARATION

The disposition of tiltmeters within the U. S. G. S. networks is such that, should a magnitude 4 or greater earthquake occur on one of the faults adjacent to an array of tiltmeters, there is a high probability of observing on more than one instrument, tilts that might result from some geophysical mechanism whose source dimension is roughly equivalent to that of the earthquake. Preliminary data and other evidence indicates that the period during which such phenomena might persist becomes longer as the magnitude of the associated earthquake increases.

Because of the very low frequency and long period of the anticipated anomalous tilting, it is necessary to insure that the tiltmeter site is mechanically stable. In selecting a site the regional and local geology, topography, drainage, material properties, vegetation and cultural features must be carefully considered. The criteria used in selecting the U. S. G. S. tiltmeter sites are described by Mortensen and Johnston (1975).

Briefly, the physical criteria for a good tiltmeter site include 1) a radially symmetric, gentle topographic high, 2) remote from bodies of water such as streams and reservoirs, 3) well drained soil, without large boulders and low in clay minerals, 4) remoteness from roads, gates and parking lots where vehicles may frequently pass, 5) sufficiently obscure to obviate possible vandalism, and 6) remote from large trees with extensive root systems. Other features peculiar to a site which might effect the short or long term mechanical or thermal stability must be considered.

At sites with nearby asymmetric or steep topography, the principal effect is large diurnal thermoelastic tilting. Another less evident effect may be topographic strain and tilt amplification. The primary effects of large ground loadings near a tiltmeter produced by vehicles, wind acting on nearby trees, water storage tanks filling or emptying, etc., are transient tilts. The effects of rainfall depend on the local geologic conditions and drainage and must be evaluated at each site. These and the effects of other tilt noise sources are the subject of an ongoing study.

The method of installing the tiltmeter is described by Mortensen and Johnston (1975) and Allen et al., (1973). Figure 3 is a cutaway diagram of a typical tiltmeter installation. The typical installation consists of a large pit, 0.9 m in diameter and 1.5m deep, lined with a fiberglass culvert to minimize thermal conduction. The culvert is surrounded by a layer of tamped sand, followed by successive layers of tar and gravel that form a seal to prevent surface runoff from travelling down the outside of the culvert and filling it from the bottom. From the bottom of the large pit, a borehole of about 20 cm diameter is drilled 1.5m to an ultimate depth of 3m. A borehole tube of aged steel tubing, closed at the bottom, is placed in this hole and surrounded by 84 to 140 mesh, pure Ottawa silica sandblasting sand. The top of the borehole tube is beaten vigorously in a radially symmetric fashion as the silica sand is layered around the outside. The object is to get the sand into a closely packed condition.

The drilling of the pit and the borehole is done with an auger rig and without the use of water, in order to insure that the surrounding soil is left as undisturbed as possible. If the soil is unconsolidated sand, such that the borehole tends to collapse, the hole may be drilled inside a tube, and the tube later withdrawn.

A second pit is drilled about 6m away. A 55-gallon drum is buried in this pit. The function of the second pit is to contain the on-site recorder, batteries and telemetry so that most routine maintenance can be accomplished without opening the large pit and disturbing the tiltmeter. The two pits are connected by a buried electrical cable housed in a flexible, armored, watertight conduit. The conduit is sealed with silicone rubber sealant where it enters the walls of the culvert and drum.

The large pit serves to decouple the tiltmeter from most sources of surface noise. It is filled with marble-sized styrofoam pellets contained in a nylon bag to reduce convection inside the pit. Both pits are covered with sturdy steel or aluminum covers that will support the full weight of a large animal. The covers are secured with chain and locks. At sites with radio telemetry a third pit is dug and a 55 gallon drum or culvert is buried to house the transmitter and its batteries. An antenna on a 6 x 6 wooden mast, or in a tree if one is convenient, is situated nearby.

INSTRUMENTATION

The U.S.G.S. tiltmeter networks employ the Kinemetrics model TM-1B biaxial shallow borehole tiltmeter and the virtually identical Rockwell International model 541B. The instrument was originally developed and manufactured by Rockwell and is now manufactured by Kinemetrics under a licensing agreement.

A description of the tiltmeter and its operation may be found in "Operating instructions for model TM-1B biaxial borehole tiltmeter" (Kinemetrics, 1975). The tiltmeter consists of a cylindrical bubble-level sensor mounted in the base of a stainless steel tubular housing 108 cm long by 5.15 cm in diameter. This housing is connected by an electrical cable enclosed in a watertight, flexible steel conduit to a waterproof junction box containing associated electronics. The sensor consists of a glass disk approximately 3.5 cm in diameter, the lower surface of which is ground concave to a spherical radius of 30.5 cm. A cylindrical vial containing a conductive fluid is mounted to the underside of the disk permitting a bubble to be trapped under the concave surface. Four orthogonal platium electrodes are metalized on the concave surface, with opposite electrodes forming the active legs of two independent AC resistance bridges. Matched pairs of precision resistors, which comprise the fixed legs of the bridges, are mounted along with a thermistor on a small circuit board inside of the stainless steel housing just above the bubble sensor. AC excitation to the bridges in the form of a 5 KH_z square wave is provided by means of an electrode metalized to the base of the fluid cavity.

Rotation of the sensor about gravitational vertical results in the bubble masking more or less of each pair of opposite electrodes, unbalancing the bridges and causing AC voltages with amplitudes directly proportional to the amount of tilt about each axis to appear at the inputs of the first-stage, AC amplifiers in the elctronics package. From the AC amplifier for each axis, the signal is fed to a full-wave synchronous demodulator that converts the AC signal to a DC level directly proportional to tilt. This signal is integrated and inverted by the final-stage, DC amplifier, which provides for filtering the output with either a 1 second or 20 second low pass option, selected by means of a switch.

The electronics provides for regulation of input power of ±9.5 to ±14 volts to ± 9 volts required to power the circuitry. A calibration feature is also provided so that, by means of a switch, a small fixed resistance may be placed across one leg of each bridge, the effect of which has been carefully measured by the manufacturer. By this means an electronically simulated tilt step is transmitted throughout the circuitry which may be used as a check on system operation.

TILTMETER INSTALLATION

The tiltmeter sensor, along with its sensitive bridge resistors, are packaged in a strainless steel tube 108 cm long and installed in the borehole as depicted in Figure 3. The tiltmeter electronics are housed in a weatherproof steel box which is placed at the bottom of the large pit on a wooden platform that prevents the insulation package from resting on the cable which connects the electronics to the tilt sensor near the top of the sensor package. Batteries, DC-DC converter, Rustrak recorder, amplifier, and telemetry transmitter are housed in the nearby drum, with electrical connection made via buried armored conduit. Figure 4 shows a block diagram of the tiltmeter system.

The tiltmeters are installed as they are delivered from the factory with one modification- the flexible metal conduit connecting the sensor package to the electronics box is replaced with a highly compliant vinyl tubing. In California where lightning is not frequent, this modification has not caused any problems.

Before installing the tiltmeter the system should be wired as in Figure 4, but with the Rustrak recorder and telemetry left unplugged. The tiltmeter should be quickly checked for proper operation by observing maximum deflections at the x and y output terminals as the probe is moved to and fro. Enough sand is poured into the bottom of the borehole so that the top of the tiltmeter will be at least 15 cm below the top of the borehole tube, but may still be conveniently manipulated with one hand. This is most conveniently accomplished by measuring with a steel tape. The borehole tube is pounded vigorously to pack this sand, in a radially symmetric fashion, just as the sand surrounding the tube was packed. The tiltmeter probe is then placed inside the tube, as nearly centered as possible, and is held in rough alignment while a 10-15 cm layer of sand is poured around its base. This sand is packed by pounding the top of the steel borehole tube in the same fashion as before, while the tiltmeter is held as nearly vertical as possible. To accomplish this it is useful to employ the external horizontal input feature of an oscilliscope to create an electrical analogy of the bubble position. The filter switch should be in the 'B' or 'C' (short time constant) position. The convention adopted in U. S. G. S. tiltmeter installations is that downward tilt to the north produces a positive signal at the y output and positive vertical deflection on the scope, and downward tilt to the east produces a positive signal at the x output and positive horizontal deflection on the scope.

