User's Manual:

Model 722 Borehole Tiltmeter

Serial Number: __________

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Read This First!

Your tiltmeter was tested thoroughly before shipment and was in perfect working condition when it left our factory. To verify that it was not damaged in transit, please perform the initial check-out procedure explained in Section 3 *immediately upon receipt*. Also, please familiarize yourself with the maintenance procedures in Section 8 before beginning to use your tiltmeter. Understanding its capabilities and limitations will help ensure that your new tiltmeter provides many years of trouble-free use.

1 Features and Specifications

Model 722 Borehole Tiltmeters are dual-axis, analog output tiltmeters, designed for high sensitivity, low noise, low power consumption, and reliability under rugged field conditions. Model 722 tiltmeters are used worldwide for monitoring the behavior of volcanoes, dams, bridges, building foundations, mines, power plants, retaining walls and many other structures. They are part of the Applied Geomechanics 700-Series of precision measurement instruments, which also includes digital readouts, data loggers, movement alarm systems, power supplies and calibration tools. Please contact Applied Geomechanics for more information about any of these products.

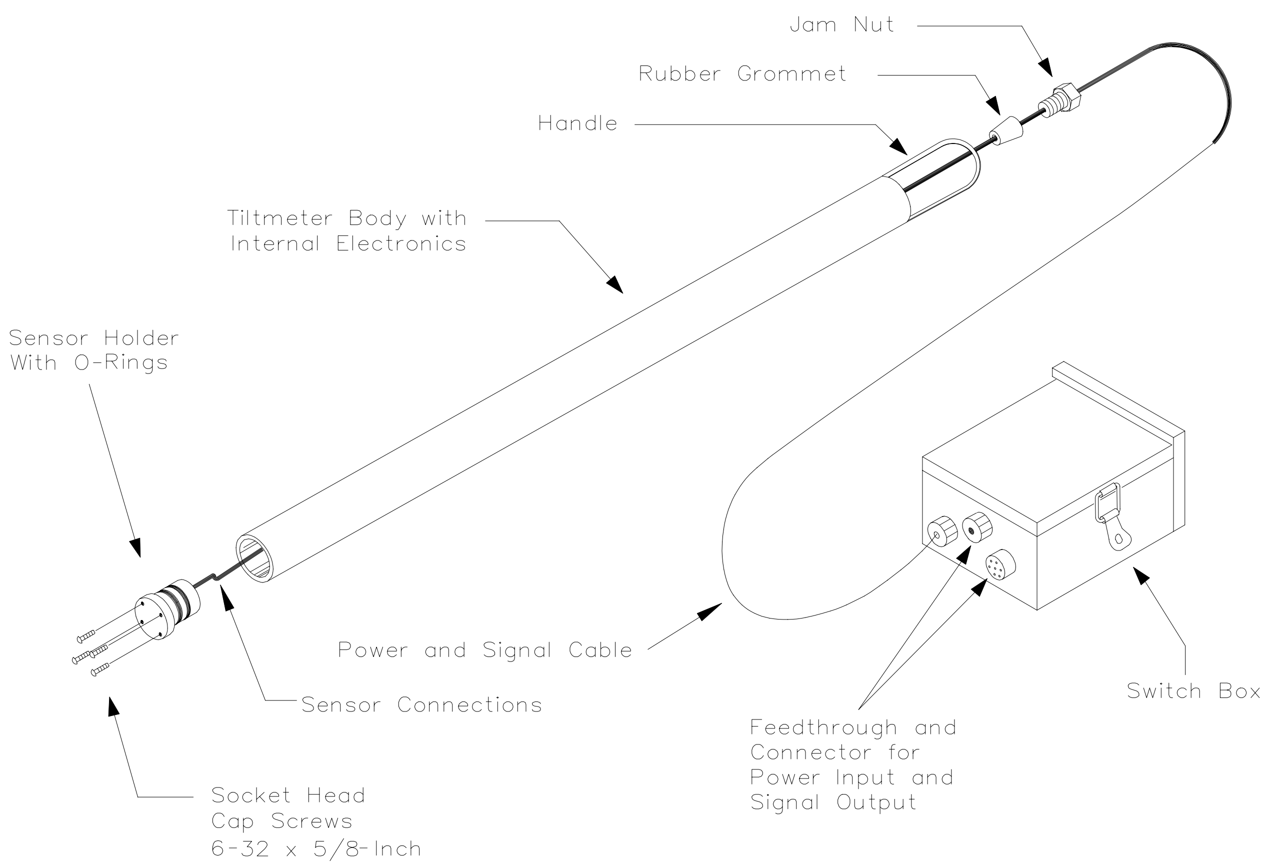


Figure 1. Model 722 Borehole Tiltmeter

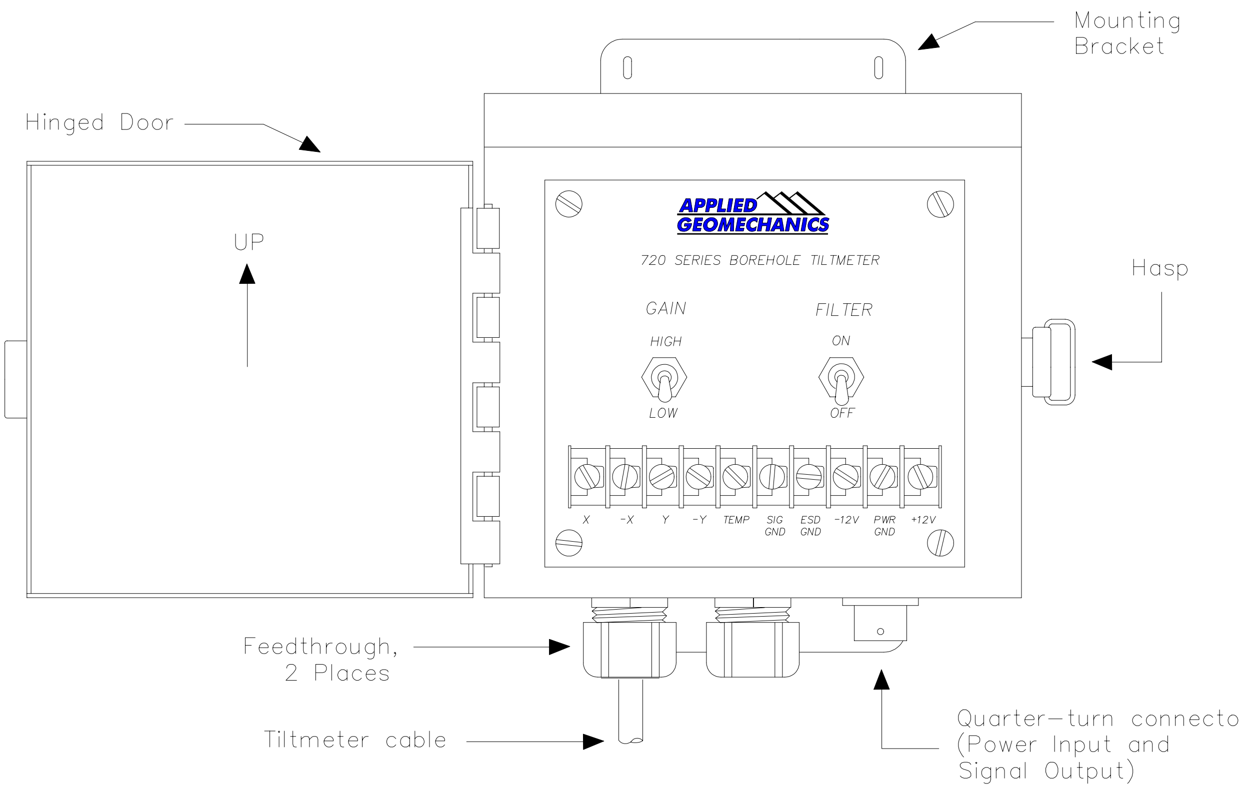


Figure 2. Switch box

1.1 Technical Features

Your Model 722 Borehole Tiltmeter consists of a cylindrical stainless steel body containing two tilt sensors, a temperature sensor and signal conditioning electronics (Figure 1). All power input and signal output connections are made at an external switch box, which is connected to the tiltmeter body via a submersible steel-reinforced cable. The switch box also contains the tiltmeter's gain and filter switches (Figure 2).

Your Model 722 Borehole Tiltmeter is distinguished by the following technical features:

- It senses changes in tilt angle with two precision electrolytic sensors, each of which is similar to a spirit level.
- Signal conditioning electronics reside on a single printed circuit board, located inside the tiltmeter body. Placement inside the tiltmeter body ensures stable, low-noise operation in a constant environment.
- All circuit board connections are gold-plated for long life and noise-free operation.
- All resistors are premium quality, 1% tolerance, metal-film type.
- All tiltmeters are hand-assembled, calibrated, and tested at our plant under stringent quality control standards.

- AGI maintains complete specifications and test records of every tiltmeter built.

