

Model 5400 Series

Gigahertz Transverse Electromagnetic (GTEM![™]) Cell

Operation Manual



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NOTES, CAUTIONS AND WARNINGS

	<p>Note: Denotes helpful information intended to provide tips for better use of the product.</p>
<div style="border: 2px solid black; padding: 5px; text-align: center;">CAUTION</div>	<p>Caution: Denotes a hazard. Failure to follow instructions could result in minor personal injury and/or property damage. Included text gives proper procedures.</p>
<div style="border: 2px solid black; padding: 5px; text-align: center;">WARNING</div>	<p>Warning: Denotes a hazard. Failure to follow instructions could result in SEVERE personal injury and/or property damage. Included text gives proper procedures.</p>





SAFETY INFORMATION

	<p>Refer to Manual: When product is marked with this symbol, see the instruction manual for additional information. If the instruction manual has been misplaced, download it from www.ets-lindgren.com, or contact ETS-Lindgren Customer Service.</p>
	<p>High Voltage: Indicates presence of hazardous voltage. Unsafe practice could result in severe personal injury or death.</p>
	<p>High Voltage: Indicates presence of hazardous voltage. Unsafe practice could result in severe personal injury or death.</p>
	<p>Protective Earth Ground (Safety Ground): Indicates protective earth terminal. You should provide uninterruptible safety earth ground from the main power source to the product input wiring terminals, power cord, or supplied power cord set.</p>



See the ETS-Lindgren **Product Information Bulletin** for safety, regulatory, and other product marking information.

GENERAL SAFETY CONSIDERATIONS

	<p>Before power is applied to this instrument, ground it properly through the protective conductor of the AC power cable to a power source provided with the protective earth contact. Any interruption of the protective (grounding) conductor, inside or outside the instrument, or disconnection of the protective earth terminal could result in personal injury.</p>
 	<p>Before servicing: contact ETS-Lindgren – servicing (or modifying) the unit by yourself may void your warranty. If you attempt to service the unit by yourself, disconnect all electrical power before starting. There are voltages at many points in the instrument which could, if contacted, cause personal injury. Only trained service personnel should perform adjustments and/or service procedures upon this instrument. Capacitors inside this instrument may still be CHARGED even when instrument is disconnected from its power source.</p>
	<p>Only qualified personnel should operate (or service) this equipment.</p>

1.0 Introduction

The **ETS-Lindgren Gigahertz Transverse Electromagnetic (GTEM!™) Cell** is a precision electromagnetic compatibility (EMC) test instrument primarily intended for use as an EMC radiated immunity and radiated emissions test facility. It is intended for installation in a corporate, laboratory, or industrial environment, where its unique characteristics allow for the performance of fast and efficient EMC radiated tests at a convenient location, without interference from the ambient electromagnetic environment.

The GTEM! is a pyramidal tapered, dual terminated section of 50-ohm transmission line. The cell is flared to create a test volume within which the Equipment Under Test (EUT) is placed. At the input, a normal 50-ohm coaxial line is physically transformed to a rectangular cross section with an aspect ratio of 3:2 horizontal to vertical. The center conductor, known as the septum, is a flat, wide conductor which, when driven by a signal generator, produces a reasonably sized region of a nominally uniform electric field distribution beneath it. This region of nominally uniform field is the test volume for radiated immunity (susceptibility) testing. By the theory of reciprocity, radiated emissions testing is also conducted in the test volume. To increase the usable test volume, the septum is located well above the horizontal centerline of the cross section, while maintaining constant characteristic impedance and uniform field distribution. The septum is terminated in a resistive array having a total value of 50 ohms for matching the impedance of the source. Test volume fields, either applied to an immunity test item or produced by the EUT during emissions testing, are terminated in RF absorber. The shape of the test volume is a tapered wedge. The fields generated by application of an RF voltage to the input of the GTEM! propagate with a spherical wave front from the apex of the GTEM! to the termination.