As soon as the tiltmeter probe is able to remain in a vertical position without being held, it should be aligned with respect to east (the fiducial mark indicates the x axis). This may be accomplished by orienting a straight edge (non-magnetic) across the top of the pit in an east-west direction using a Brunton compass, compensated for local variation. The position of the straight edge should be marked on the fiberglass culvert with a marking pen to obviate later inadvertent misalignment. The tiltmeter may then be rotated by the installer while the orientation is adjusted from above by an observer. Several checks of the orientation should be made during the tiltmeter probe emplacement process.

With the tiltmeter positioned near null the rezeroing potentiometers should be shorted out of the bridge using a clip lead or set at mid-range. The emplacement of the tiltmeter proceeds with successive 15 to 20 cm layers of sand, each well packed as before by vigorous symmetric pounding of the borehole tube while keeping the x and y outputs near null. During the early stages of emplacement the position of the tiltmeter probe may be returned to null from relatively large deflection, and thus the installers' oscilliscope may be set to a coarse range, say .5 or 1 v/div. By the time sand is packed around half the height of the probe, however, the position adjustments should be small and the oscilliscope should be set to a range of 50 to 200 mv/div. depending on the scale factor of the tiltmeter.

At about this stage of emplacement the configuration should be sufficiently elastic that the output returns to the same position when the interconnecting cabling is gently wiggled. With the remaining layerings of sand the output should be kept within 100-400 mv, depending on scale factor. When the sand is within 20 to 30 cm of the top of the tiltmeter probe, it will be observed that pressure at the top of the probe produces an apparently contradictory tilt signal at the output. When this condition is reached, only very slight position changes may be made, and the bubble position must be checked after each tap on the borehole tube. At this stage of emplacement the x and y outputs of the tiltmeter should be within 40 or 200 mv of null (1 μ radian) depending on the scale factor of the tiltmeter. The borehole tube should be filled until sand covers the top of the tube. While it may be possible to recover a null tilt output from a position far from zero at a late stage of emplacement, the use of significant pressure at the top of the tiltmeter probe, which such a procedure requires, may result in small stresses being locked into the probe or the surrounding sand causing excessive drift of the output signal as the stresses are gradually relieved, or steps in the output signal in response to minor ground noise.

This completes the tiltmeter installation. The filter switch is now returned from the 'B' position, momentarily to the 'C' position to ground the capacitor in the output filter, and finally to the 'A' (long time constant) position. The outputs should be checked again, and electrically rezeroed if necessary. Activated dessicant should be placed inside the electronics box, and the box closed. The wooden stand is positioned carefully in the bottom of the pit, avoiding contact with the sensor cable and borehole tube. The wooden stand may be raised or lowered by means of a line attached at its center and tied off at the top of the pit. The electronics box is placed on top of the wooden stand and the package of styrofoam insulation is lowered into the pit. The steel lid is fastened securely with chain and locks.

The newly installed tiltmeter will drift as it becomes acclimated and should be visited within a week of initial emplacement. The length of time required for an instrument to stablize to a small constant drift rate will vary from site to site, with one month being typical. Likewise, the final stability of the tiltmeter will vary depending on the site, but for acceptable results the drift, once the instruement site has had time to stabilize, should be constant or smoothly varying and small.

Morrisey (1976) installs his tiltmeters without the use of a steel tube lining the borehole. This method is being evaluated at the Sage Ranch site for possible application in the California tiltmeter network. In this case the sand is packed by means of a "sheeps' foot" tamper specially made for this application.

PROCEDURE FOR TILTMETER MAINTENANCE

It is not possible to do more than provide the technician servicing a remote tiltmeter site with guidelines for checking and maintaining the field equipment. In general, the condition of the instrument and site will not be known in exact detail prior to the visit. The technician should be prepared, therefore, to troubleshoot and remedy any problems, whether instrumental, electronic or site related, that may become apparent during the course of his visit.

Maintenance should be scheduled so that minimum instrument down-time is achieved while avoiding unnecessary visits and utilizing the servicing technicians' time most effectively. This can be achieved by closely monitoring the telemetry, which will reveal when an instrument fails and whether it requires rezeroing, and by maintaining and referring to an accurate record of previous maintenance history. The onsite Rustrak recorders operate at a chart speed of 1/2 inch per hour and the standard chart is 63 feet long, which implies that the chart paper should last for 63 days. In practice it has been found that the chart paper coils more losely onto the take-up spool than on the supply spool, and it is difficult to assure proper operation of the recorder for more than 7 or 8 weeks, and in any case the recorder should be checked for proper take-up spooling at each service visit.

The Union-Carbide Air Cell batteries, of 2.5 volt 1,000 amp-hr capacity, are connected in series to supply 5 volts to the DC-DC converter that powers the tiltmeter and Rustrak recorder. A separate similar set of batteries supply power for the digital telemetry transmitter, which, if powered by the same batteries as the other equipment, would exceed the 1 ampere current supplying capacity of the aircell batteries. The batteries supplying the digital telemetry transmitter last in the field for nearly their shelf life because of the short duty cycle of the transmitter, and it is therefore most convenient to replace them only if they fail to power the transmitter. The batteries supplying power to the tiltmeter and Rustrak recorder last between 4 and 6 months depending on peripheral equipment and the efficiency of the DC-DC converter being used. The voltage of these batteries should be checked during each maintenance visit. Batteries and chart paper, along with periodic rezeroing, are the only items in the tiltmeter system which require servicing on a regular basis.

The tiltmeter system utilizes three types of DC-DC converters. The Analogic models MP 3015 or 3020 are highly regulated types which convert 5 volts to $\pm$ 15 volts. Their regulation is required in the digital telemetry transmitter, but results in lower efficiences than the unregulated types. They may be used to power the tiltmeter and Rustrak recorder, but their regulation is not required in that application because of the internal regulation in both devices, and the lower efficiency results in shorter battery life. Either of two unregulated DC-DC converters, Semiconductor Circuits model DTD5-12D100, which converts 5 volts to $\pm$12 volts, or an inhouse design, which outputs

±10.5 to ±12.5 volts, are commonly used to supply the tiltmeter and Rustrak recorder. They operate at efficiences of roughly 75% and provide the longest battery life. The three different DC-DC converters are mounted on printed circuit cards with identical pin-outs on card-edge connector lands. It has been found in practice that the batteries should be replaced when their series output reaches certain values depending on the type of DC-DC converter in use as follows:

Analogic converter -
battery voltage less than 4.86 volts
Semiconductor Circuits converter -
battery voltage less than 4.96 volts
inhouse design converter -
battery voltage less than 4.96 volts

It may be found that at installations employing bias steppers (Figure 6) the minimum voltages listed above will have to be adjusted upwards due to higher current drains and longer intervals between servicing. The circuit boards with the two commercial converters incorporate a simple reed relay and diode circuit to protect against reversed voltage at the input (see Rogers, et. al., 1977).

When visiting a tiltmeter site the servicing technician should first open the recorder-telemetry pit and measure with a DVM the x and y output voltages of the tiltmeter in the recorder box, and the x and y output voltages of the amplifier if one is installed, and record these voltages in a notebook kept for that purpose. This provides a rough calibration on the telemetry and recorder and recovers a close estimate of net tilt should the recorder be offscale and the telemetry record not be continuous. In general, voltage measurements for the purpose of calibration or recovering of net tilt amounts should be made at the recorder box so as not to disturb the instrument electronics or sensor.