The precision electrolytic level sensors inside your tiltmeter -one for each axis of tilt - convert changes of tilt angle to changes of resistance. These resistance changes are sensed through a voltage divider circuit (Figure 3). The tiltmeter electronics excite the electrolytic sensors with an AC signal, then amplify, rectify and filter the returned AC signals to form high-level DC outputs proportional to the X- and Y-channel tilt angles. The resulting low-impedance DC outputs can be read by strip chart recorders, digital voltmeters, data loggers, analog-to-digital conversion cards and most other standard recording devices. The tiltmeter's electronics will drive cables over 1000m long.

Your Model 722 tiltmeter also contains a temperature sensor, installed on the printed circuit board inside the tiltmeter body. The measured temperature is one of the output channels of the tiltmeter. Temperature measurements enable you to evaluate thermoelastic ground deformation and to compensate for the temperature coefficients of the tiltmeter's sensors.

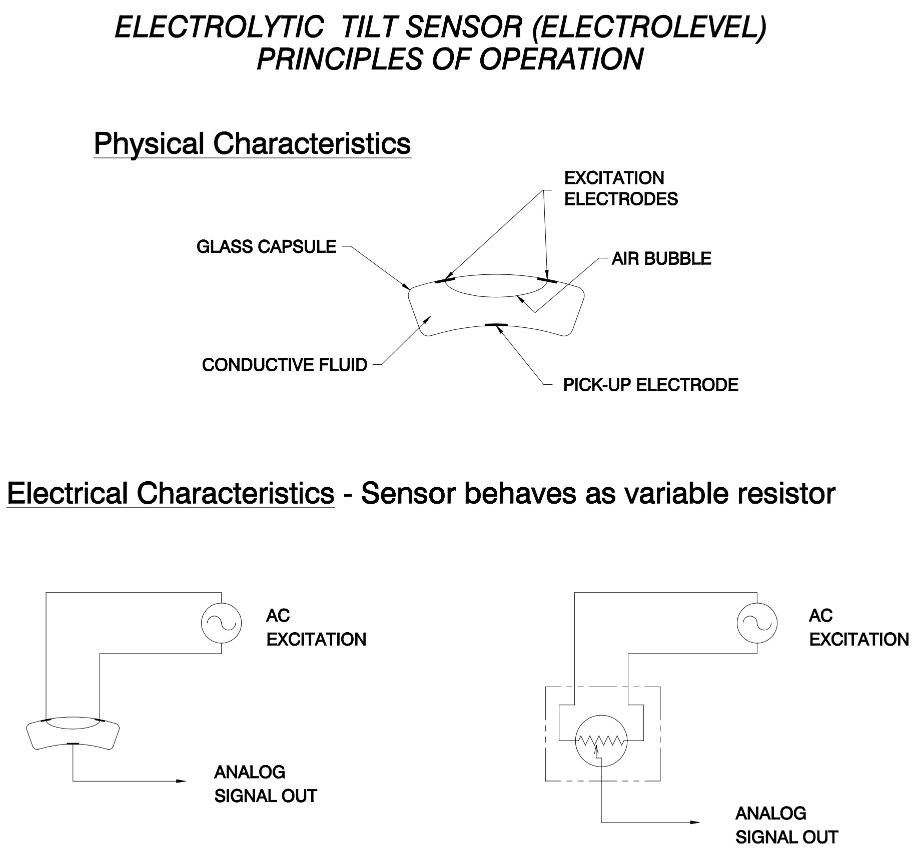


Figure 3. Electrolytic tilt sensor

1.2 Specifications

General specifications for borehole tiltmeters are listed below. Appendix B contains the calibrated scale factors for your instrument.

Channels	Two orthogonal tilt channels (X & Y), one temperature channel
Tilt Range	• 722-A: ±8000 μradians (± 0.5 degree) in low-gain setting, ±800 μradians (± 0.05 degrees) in high-gain setting; • 722-B: ±5 degrees in low-gain setting, ±0.5 degrees in high-gain setting
Resolution	• 722-A: 0.1 μradian • 722-B: 1 μradian
Repeatability	• 722-A: 1 μradian • 722-B: 2 μradians
Linearity	• 722-A: 2% of full span • 722-B: 1.5% of full span
Scale Factors (typical)	• 722-A: 1 μradian/mV (low-gain), 0.1 μradian/mV (high-gain) • 722-B: 10 μradians/mV (low-gain), 1 μradian/mV (high-gain) • Scale factors are for single-ended output; differential scale factors are half these values.
Filters	• Two 2-pole Butterworth filters, roll-off = 12 dB/octave (40 dB/decade) above corner frequency, $f_C = 1/(2\pi\tau)$ • Time constants, τ = 0.3 second (filter "OFF") and 20 seconds (filter "ON")
Temperature Coefficients	• Scale factor: K_S = +0.05%/°C typical • Zero shift: K_Z = 2 μradians/°C typical (722-A), K_Z = 7 μradians/°C typical (722-B)
Output Voltage Range	±8 volts DC (single-ended) and ±16 volts DC (differential), both provided
Output Impedance	270 ohms, short circuit and surge protected
Temperature Sensor Output	0.1°C/mV (single-ended), 0 mV = 0 °C, –40° to +100°C range, ± 0.75°C accuracy
Power Requirements	+11 to +15 VDC and –11 to –15 VDC @ +15 and –7 mA typical; 250 mV peak-to-peak ripple max.
Connections	10-pin, quarter-turn connector on outside of switch box plus terminal strip inside switch box