Standard Configuration



DO NOT remove polystyrene blocks from inside the GTEM!. Polystyrene blocks provide dielectric structural support.

Blank Feed-Through Panel

A blank, 304-mm square, removable panel can be installed in the GTEM! wall to accommodate additional cable entries. Separate blank removable panels are available and are interchangeable.

Internal EUT Positioner

A multi position EUT positioner is available for the GTEM! to assist in locating the EUT for radiated emissions testing.



The term *positioner* can be used interchangeably with the term *manipulator*.

Custom Signal Filters

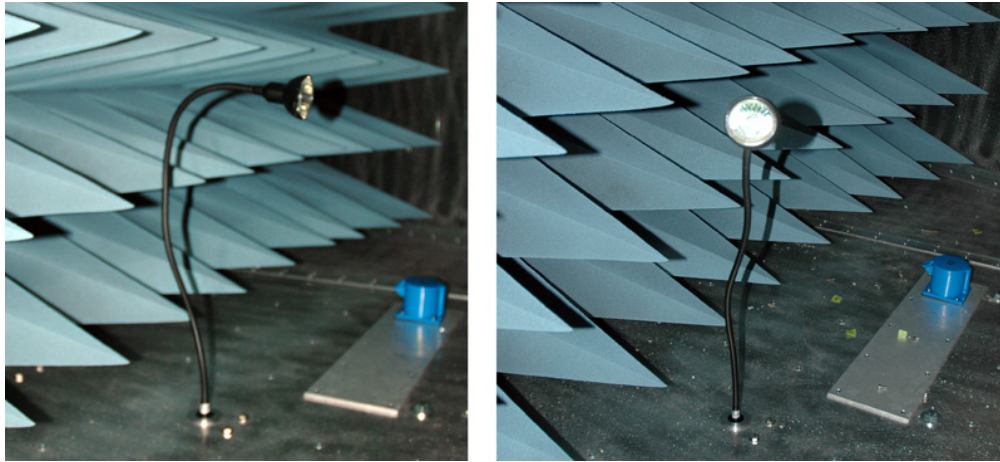
To meet unique signal input and output requirements, a custom designed filter is available mounted to penetration panels.

Custom Power Filters

For additional EUT power input requirements, a number of single and three phase input power filters are available to provide almost any input power requirement to EUT in a GTEM!. These power inputs are independently switched; they are not controlled through the main power switch on the power distribution panels.

Custom Internal Illumination

A low voltage light source is available for installation in the Model 5405, Model 5407, and Model 5411. A power filter is also supplied as part of the light assembly.



Optional Items

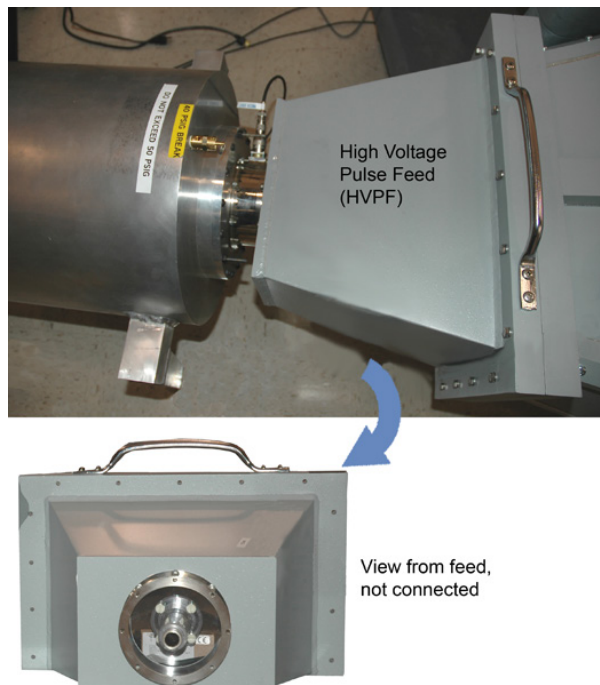
Every application for a GTEM! in EMC testing will be unique or may have unique requirements. If a modification to the GTEM! will accelerate test performance, contact ETS-Lindgren. Most of the standard items described in the previous section are field installable and can be retrofitted after delivery.