If the x and y inputs to the recorder are recording near midrange the tiltmeter need not be disturbed. Where a bias stepper is installed, and x and y are within the range of the electrical rezero (not the full output range), about ± 1.6 volts, the tiltmeter need not be rezeroed. The date and time (G.M.T.) of the visit should be noted on the strip chart, without advancing the chart, and in a field notebook or record card. The recorder should be checked for proper chart spooling and clear printing and the telemetry checked for power-up, FSK output, and shutdown. Telemetry problems may be detected and partially diagnosed at the receiving location prior to the service visit.

If the x and y inputs to the Rustrak recorder are offscale or nearly so, they must be biased to a null position using the electrical rezero feature of the tiltmeter. In this case the recorder should be advanced slightly and temporarily unplugged, noting the end of trace time and date on the chart beneath the end of the x and y traces. The tiltmeter pit may then be opened and the styrofoam insulation and electronics package carefully removed. Caution must be observed so as not to disturb the sensor by moving the cable connecting it to the electronics package near the sensor end. The x and y outputs are observed with an oscilliscope or DVM and are biased to null using pots R3 and R6 (Figures 7 and 8). The filter should be switched to the 'B' or 'C' (short time constant) position for rezeroing, and momentarily switched to 'C' and returned to the 'A' (long time constant) position upon completing the rezeroing. The electronics package may then be sealed and it and the insulation returned to the pit. The recorder should be plugged in, checked for on-scale operation, and the start-trace time noted on the chart.

If the x or y outputs of the tiltmeter are beyond electrical rezero range, the tiltmeter must be mechanically rezeroed. This is accomplished by vacuuming most of the sand from the borehole tube and reinstalling the instrument, duplicating the original installation procedure previously described. If the sand removed is dirty or wet it should be replaced with clean dry sand. The alignment should be checked with a Brunton compass in the same manner as during the initial installation procedure. An instrument which has been mechanically rezeroed will drift and should be visited after roughly one week for electrical rezeroing.

Careful field notes covering all aspects of maintenance and trouble-shooting should be recorded on the site at the time of the service visit to ensure completness.

Troubleshooting of the various components of the tiltmeter system is occasionally required. Many problems may be corrected in the field, while other problems require that a unit be replaced in kind and returned to a shop facility or to the manufacturer for repair.

Problems which involve the tiltmeter sensor or electronics should be diagnosed by referring to the typical waveshape diagrams, but all repairs which affect scale factor or calibration must be conducted by the manufacturer since extensive facilities are required for sensor assembly and recalibration. Any diagnosis which may be accomplished in the field, however, is extremely helpful in the repair process. Table III lists symptoms of some common problems with various elements of the tiltmeter system and suggests checks and remedies.