1.3 Physical Characteristics

Size	Tiltmeter: 2.13 x 34.8 inches (54 x 883 mm), see Figure 4. Switch box: 6 x 6 x 5 inches (152 x 152 x 127 mm)
Weight	Tiltmeter: 15 lb (6.8 kg). Switch box: 6 lb (2.7 kg)
Materials	Tiltmeter: 304 stainless steel. Cable: Polyurethane jacket, steel reinforced. Switch box: painted steel

1.4 Environmental Range and Limitations

Temperature	–25° to +70°C operational, –30° to +100°C storage
Humidity	Tiltmeter: Submersible to 5 bars (72 psi) Switch box: 0 to 90%, noncondensing. Rainproof when installed in vertical orientation.

Switch boxes labeled "rainproof" will shed rain when installed in the vertical, upright position (Figure 2). The switch box is not waterproof, so never allow it to be submerged or allow water to accumulate inside. *WATER DAMAGE TO THE SWITCHES OR CONNECTIONS VOIDS THE WARRANTY!*

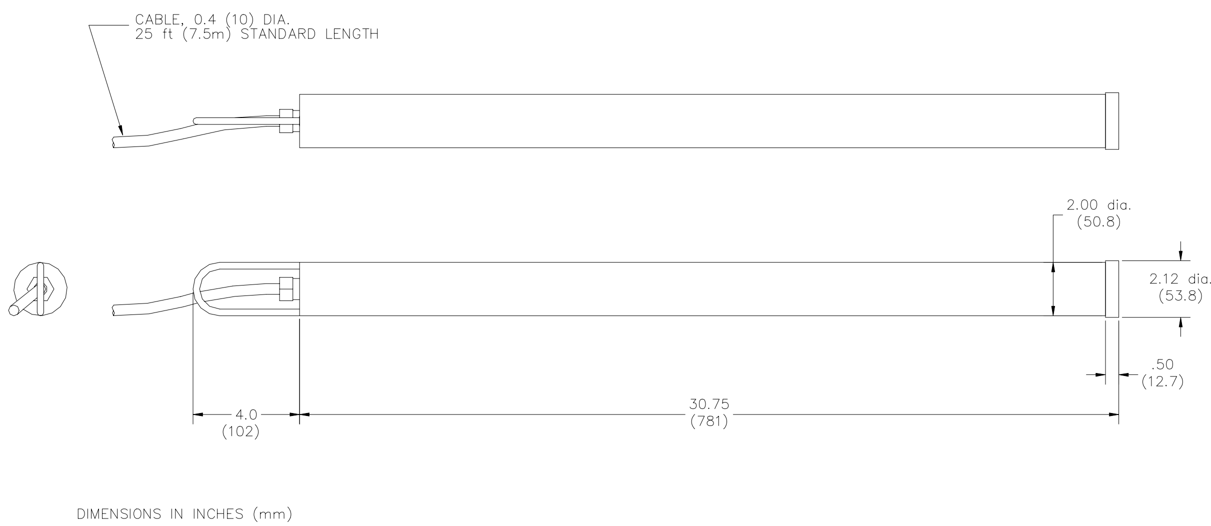


Figure 4. Tiltmeter dimensions

2 Using the Switch Box

2.1 Switches

The functions of the two control switches in the switch box (Figure 2) are described below. Your tiltmeter has no ON-OFF switch. It is operating whenever power is connected to the +12 Volt and –12 Volt terminals (Figure 5) or connector pins.

Control/Indicator	***Function***
Filter	Two-position switch selects the time constant of the low-pass filter applied to the output of the tilt sensors (Section 1.2)
Gain	Two-position switch controls amplification (gain) applied to the tilt outputs. Typical scale factors for each gain setting are in Section 1.2. Calibrated scale factors for your tiltmeters are in Appendix B.

2.2 Terminal Strip Connections

All power input and signal output connections are made on the terminal strip inside the switch box or at the 10-pin connector on the bottom of the switch box. Connector pin assignments are listed in Appendix B. Functions of the terminals are explained below:

Terminal	*Function*
X	X tilt channel output. When recording a single-ended value, this signal is referenced to SIG GND. When recording a differential value, this signal is referenced to –X.
–X	X channel output multiplied by –1
Y	Y tilt channel output. When recording a single-ended value, this signal is referenced to SIG GND. When recording a differential value, this signal is referenced to –Y.
–Y	Y channel output multiplied by –1
TEMP	Temperature sensor output. This value is a single-ended signal and is referenced to SIG GND.
SIG GND	Reference ground for the single-ended outputs of the tiltmeter. SIG GND and PWR GND are common in the tiltmeter and switch box.
ESD GND	This terminal is provided for grounding (earthing) of the shield of tiltmeter cable (see Section 5).
-12V	Connect –11 to –15 Volts DC to this terminal.
PWR GND	Connect the power ground (power common) to this terminal.
+12V	Connect +11 to +15 Volts DC to this terminal.

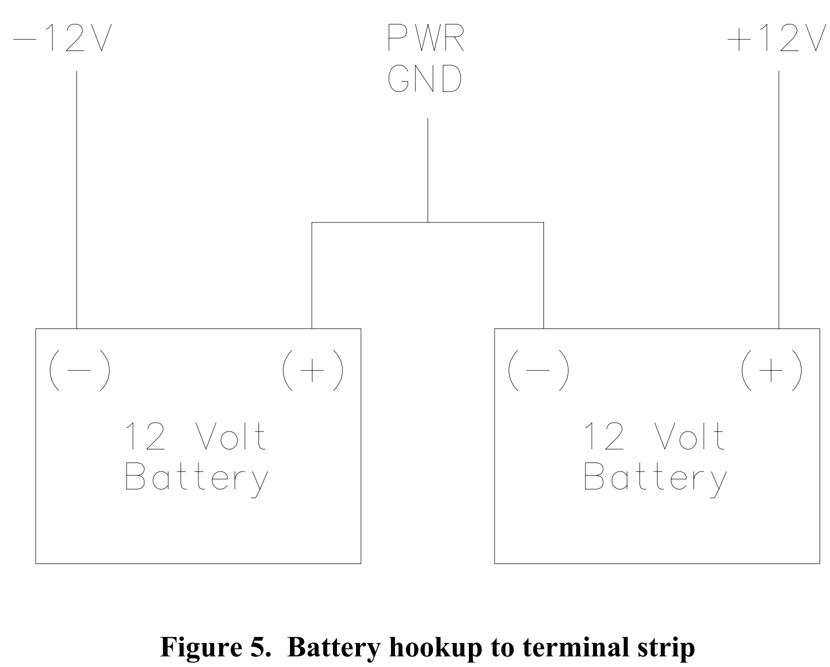
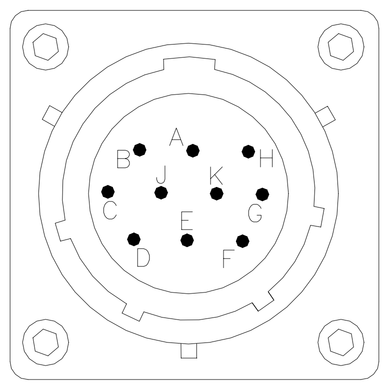