REFERENCES

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FIGURE CAPTIONS

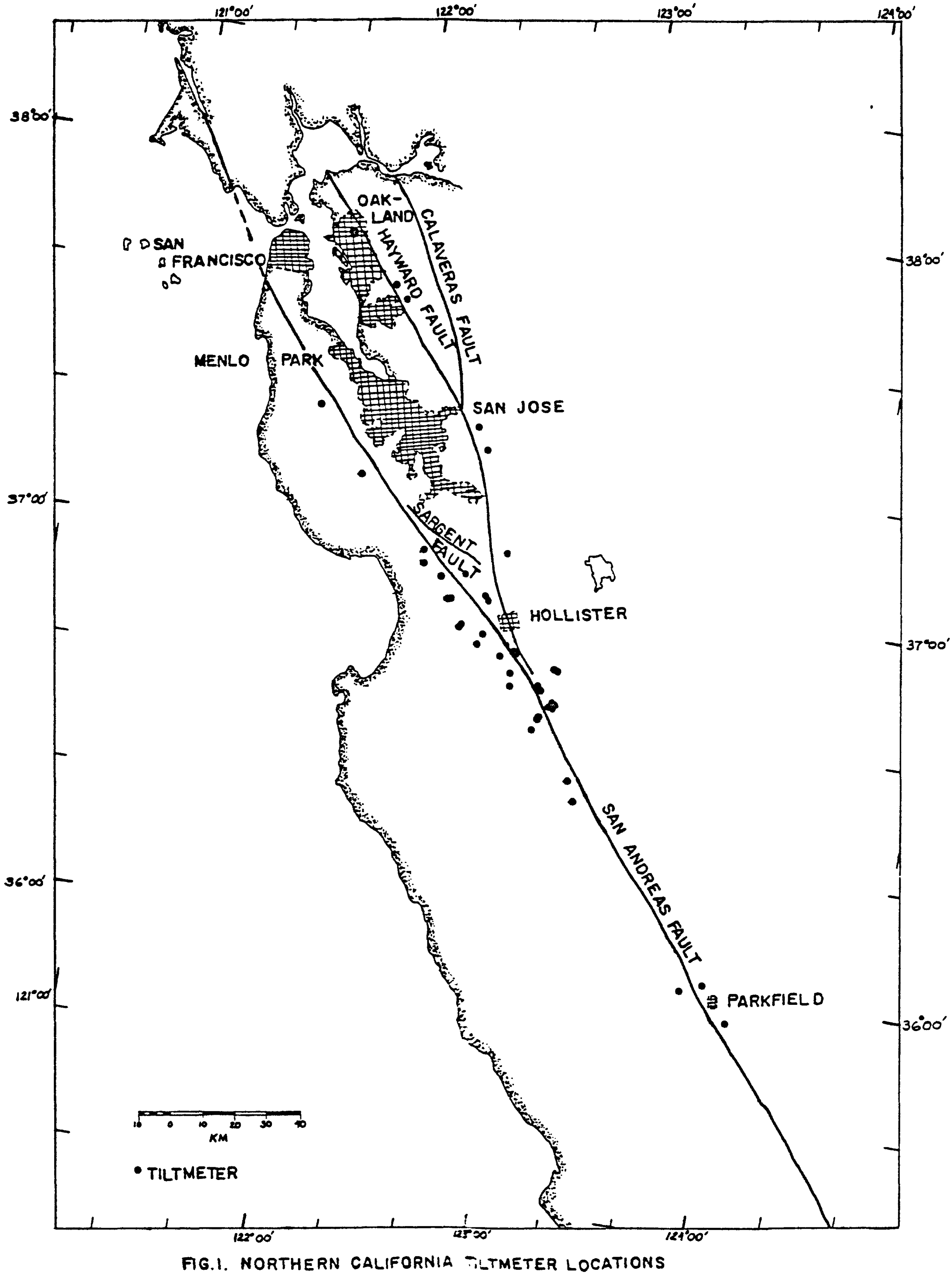


FIG.1. NORTHERN CALIFORNIA