Figure 5. Battery hookup to terminal strip

2.3 Connector Pin Assignments

The 10-pin quarter-turn connector on the bottom of the switch box is used for connecting an Applied Geomechanics Model 771 Digital Readout Unit for installing, reveling or manually reading your tiltmeter. It may also be used as the primary power input and signal output connection during long-term monitoring, instead of the terminal strip. Pin assignments in this connector are shown in Table 1, which also shows the corresponding wire colors in the switch box. This connector (female receptacle) is Applied Geomechanics part no. 62301. The mating plug is part no. 62302. The plug is not included with your tiltmeter, but may be ordered separately.

Table 1. Connector Pin Assignments



P/N 62301 Female Receptacle

Pin #	Signal/Function	Wire color*
H	+12 V	red
A	PWR GND (power ground))	black
B	–12 V	purple
G	+Y	blue
K	–Y	brown
J	–X	gray
C	+X	green
F	ESD GND (tiltmeter cable shield)	drain wire (clear)
E	SIG GND (signal ground)	white
D	TEMP (temperature)	yellow

* Color of wires between connector and terminal strip. See Figure 8 for tiltmeter cable wire colors.

3 Initial Check-Out Procedure and Sign Convention

Upon receipt of your tiltmeter and before each installation, verify that it is functioning properly by following the steps below. These steps will familiarize you with its operation and should be performed by everyone who will use it. To perform this procedure you will need the following equipment:

- One (1) Model 771 Digital Readout Unit (DRU) *or* one (1) digital voltmeter and one (1) ±12-volt DC power source (transformer or two 12-Volt batteries).

CHECK OUT PROCEDURE:

1. Set the GAIN switch inside the switch box to LOW (Figure 2).

2. Set the FILTER switch inside the switch box to OFF.

3. Connect the DRU to the switch box at the 10-pin connector, or connect your power supply and voltmeter to the terminal strip inside the switch box (Figures 2 and 5).

4. Turn on the DRU or voltmeter.

5. Plant the bottom of the tiltmeter firmly on the ground and rotate the tiltmeter back and forth parallel to the handle on top of the tiltmeter. This is the "Y" tilt plane. Rock the instrument back and forth while you read the output on the DRU or voltmeter displays. Verify that the +Y and −Y polarities are as shown in Figure 6 and that the outputs swing to full scale (approx. ±8 volts for single-ended output) in both the positive and negative directions.

6. Move the GAIN switch to HIGH (Figure 2). The output should increase by about 10x. Because of the difficulty of keeping the tiltmeter stationary during this test, the displayed output may not change by exactly 10x. Nevertheless, it should clearly go up to a higher value.

7. Repeat step 5 with the GAIN switch in the HIGH position.

8. Repeat steps 5-7 for the X tilt direction (Figure 6).

9. With the tiltmeter upright and balanced on the ground , verify that the FILTER switch is operating by observing the instrument outputs with the switch first in the OFF position, then in the ON position. With the filter OFF, the output should respond immediately to the slightest movement. With the filter on, the response should be more gradual.

10. Finally, check the temperature by turning the MODE switch of the DRU to TEMP, or by touching the probes of your digital voltmeter to the TEMP and SIG GND positions on the terminal strip in the switch box (Figure 2). The voltage displayed should be the ambient temperature x 0.01. For example, if the temperature of the tiltmeter is 25°C, the output should read 0.250 Volt.

If your tiltmeter fails to pass any of these tests, first make sure that all connections are secure and that the terminal strip is receiving power. If these checks do not remedy the problem, first refer to Section 8.3, or contact Applied Geomechanics for assistance.

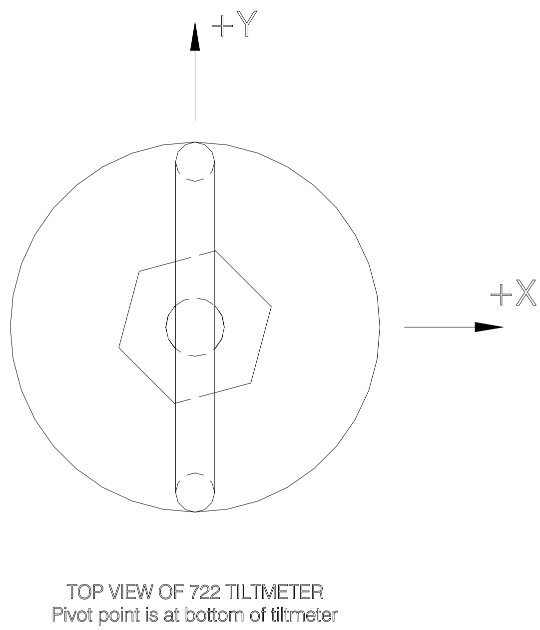


Figure 6. Tiltmeter sign convention

4 Installing Your Tiltmeter in a Borehole

4.1 General Considerations

The procedure below describes installation of a Model 722 tiltmeter in a shallow borehole - shallow enough that the tiltmeter can be lowered into the hole by hand at the end of a rope or pipe, then coupled to the walls of the hole using clean sand poured in from above. The maximum practical depth for installation in this manner is typically in the range of 8-10m.

Because your Model 722 tiltmeter is very sensitive, it can detect ground movements caused by cultural activity (traffic, emptying and filling of tanks, etc.) and environmental changes (temperature, barometric pressure, rainfall). These effects are attenuated as depth increases, but can have magnitudes of microradians to tens of microradians in the first 5m below the ground surface. For optimum performance, operate your tiltmeter in a constant-temperature environment as far as possible from the effects of cultural activity. Borehole installations should be at least 3 meters deep and preferably deeper. A borehole in an underground mine or deep tunnel is a very stable operating environment in the absence of traffic and other cultural effects.

4.2 Shallow Borehole Preparation

The ideal hole diameter is 20-30 cm (8-12 inches). This diameter allows room for manipulation of the tiltmeter after it has been lowered to the bottom of the hole. If the ground is dry and the hole will stay open, casing is not necessary. If caving is a problem, the hole should be cased. In soft ground a steel casing can be driven to the desired depth using a pile driving machine (Figure 7a). In hard ground the hole should be drilled with an auger or rotary drill. After drilling, a steel or plastic casing should be lowered into the hole. The bottom of the casing may be capped or open. If open, the bottom of the casing can be sealed with concrete after installation to impede water infiltration. The annular space between the casing and the hole boundary should then be filled with concrete, or with clean, firmly tamped sand (Figure 7b). Water remaining in the hole should be pumped out or blown out with compressed air before installation of the tiltmeter. For best results, the hole should remain dry during installation. The sand will compact and the installation will stabilize faster if the sand is dry. Water entry into the hole after installation is alright. Whether the hole is wet or dry, the best readings are obtained when there is a firm and stable coupling between the tiltmeter, the casing and the surrounding earth. If the hole is wet, the most stable readings are obtained when the moisture content of the sand or water head remains constant.

Figure 7 shows a larger casing diameter in the upper 1 meter of soil. This optional feature helps decouple the inner casing from deformation of the surface soil layer. The inner casing should extend above the bottom of the decoupled zone to keep water and debris from falling into the hole.

4.3 Installation Procedure

The following steps describe installing the tiltmeter into the finished hole using sand to couple it to the borehole or casing walls. This procedure uses the tools in Applied Geomechanics Model 729 Borehole Tiltmeter Installation Kit to lower the tiltmeter into the hole, orient its azimuth, level the tiltmeter and compact the sand in the hole. Additional installation instructions are found in the user's manual for the Model 729 kit. To perform this procedure you will need the following equipment:

- One (1) Model 729 Borehole Tiltmeter Installation Kit
- One (1) Model 771 Digital Readout Unit (DRU) *or* two (2) digital voltmeters and two (2) 12-Volt batteries
- Bright light or mirror to reflect light into the hole
- Tape measure

PROCEDURE:

1. Tamp the bottom of the hole to compact any loose dirt using the tamper from the Model 729 tool kit. Then fill the bottom of the hole with 10-20 cm of fine sand and tamp again.

2. Tie a brightly colored piece of cloth or tape to the +Y side of the tiltmeter handle (Figure 6). Lower the tiltmeter to the bottom of the hole using a rope or the installation hook from the Model 729 tool kit. ***CAUTION: Avoid lowering the tiltmeter into the borehole or pulling it out using the tiltmeter cable. Doing so can unnecessarily stress the internal electrical connections.***

3. With the tiltmeter still suspended from the rope or installation hook and in a vertical position, fill the hole until sand covers the *lower half* of the tiltmeter. The sand should support the tiltmeter so that it remains vertical and does not fall over when the rope or hook is removed.

4. Now rotate the tiltmeter about its vertical axis using the installation hook until the azimuth (+Y tilt direction) has the desired bearing. Record this direction, remove the hook from the tiltmeter and then from the hole. If you have used a rope instead of the hook, you will not be able to rotate the tiltmeter. In this case, measure the azimuth of the tiltmeter handle (+Y tilt direction) by looking down the hole and using a compass. Sunlight reflected from a mirror is a good way to see into the hole.

5. Next, connect the DRU to the connector on the switch box. Or, connect two 12-Volt batteries and two digital voltmeters to the terminal strip in the switch box. Turn the DRU's POWER switch ON. Turn the

tiltmeter GAIN switch to LOW and its FILTER switch to OFF (Figure 2). You are now ready to level the tiltmeter.

6. Level the tiltmeter by gently tamping the sand surrounding it using the tamper or goat's foot from the Model 729 tool kit. Read the tilt output on the DRU or voltmeters. Tamp the sand until the output on both channels is within ±1.0 Volt.

7. Add more sand until only the top *quarter* of the tiltmeter is uncovered by sand. Continue leveling as in step 6 until the output is within ±0.1 Volt on both channels.

8. Fill the hole with sand to the top of the tiltmeter, leaving the handle sticking out above the sand. This way the tiltmeter can be easily extracted from the hole at a later time.

9. Turn the GAIN switch in the switch box (Figure 2) to HIGH and continue tamping the sand until the output on both channels is a close to 0 volts as possible. When this is done, tiltmeter installation is complete. You may now turn the FILTER switch to ON if you wish to record filtered data.

10. When you have completed installaing the tiltmeter, cover the hole for safety.

WARNING:
ALWAYS COVER THE HOLE AFTER TILTMETER INSTALLATION. AN OPEN HOLE IS DANGEROUS!