TILTMETER LOCATIONS

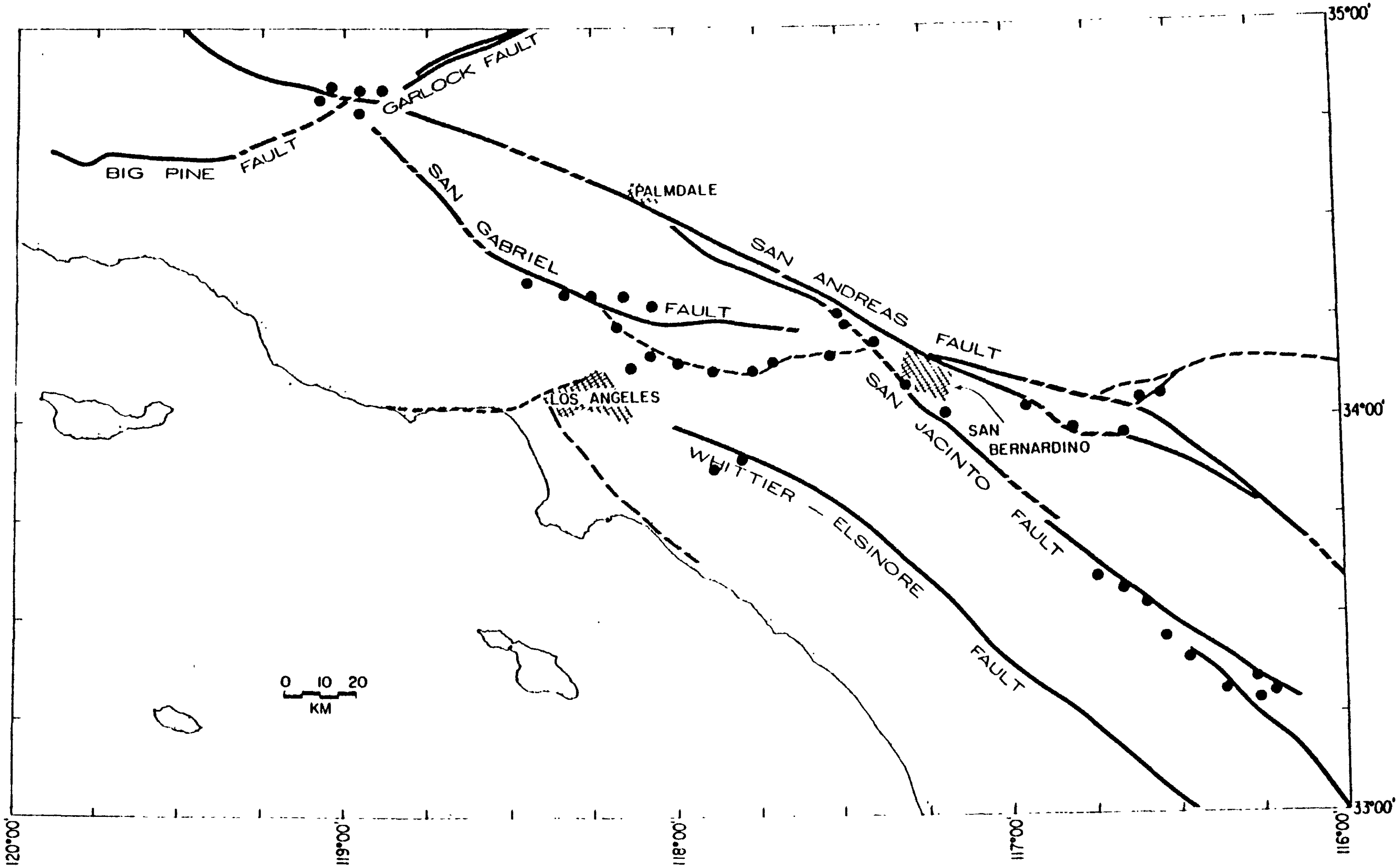
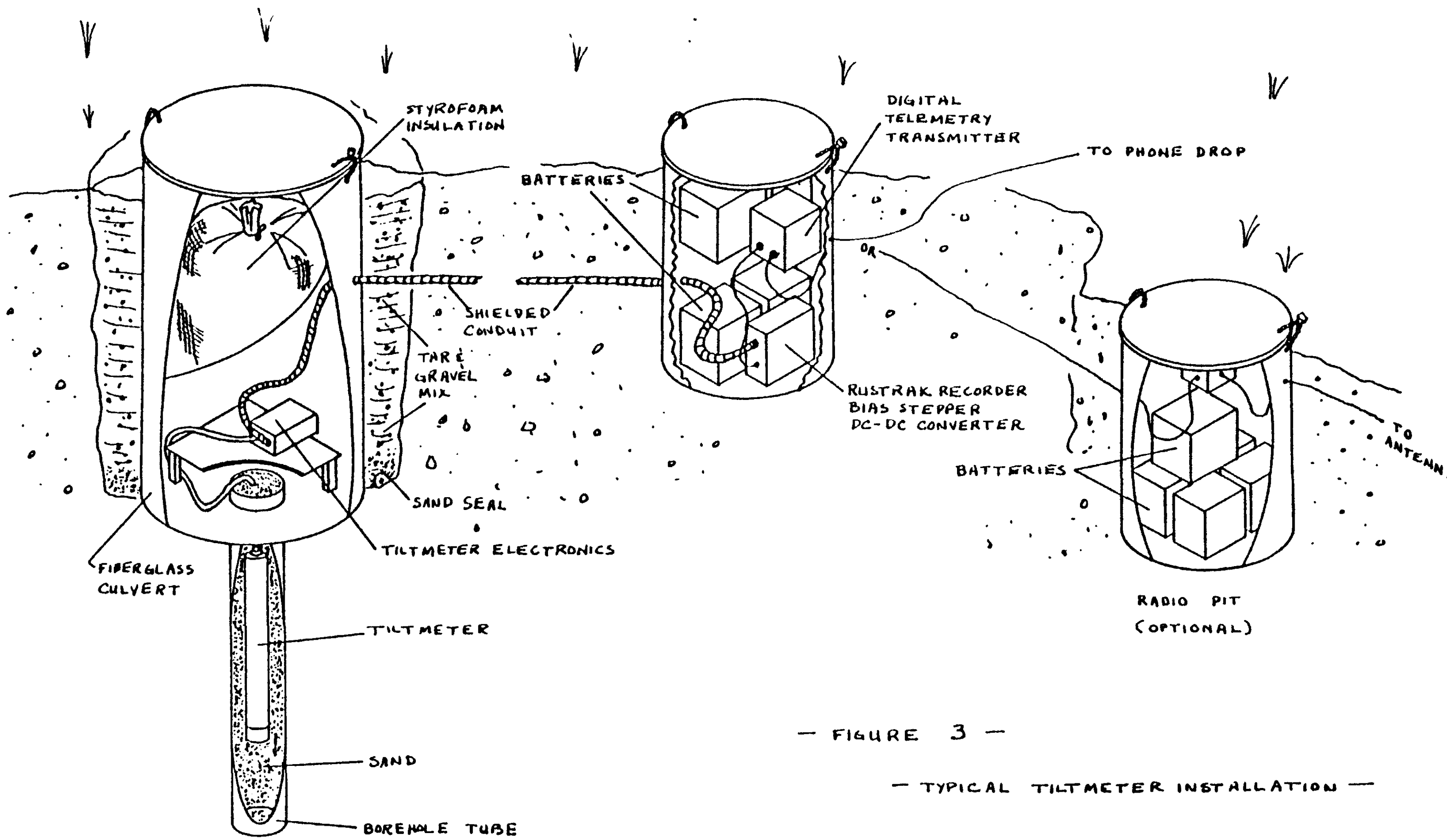
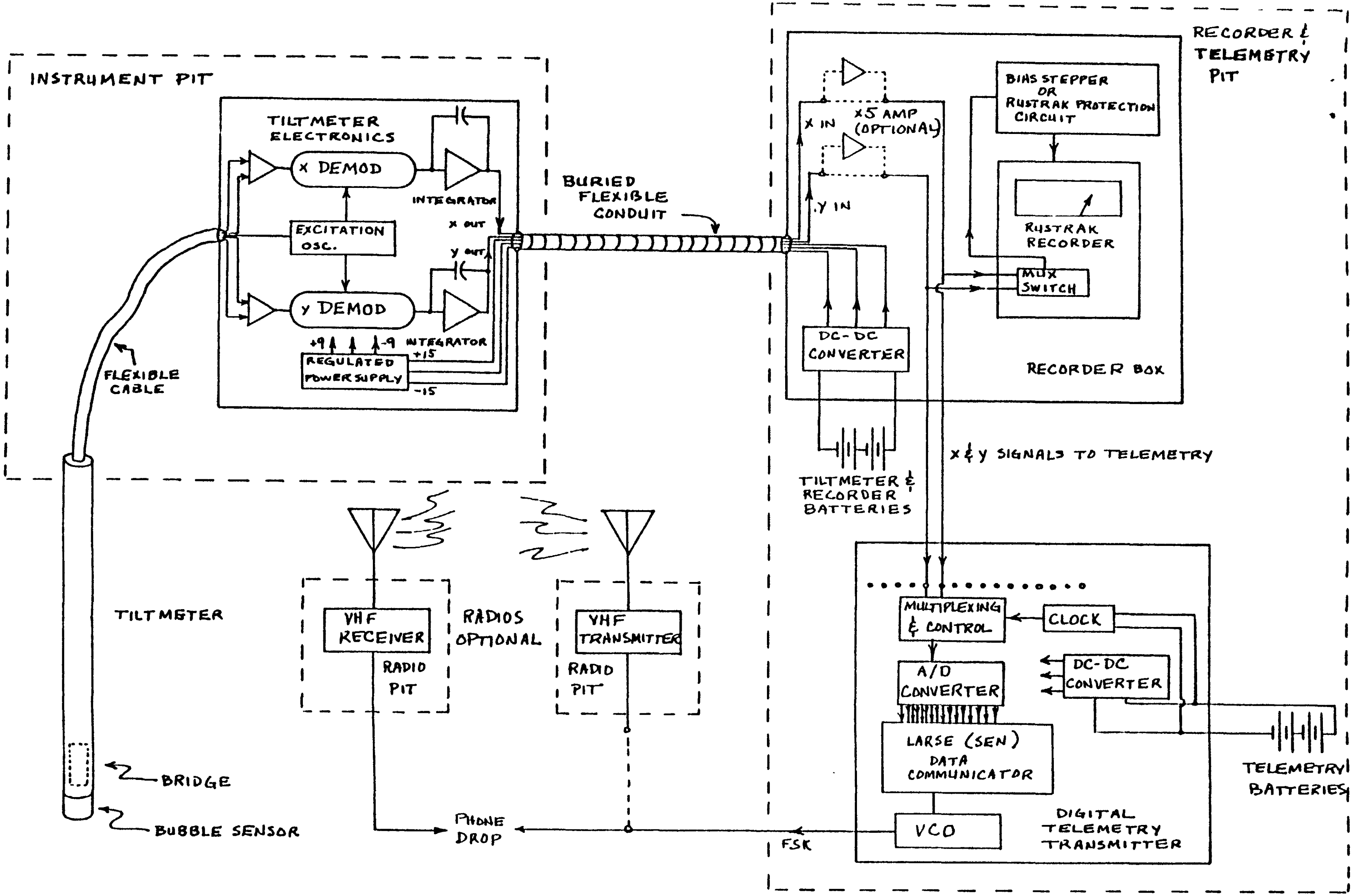