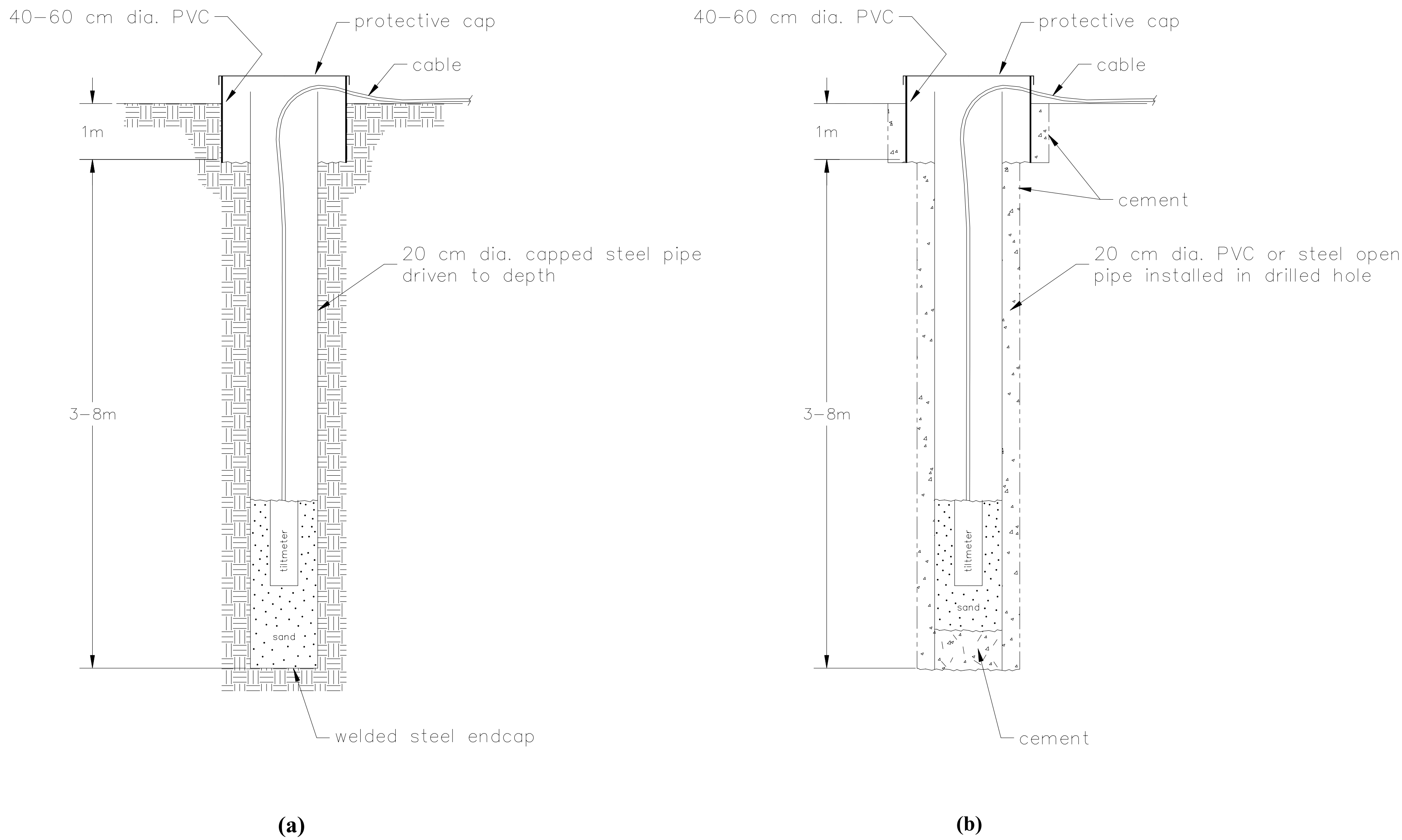


Figure 7. Recommended borehole preparation: a) driven casing, b) cemented casing

5 Grounding and Transient Protection

5.1 Power and Signal Grounds (PWR GND and SIG GND)

Your tiltmeter has a common power and signal ground wire in the tiltmeter cable. Signal and power grounds are common on the signal conditioning circuit in the tiltmeter (Figure 8). The common ground inside the switch box is the reference potential for the single-ended tilt signals (+X, −X,+Y and −Y) and for the temperature (TEMP) signal. If you will be recording single-ended signals, we recommend that you do *not* short PWR GND and SIG GND at your power supply or recorder location. Current to power the tiltmeter flows in the power ground wire. From Ohm's Law we know that the ground potential will be different at opposite ends of this wire because of wire resistance. By keeping signal ground separate from power ground, your recorded data will not reflect this potential difference. By running separate signal and power ground wires from the switch box to your recorder, single-ended tilt and temperature readings will be the same at your recorder as they are at the switch box.

5.2 Earthing (ESD GND)

Variable-resistance type surge absorbers (transient voltage suppressors) connect each of the wires in the tiltmeter cable, except the shield and drain wire, to the stainless steel tiltmeter case (Figure 8). When the tiltmeter is buried in damp ground, the surge absorbers short high-voltage transients to earth and thereby reduce the likelihood of an electronic failure. Under normal operating conditions the surge absorbers have extremely high impedance and have no effect on tiltmeter performance.

High-voltage transients are the most common cause of failure of field instruments in outdoor installations. In a typical occurrence, a transient from a lightning strike or power surge travels along the cable until it encounters the instrument's electronic circuitry, where the delicate low-voltage components are overloaded and fail. The surge absorbers in your tiltmeter begin to short the transient to the case and into the earth when the common mode potential difference exceeds 18 Volts. Commercially available surge suppression circuitry may be added at the switch box to provide additional protection for your tiltmeter. Contact Applied Geomechanics for details.

The shield of the tiltmeter cable is connected to the ESD GND terminal in the switch box (Figures 2 and 8). The shield is *not* connected to the stainless steel tiltmeter body. Earthing the shield may help suppress transients and reduce noise in your signals. The shield may be earthed by connecting the ESD GND terminal to a copper grounding rod with a 16 AWG or heavier copper wire. Alternatively, the tiltmeter cable shield may be connected to the shield of your power and signal cable at the ESD GND terminal, then earthed at your power supply location. The shield should be earthed at one location only to prevent ground loops.

Power ground (PWR GND) is sometimes connected to the cable shield, then earthed to help reduce noise in the power circuit. Earthing should be done at one location only, typically the power supply location, to prevent ground loops.