FIG. 2. SOUTHERN CALIFORNIA TILTMETER NETWORK



— FIGURE 3 —

— TYPICAL TILTMETER INSTALLATION —



— FIGURE 4 —

~ BLOCK DIAGRAM OF TILTMETER SYSTEM ~

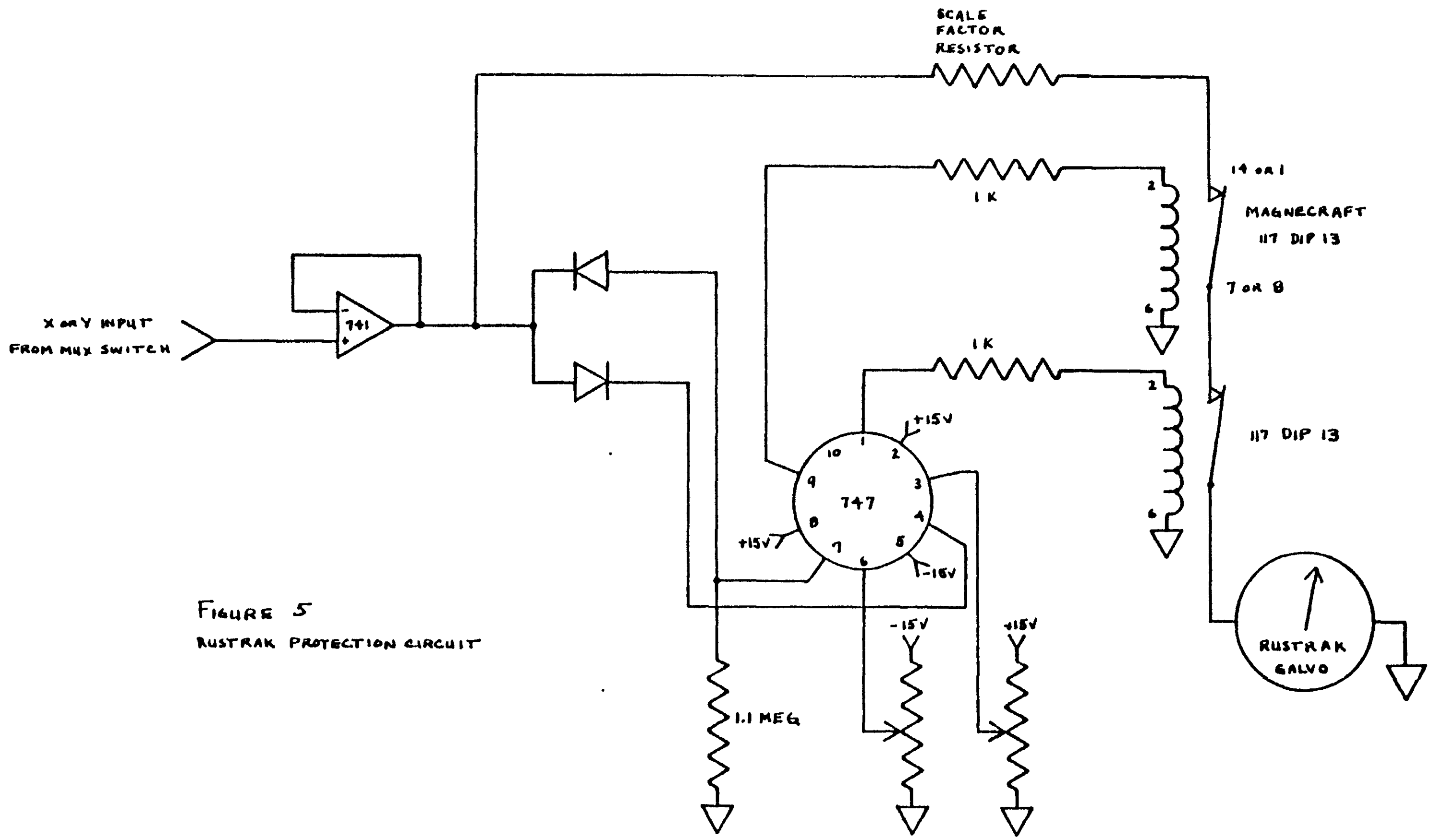
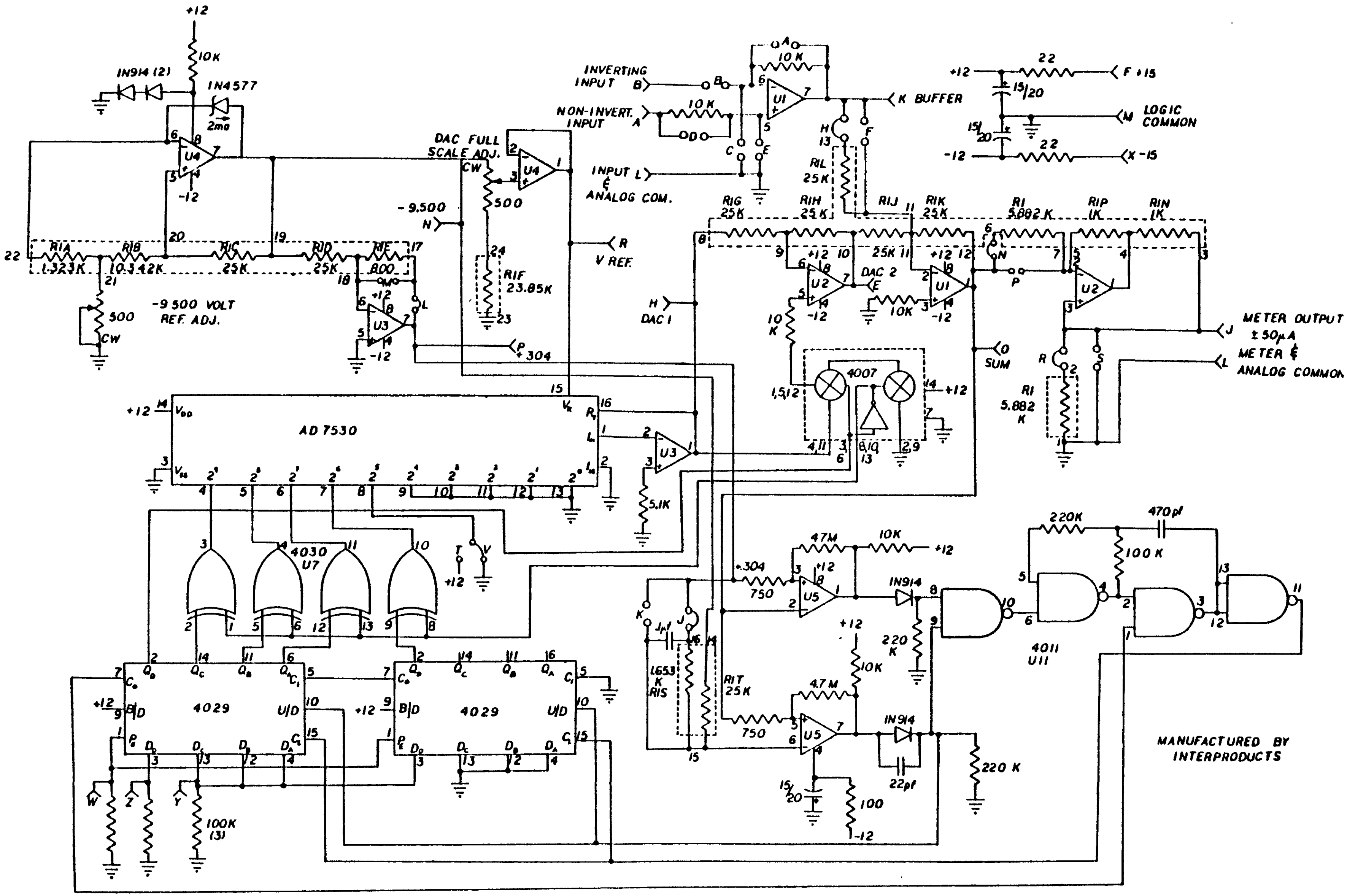


Figure 5

RUSTRAK PROTECTION CIRCUIT



NOTE: U1,2,3 & 4 - DEVICE LM358
U5 - DEVICE LM 393
—< A - CARD CONNECTOR PIN

FIG. 6 BIAS STEPPER

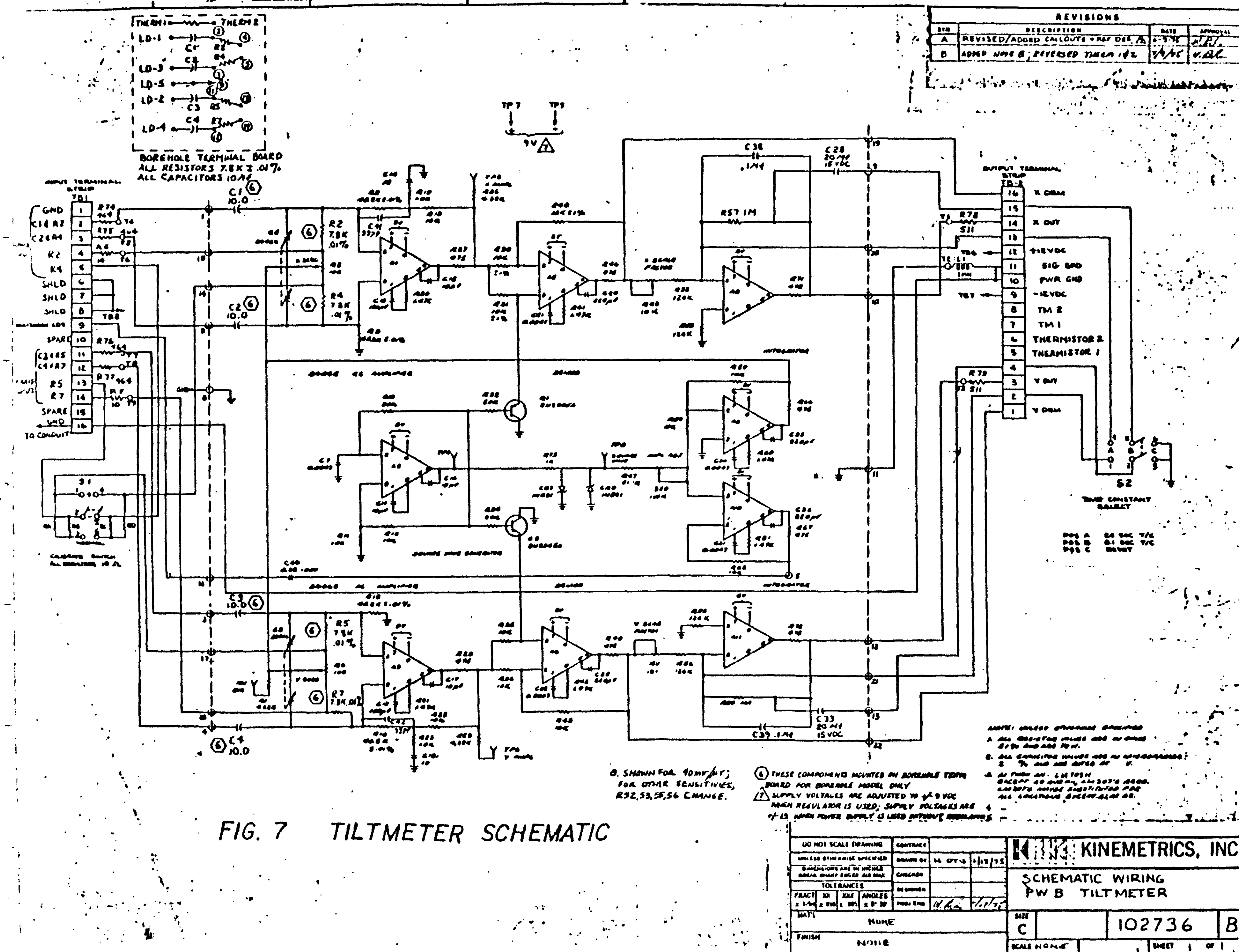


FIG. 7 TILTMETER SCHEMATIC

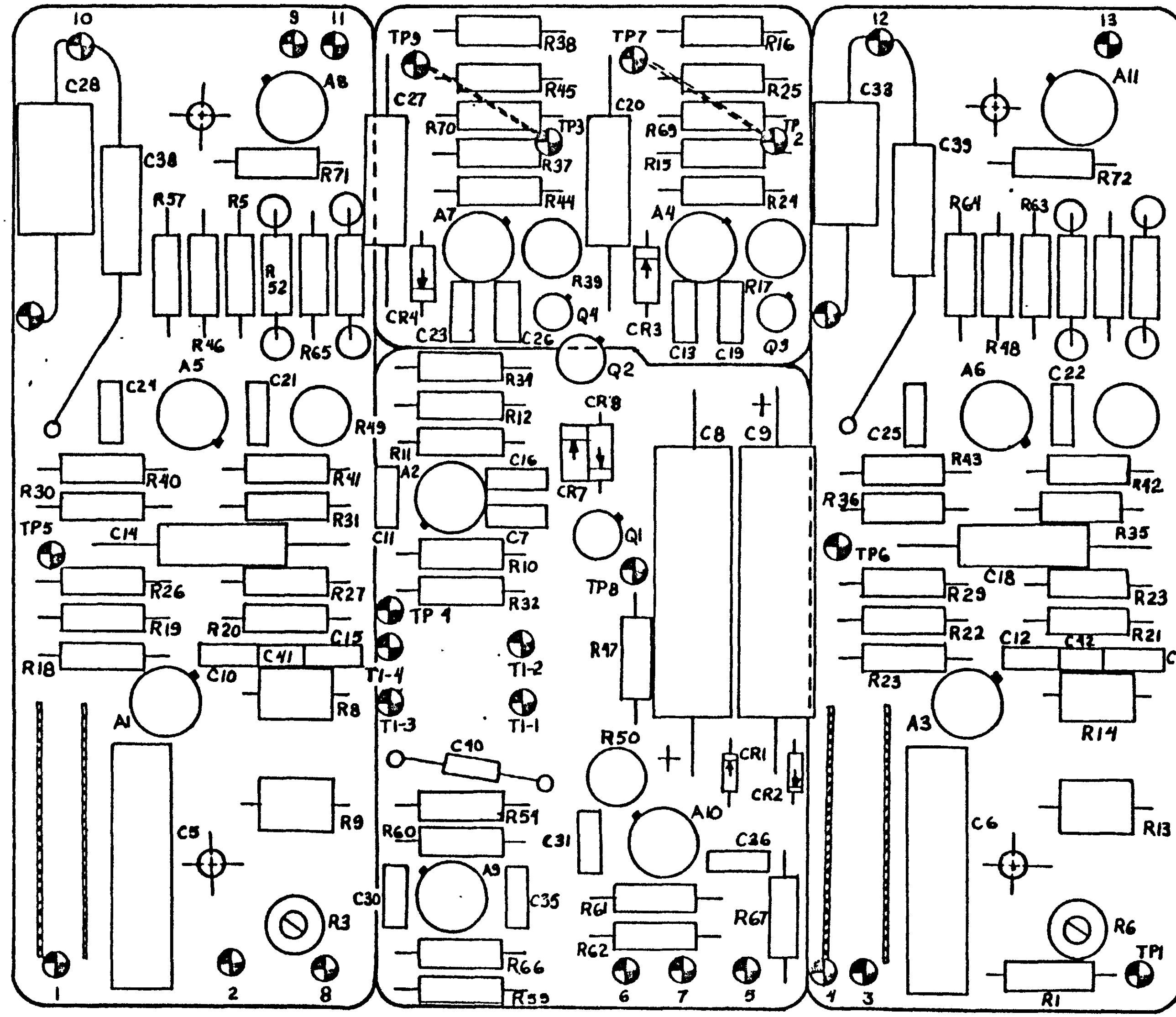


FIG. 8. TILTMETER ELECTRONICS LAYOUT

TABLE 1, NORTHERN CALIFORNIA TILTMETER

LOCATIONS

	STATION	LATITUDE	LONGITUDE	DATE INSTALLED
1.	Aromas 1	36° 52.42'	121° 38.47'	1976
2.	Aromas 2	" "	" "	1976
3.	Bear Valley 1	36° 34.28'	121° 11.25'	1973
4.	Bear Valleys	" "	" "	1976
5.	Berkeley	37° 52.67'	122° 14.18'	1970
6.	Black Mtn.	37° 19.05'	122° 09.22'	1976
7.	Campesino (Avilla)	36° 50.17'	121° 32.50'	1975
8.	Church	36° 47.97'	121° 28.37'	1976
9.	Coyote	37° 03.93'	121° 29.93'	1976
10.	Cull Creek	36° 43.93'	122° 04.08'	1976
11.	Dry Lake	36° 28.75'	121° 05.08'	1975
12.	Gold Hill	35° 49.66'	120° 19.95'	1976
13.	Grass Valley	36° 43.35'	121° 20.75'	1975
14.	Hayward	36° 39.10'	122° 02.80'	1976
15.	La Gloria	36° 33.92'	121° 12.85'	1975
16.	Lange Canyon	35° 54.28'	120° 28.55'	1976
17.	Libby	36° 41.60'	121° 20.58'	1975
18.	Mc Entee	36° 56.25'	121° 41.33'	1976
19.	Melendy	36° 34.95'	121° 10.70'	1974
20.	Melendy A	36° 35.30'	121° 11.25'	1976
21.	Melendy B	36° 36.37	121° 10.78'	1976

STATION		LATITUDE	LONGITUDE	DATE INSTALLED
22.	Melendy C	36° 35.18'	121° 11.03'	1976
23.	Mount Hamilton	37° 19.30'	121° 40.07'	1975
24.	Mount Maddonna	37° 01.40'	121° 43.55'	1973
25.	Muertas 1	36° 53.50'	121° 38.47'	1976
26.	Muertas 2	" "	121° 32.83'	1976
27.	New Idria 1	36° 41.38'	121° 12.83'	1975
28.	New Idria 2	" "	" "	1975
29.	Nutting	36° 49.45'	121° 27.53'	1973
30.	Oroville	39° 29.55'	121° 29.50'	1975
31.	Presidio	37° 47.68'	122° 28.50'	1970
32.	Renick	37° 10.68'	122° 01.43'	1976
33.	Richmond	37° 15.62	121° 42.25'	1975
34.	Sage North	36° 40.33'	121° 15.47'	1976
35.	Sage South	" "	" "	1975
36.	Sago (Harris Tunnel)	36° 45.20'	121° 23.70'	1974
37.	San Juan Bautista	36° 50.00'	121° 32.47'	1975
38.	Sargent	36° 55.63'	121° 35.33'	1974
39.	Smith Ranch	36° 58.78'	121° 44.13'	1976
40.	Stone Canyon	36° 38.37'	121° 15.63'	1974
41.	Topo Valley	36° 25.75'	121° 03.13'	1976
42.	Tres Pinos 1	36° 46.67'	121° 20.93'	1973
43.	Tres Pinos 2	" "	" "	1977
44.	Turkey Flat	35° 51.88'	120° 23.00'	1977

TABLE II, SOUTHERN CALIFORNIA TILTMETER

LOCATIONS

	STATION	LATITUDE	LONGITUDE	DATE INSTALLED
1.	Azuza	34° 07.88'	117° 53.12'	1974
2.	Barley Flat	34° 16.38'	118° 04.08'	1976
3.	Borrego Badlands	33° 17.20'	116° 15.77'	8/76
4.	Buck Canyon	34° 19.83'	118° 20.48'	1974
5.	Cal Tech	34° 08.03'	118° 07.55'	1975
6.	Cherry Creek	34° 50.93'	119° 03.38'	1976
7.	Clark Lake	33° 20.33'	116° 15.80'	1974
8.	Cuddy Flat	34° 50.47'	118° 59.88'	1976
9.	Demens Danyon	34° 10.28'	117° 34.95'	1974
10.	Fall Creek	34° 18.37'	118° 09.50'	1974
11.	Fig Tree Valley	33° 26.32'	116° 31.00'	1977
12.	Frazier Mtn.	34° 47.80'	118° 57.45'	1976
13.	Fullerton State College	33° 53.07'	117° 53.07'	1974
14.	Glen Helen	34° 10.83'	117° 23.12'	1974
15.	Glen Ranch	34° 15.53'	117° 29.45'	1974
16.	Greer	34° 09.70'	117° 58.97'	1974
17.	Hamilton School	33° 34.30'	116° 39.50'	1974
18.	Jeffrey Pines	34° 49.22'	119° 06.25'	1976
19.	Krammer Ranch	33° 53.70'	117° 46.62'	1974
20.	Kwkw Radio Station	34° 09.62'	118° 04.75'	1974