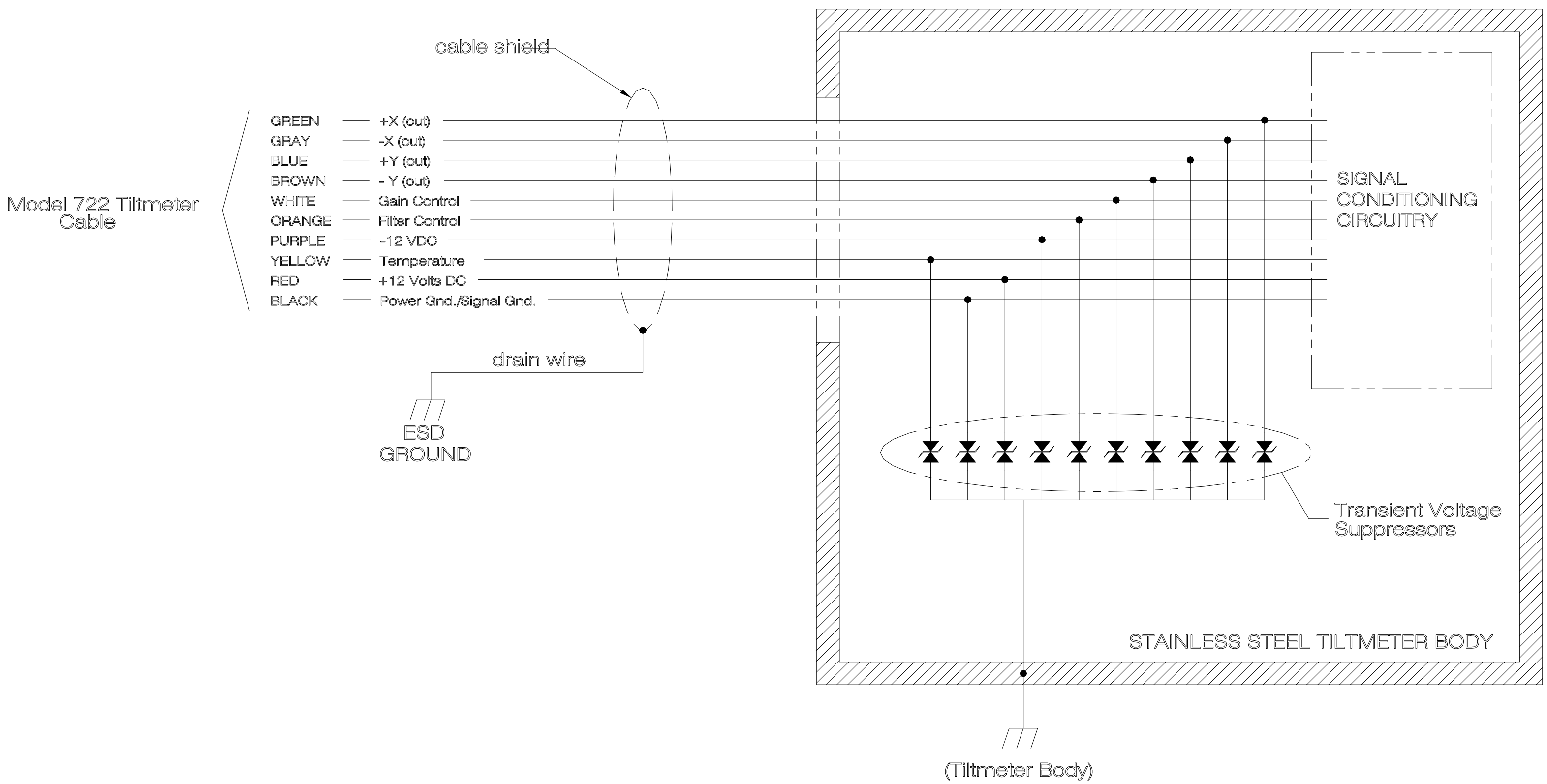


Figure 8. Transient protection and cable wiring

6 Recording Tiltmeter Data with External Recorders

The low-impedance voltage outputs of Model 722 Borehole Tiltmeters are readily measured by a variety of external devices, including digital voltmeters, oscilloscopes, strip-chart recorders, data loggers and personal computers with data acquisition boards. All connections are made at the terminal strip in or the 10-pin connector on the switch box (Figure 2, Table 1). Follow the instructions for connecting single-ended or differential signals to the input channels of your data acquisition equipment and you will be ready to record. The amplifiers in Model 722 have been used to drive cables as long as 1500m in previous projects.

7 Converting Output Readings to Tilt Angles and Temperatures

The tiltmeter output voltages are quickly converted to tilt angles as follows: multiply the voltage reading by the scale factor supplied in Appendix B. For example, if the scale factor is 0.1 microradian/mV (0.1 microradian/0.001 Volt) and the voltage reading is +0.152 Volt, then the tilt angle is +15.2 microradians from sensor null.

Similarly, temperature is obtained by multiplying the TEMP output voltage by the scale factor of the tiltmeter's temperature sensor, 0.1°C/mV where 0 mV = 0°C (Section 1.2). For example, if the voltage reading is +0.204 Volt (204 mV), the temperature is +20.4°C.

8 Maintenance and Troubleshooting

Basic maintenance and diagnostic procedures are discussed below. Apart from these procedures, your tiltmeter is not field-serviceable. Should you encounter problems not described here, please contact Applied Geomechanics in California for assistance. You may reach us at telephone (831) 462-2801, fax (831) 462-4418 or by email at *applied@geomechanics.com*. A service engineer will assist you in determining the cause of the problem and whether the tiltmeter can be repaired in the field or should be returned to the factory for servicing.

Caution: Do not try to open your tiltmeter without first receiving disassembly/assembly instructions from Applied Geomechanics.

WARNING!
IF THE TILTMETER IS OPENED, NEVER USE AN OHMMETER TO MEASURE THE TILT SENSORS INSIDE THE TILTMETER. APPLYING DC CURRENT THROUGH THE SENSORS WILL CAUSE PERMANENT DAMAGE THAT IS NOT COVERED BY THE WARRANTY

8.1 Routine Maintenance

If properly maintained, your Model 722 Borehole Tiltmeter will give you many years of trouble-free service. Routine maintenance should include regular cleaning of dust, dirt, water and oil from the tiltmeter (when not installed underground), tiltmeter cable, switch box and switch panel. Accumulation of dirt or water on electrical connections can cause corrosion, short circuits, noisy output and other electronic malfunctions. Whenever possible, keep the lid of the switch box closed.

The borehole tiltmeter body is fully sealed and will operate under water to a pressure of 5 bars (72 psi). Clean sand and dirt out of the mouth of the jam nut (Figure 1) when the tiltmeter is removed from a hole. Abrasion caused by the sand can thin the cable jacket. Avoid cuts or other damage to the cable jacket. A hole in the jacket will allow water to wick down the cable and into the tiltmeter, where it will damage the tiltmeter electronics.

Install the switch box in the vertical upright orientation shown in Figure 2. Rain cannot enter the switch box when it is in this position. The switch box is not sealed and must never be submerged. Do not spray the switch box with water from below, as it may leak if this occurs. *WATER DAMAGE INSIDE THE SWITCH BOX VOIDS THE WARRANTY!*

Keep your tiltmeter away from extremes of heat and cold. Extreme temperatures shorten the life of the seals and unnecessarily stress the electronic components. Avoid prolonged exposure of the tiltmeter to direct sunlight on hot days. The stainless steel body is an excellent heat conductor and has a high heat storage capacity. When left in direct sunlight, internal temperatures can rise high enough to damage internal components.

If you disassemble the tiltmeter for any reason, make sure that the O-rings and the rubber grommet in the cable head are clean, undamaged and are properly seated during reassembly (Figure 1). A cracked, cut or broken O-ring can result in leakage of water into the tiltmeter. A light coating of silicon grease or O-ring lubricant before reassembly will prolong the life of the O-rings and grommet and is recommended.

The tiltmeter cable has an internal steel strength member that is tied to strain reliefs inside the tiltmeter body and inside the switch box. *We nevertheless recommend that you avoid raising or lowering the tiltmeter using the cable, as slippage of the outer jacket and conductors can stress and damage the electrical connections*. Instead raise and lower the tiltmeter using a rope or the hook in the Model 729 Borehole Tiltmeter Installation Kit. For the same reason, *do not pull on the cable where it enters the switch box.*

8.3 Problems You Might Encounter

8.3.1 No Output

Failure to obtain an output signal from the tiltmeter normally is the result of lack of power or a broken wire or connection. If you are getting no output from the +X, +Y, −X, −Y or TEMP channels, first check that ±12 Volt DC power is being supplied to the terminal strip or 10-pin connector on the switch box (Figure 2), then check that the connector and/or wires are securely attached.

If you have verified that power is being supplied to the switch box and all connections are good, there may be a broken wire or bad connection inside the switch box, in tiltmeter cable or in the tiltmeter itself. Wiring inside the switch box can be checked by carefully lifting the switch plate out of the box after first removing the four hold-down screws in the corners (Figure 2). Use an ohmmeter to check continuity in the switch box. See Table 1 and Figure 8 for wire color coding. If your checks establish that the internal switch box wiring is good, check for cuts in the tiltmeter cable that may have severed a wire. If these checks reveal no wiring problems, contact Applied Geomechanics for assistance.

8.3.2 Output Is Fixed at Limits of Range

In this condition the output stays at the limits of its voltage range (about +8 Volts or −8 Volts for single-ended output). The cause is typically not an electrical problem, but simply the fact that one or both tilt sensors is tilted out of range. This is especially likely to occur in HIGH GAIN. If the tiltmeter is already installed in a borehole, switch to LOW GAIN and measure the output again to see if it has dropped to within ±8 Volts. If it has, there is no electronic problem. The tiltmeter is simply tilted beyond the HIGH GAIN angular range. You must relevel the tiltmeter in the hole to bring it within range in the HIGH GAIN setting.

If the tiltmeter is *not* already installed in a borehole, follow the initial check-out procedure in Section 3 to verify whether its output will swing to the +8 and −8 Volt limits on both the X and Y channels when you move it. If it does, there is not a problem. However, if the output remains fixed at the limit during this test, there could be a short circuit to +12V or −12V power somewhere in the wiring, or a broken power or ground connection. Inspect the wiring and connections as described in Section 8.3.1. If the wiring is found to be in order, the cause may be a bad connection or bad component inside the tiltmeter. The tiltmeter must be repaired at the factory to correct such a problem. Contact Applied Geomechanics for assistance if the problem has been traced to the circuitry inside the tiltmeter.

8.3.3 Noisy Output

This condition is characterized by output oscillations with amplitudes of a few microradians (tens of millivolts in HIGH GAIN for Model 722-A). The oscillations can have periods of less than a second to about ten seconds. Noise of this type is commonly low-amplitude ground vibration or natural microseismicity, i.e., seismic surface waves passing through the shallow tiltmeter installation. The amplitude of this noise will be about 10x greater in HIGH GAIN than in LOW GAIN. Turning the FILTER switch to the ON position (Figure 2) should remove most of the microseismic noise in the tiltmeter output.

Low-frequency ground movements can also be caused by cultural and environmental activity near the tiltmeter. Examples of such activity are wind blowing through trees, traffic on nearby trails or highways, animals grazing nearby and burrowing animals. The tiltmeter installation should be sited to minimize these effects.

Another source of noisy output is bad grounding. Verify that all ground connections are in place to eliminate this possibility. Earthing the shield of your cable and/or power ground may reduce noise caused by nearby 50-60 Hz and radio frequency noise sources. *These wires should be earthed in one location only*. Earthing in more than one location produces ground loops, in which the earth completes a circuit of current flow through your ground wires. Ground loops always result in undesirable noise and unpredictable results.

Finally, noisy output can be caused by damp connections. Check the terminal strip and/or connector to make sure it is dry.

If these checks don't identify the source of the noise, contact Applied Geomechanics for assistance.

8.3.4 Daily and Seasonal Output Fluctuations

These gradual fluctuations mainly result from natural ground movements caused by weather and climate changes, e.g., temperature fluctuations; wetting, drying and freezing of the ground; and changes of barometric pressure. They rarely indicate a problem with your tiltmeter. However, they can mask the small deformations that you are trying to measure. For this reason, we include this discussion of their origins and methods for minimizing them in your measurements.

Temperature changes affect the tiltmeter in two ways: 1) They produce thermoelastic deformation of the ground, which is measured by the tiltmeter; and 2) thermal expansion and contraction of the liquid in the tilt sensors cause small output changes unrelated to actual ground movement. The latter effect is described by the tiltmeter's temperature coefficients (Section 1.2). The most obvious way to eliminate these effects is to install your tiltmeter deeply enough to remove all temperature fluctuations. Temperature changes and attendant thermoelastic deformations caused by heating and cooling of the ground surface diminish rapidly with increasing depth. Daily temperature fluctuations in the ground are almost zero at a depth of 1 meter.

Annual fluctuations are 90-95 percent attenuated at a depth of 20m. Installations deeper than 20m should show little effect from temperature.

The temperature sensor is installed in the bottom of the tiltmeter beside the tilt sensors. You can remove the effect of temperature change on the tilt sensors by applying the temperature coefficients of your instrument, as described in Applied Geomechanics technical note B-95-1005 (available on request). This correction is performed automatically by Applied Geomechanics *TBASE II Database and Analysis Software*. The output fluctuations remaining after correction for the tiltmeter's temperature coefficients are the actual ground movements measured by the tiltmeter.

Barometric pressure changes produce ground deformation by changing the atmospheric pressure on the earth's surface. These changes are not predictable, but can be recognized by comparing barometric pressure readings to your tilt measurements.

Wetting, drying and freezing of the ground cause ground expansion and contraction. These deformations are unpredictable but may be recognized by comparing your tilt data to rainfall and surface temperature records. These effects diminish with increasing tiltmeter depth.

A Warranty and Assistance

Standard goods (those listed in Applied Geomechanics' published sales literature, excluding software) manufactured by Applied Geomechanics Inc. (AGI) are warranted against defects in materials and workmanship for twelve (12) months from the date of shipment from AGI's premises with the following exceptions: Series 900 analog and digital clinometers are warranted against defects in materials and workmanship for 90 days from the delivery date. AGI will repair or replace (at its option) goods that prove to be defective during the warranty period provided that they are returned prepaid to AGI and:

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b) that notice is received by AGI within 30 days of the defects becoming apparent, and
c) that return authorization is received from AGI prior to the goods being sent back.

Should goods be damaged in transit to the Purchaser, AGI will accept no liability unless the Purchaser can show that such damage arose solely from AGI's failure to pack the goods properly for shipment.

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B Calibration Data for Your Tiltmeter

This section presents calibration data and scale factors measured for your tiltmeter on NIST-traceable calibration equipment at the Applied Geomechanics factory. Calibrations are performed by rotating the tiltmeter in each of its principal planes (X and Y) over a range of at least 11 known angles and measuring its output. Each scale factor reported is the slope of a linear regression line over the full calibration range. Nonlinearity is the maximum deviation of any point from the regression line, expressed as percentage of full span (±1000 microradians angular range = 2000 microradians span, etc.). The heading of the scale factor table indicates whether the scale factor is for single-ended or differential output. Single-ended scale factor = 2 x differential scale factor.

Single-Ended Scale Factors					
Model 722 Borehole Tiltmeter				**Serial No.**	
Channel (X or Y)	Gain (LOW or HIGH)	Calibration Range (units are circled) μradians arc seconds arc minutes degrees	Calibration Temp. (^{o}C)	Scale Factor (units are circled) μradians/mV arc seconds/mV arc minutes/Volt degrees/Volt	Nonlinearity (% of FS)

Differential Scale Factors					
Model 722 Borehole Tiltmeter				**Serial No.**	
Channel (X or Y)	Gain (LOW or HIGH)	Calibration Range (units are circled) μradians arc seconds arc minutes degrees	Calibration Temp. (°C)	Scale Factor (units are circled) μradians/mV arc seconds/mV arc minutes/Volt degrees/Volt	Nonlinearity (% of FS)

C Angle Conversion Chart

Angle Conversion Chart						
	degrees	**arc minutes**	**arc seconds**	**μradians**	**mm/meter**	**inches/ft**
1 degree =	1	60	3600	17453	17.5	0.209
1 arc minute =	0.0167	1	60	291	0.291	$3.46E^{-3}$
1 arc second =	$2.78E^{-4}$	0.017	1	4.85	$4.85E^{-3}$	$5.82E^{-5}$
1 μradian =	$5.73E^{-3}$	$3.44E^{-3}$	0.206	1	0.001	$1.20E^{-5}$
1 mm/meter =	0.057	3.436	206.2	1000	1	0.012
1 inch/ft =	4.785	286.5	17182	83333	83.33	1