	STATION	LATITUDE	LONGITUDE	DATE INSTALLED
21.	La Verne	34° 07.77'	117° 46.38'	1974
22.	Lytle Creek Ranger Station	34° 14.00'	117° 28.72'	1974
23.	Millard Canyon	33° 58.28'	116° 48.10'	1976
24.	Morongo Valley (BLMI)	34° 03.55'	116° 32.47'	1976
25.	Morongo Valley (BLM II)	34° 01.50'	116° 36.00'	1976
26.	Raney	34° 02.66'	116° 35.83'	1976
27.	Oso Ranch	33° 19.78'	116° 22.33'	1974
28.	Padua Hills	34° 09.12'	117° 41.97'	1974
29.	Pine Flat	34° 01.33'	116° 54.35'	8/76
30.	Pioneer Town	34° 09.37'	116° 30.15'	8/76
31.	San Bernadion Valley College	34° 05.30'	117° 18.57'	1976
32.	Table MTN 1	33° 31.70'	116° 35.60'	1974
33.	Table MTN 2	" "	" "	1977
34.	Tackett	34° 49.92'	118° 54.22'	8/76
35.	Trail Canyon	34° 18.23'	118° 15.32'	1974
36.	Tripp Flat	33° 35.50	116° 44.50'	1975
37.	Truck Haven	33° 18.37'	116° 04.13'	1974
38.	Weilenga Ranch	34° 00.88'	117° 11.37'	1974
39.	Whitewater	33° 57.13'	116° 39.12'	1976
40.	Wilson Canyon	34° 20.65'	118° 27.22'	1975

TABLE III

TROUBLESHOOTING

Unit	Symptom	Possible Cause	Diagnostic Procedure	Remedy	Repair Possible in Field - F Repair in Shop - S By Manuf. - M
Rustrak Recorder	Not clicking - dead	1. dead batteries 2. bad DC-DC 3. open or short in cable	1. check batteries 2. check DC-DC 3. check Rustrak plug & connections underneath board	1. replace 2. replace 3. resolder bad connections	F F F
	Paper not advancing - jammed	1. Paper not spooling right 2. Too much loose paper on takeup spool	1. check take up spool & chart feed 2. check take up spool	1. Tear off paper & restart 2. replace paper with new roll	F F
	Both traces "fuzzy"	1. Tiltmeter output filter left on short time constant	1. check	1. change to 'A' position	F
	One trace"fuzzy" or irregular	1. Mux switch not timed right	1. operate switch manually	1. replace Rustrak, realign switch	S
	Needle seems undamped- no record	1. open galvo	1. measure coil resistance	1. replace Rustrak 2. replace galvo	1.F 2. S or M

Unit	Symptom	Possible Cause	Diagnostic Procedure	Remedy	Repair in: Field Shop. Manuf.
Protection Circuit	Offscale signal not interrupted	1. Comparator not set close enough to chart edge	1. measure voltage at pins 3 and 6 of 747	1. reset comparator to 100 mv beyond chart edge	F or S
		2. Board misassembled; 1.1 Meg resistor and diode interchanged on one side.	2. input side of both diodes should read the same; check	2. resolder board-may require new diode	F or S
		3. Relay not turning on	3. check 747, relay, and 1K resistor	3. repair or replace	F or S
	No sensitivity	1. Bad input buffer	1. Check input and output of 741	1. replace 741	F or S
DC-DC converter	no output or low output	1. Leads on batteries reversed	1. check leads	1. reverse leads	F
		2. low batteries	1. check batteries	1. replace batteries	F
		3. Bad DC-DC unit	3. check input and output	3. replace card	F

Unit	Symptom	Possible Cause	Diagnostic Procedure	Remedy	Repair in: Field Shop Man.
Amplifier	no output or not amplifying	1. Bad 741	1. check input and output	1. replace 741	F
Tiltmeter	no output	1. no power	1. check batteries, check DC-DC		F
	unstable output	1. blown op amp 2. burned resistor 3. unshielded input lead giving trouble 4. bad solder connection	1. wave form tracking 2. " " 3. " " and wiggle lead 4. waveform tracing, and wiggle connections	1. diagnose only 2. " " 3. " " 4. resolder	M M M F
	output steps or jumps	1. many reasons	1. waveform tracing	1. diagnose only	M
	output drifts when filter swtiched from 'C' to 'A'	1. switch not fully grounding capacator	1. flip switch several times & watch output, or short switch 2. leave switch in 'C' position for ∿30 sec and watch output	1. replace switch	F or S

Unit	Symptom	Possible Cause	Diagnostic Procedure	Remedy	Repair in: Field Shop Manuf.
Tiltmeter (continued.)	output locked at full range	1. tilted beyond range		1. mechanically rezero; site may be unstable	F
	output locked, will not respond	1. blown op amp	1. waveform tracing	1. diagnose only	M
		2. burned resistor	2. " "	2. " "	M
		3. many other reasons	3. " "	3. " "	M
	will not rezero	1. tilted beyond range of electrical rezero	1. check for proper output	1. mechanically rezero	F
		2. bad rezero pot	2. waveform tracing	2. replace pot	F or S

TABLE IV COMPONENT SPECIFICATIONS

DC/DC Converter:

Semiconductor Circuits

Model D7D5-12D100

Input Voltage	5VDC ± 15%
Output Voltage	±12VDC + 3%
Output Current	±100 ma max
Efficiency	75%

Analogic

Model 3020

Input Voltage	5VDC ± .25V
Output Voltage	±15VDC ± 0.5%
Output Current	±150 ma max
Efficiency	65%

USGS

Input Voltage	5VDC
Output Voltage	±12VDC, +3V to -1.5V
Output Current	40 ma

AMPLIFIERS

Signal Input Voltage	± 5VDC
Input Voltage	± 10 VDC to ± 15 VDC
Gain	χ5 ± 5%, Linearity ± 1%

Rustrak Strip Chart Recorder

Model #2146/F137
2 Channel Recorder 50-0-50 µA Range Each Channel with 12VDC Event Marker

Power	+12VDC
Drive Motor	1 RPM, 12VDC
Chart Speed	1/2 inch/Hr, 12.7 mm/Hr
Duration of Chart Paper	9 weeks
Geartrain Number	1
Geartrain Ratio	60:1
Strike/Sec	1 strike /4 sec
Input Impedance	4600 ohms

Protection Circuit

Power	± 12VDC, 396 mw
Input Impedance	> 1 megaohm
Temperature Range	0°C to 70°C
Input Voltage	Calibration adjusted to Equal 200 millivolts/17 minor divisions on Rustrak chart through series output resistor. Maximum shutoff input of ± 450 millivolts adjusted by 200 k ohm pots.

Bias Steppers

Input Voltage	± 9VDC protected against 150V
Input Impedance	20 megohm minimum
Output Current Range	±50 microamps/step standard
Maximum Recorder Impedance	100 K ohms
Number of Steps	32
Stepwidth	.588 V/step referred to input
Stepwidth Accuracy	± 8mv
Step Switch Points	each .594V; the first at ± .297V
Power Supply	± 12VDC, 7 ma; 5% regulation

Operating Temperature Range -10°C to +50°C

Tiltmeter

Scale Factor

χ&Y Demod Outputs	typically 5 mv/microradian
χ&Y Outputs	typically 200 mv/microradian
	some 40 mv/microradina

see calibration data sheet for each instrument.

Output Impedance

χ&Y Demond	<1000 ohms
χ&Y Outputs	<1000 ohms

Output Range

χ&Y Demond Outputs	± 8VDC, nominal
χ&Y Outputs	± 7VDC, nominal

Input Power

Voltage	± 12VDC
Power Consumption	650 milliwatts

Thermal

Operating Temperature Range	-20°F to +120°F -29°C to + 49°C
Storage Temperature Range	-65°F to 140°F -54°C to 60°C
Temperature Gradient Stability	50 microradian/°F
Temperature Sensitivity	0.006 microradians/microradina/°