High Voltage Pulse Feed

The GTEM! is typically used for CW emission and immunity tests. It can also be used for high voltage pulse radiated immunity measurements. The High Voltage Pulse Feed (HVPF) is a replacement feed section supplied for use with Model 5411. The HVPF is available as a bolt on (standard) or clamp on section. In both cases, the septum is fitted with an edge connector, which makes removal of the complete CW section possible without disassembly.



High voltage pulse generator supplied by others.



The standard 7/16 to N adapter fitted to the front of the CW section is designed for CW RF use and can be used for RF voltages up to 800 volts. The dielectric withstand voltage for the connector is 2.3K volts. The voltage at the connector of this feed section should not exceed 2.3K volts since it will be impossible to predict when breakdown will begin to occur. The potential for breakdown increases as a function of the humidity level, pulse width, and voltage magnitude. While it is possible to use the CW section for very short duration pulses greater than 2.3K volts, it is recommended that for pulse measurements where the peak voltage of the pulse is expected to exceed 3K volts regularly, the HVPF should be used.



The GTEM! is equipped with a door interlock switch. The door interlock switch must be integrated into the control system to ensure personnel safety when GTEM! door is opened. RF power must be removed prior to opening the GTEM door to avoid exposure to hazardous RF fields.

Basic Theory of RF Operation

The GTEM! is essentially a section of asymmetric rectangular transmission line with a unique flared geometry and a hybrid termination. There is a 50-ohm resistor termination for currents flowing on the septum, and an RF foam absorber termination for electromagnetic fields generated in the GTEM! that propagate towards the back wall. An RF signal applied to the center conductor will result in the generation of a predominantly vertical \vec{E} field above and below the septum with radiating components toward the outer conductor, as is the case in a coaxial transmission line.

Ideally, the center one third of the volume below the septum, both vertically and horizontally, is of sufficient uniform distribution to allow the use of the GTEM! for immunity testing. In actuality, a test volume producing accurate results for radiated emissions testing may be as large as two thirds of the vertical and horizontal dimensions (depending on the type of equipment under test). Under ideal circumstances, the magnitude of the field changes gradually from a maximum at the septum, to zero at the outer cell wall (conductor). The uniform area, therefore, lies in the region where this transition in field is within the limits of the specified measurement uncertainty.

The frequency of the transverse electromagnetic mode (TEM) mode supported in the cell is a function of the distance between the center conductor (septum) and the outer conductor. Above frequencies where this distance is greater than a wavelength, higher order modes may also be supported.

The presence of the Equipment Under Test (EUT) may also affect the performance of the GTEM! since to the advancing wave, it would appear as a change in the impedance of the incident field.

The GTEM! provides a matched termination to input signals; there are no severe VSWR problems as usually experienced with low frequency biconical class antennas. It is relatively easy to produce low frequency intense electromagnetic fields with the GTEM!. The capability of a GTEM! to operate without size or scaling problems well into the GHz frequency range allows the testing of items without the need for the antenna changes associated with other test sites.

ETS-Lindgren Product Information Bulletin

See the ETS-Lindgren *Product Information Bulletin* included with your shipment for the following:

- Warranty information
- Safety, regulatory, and other product marking information
- Steps to receive your shipment
- Steps to return a component for service
- ETS-Lindgren calibration service
- ETS-Lindgren contact information

2.0 Maintenance



Before performing any maintenance, follow the safety information in the ETS-Lindgren Product Information Bulletin included with your shipment.



Maintenance is limited to the components as described in this manual. If you have any questions concerning maintenance, contact ETS-Lindgren Customer Service.

Periodic maintenance will ensure the continued performance of the Gigahertz Transverse Electromagnetic (GTEM!™) Cell. Several areas must be considered, as described in the following sections.

Performance Monitoring

On site VSWR measurements are normally performed at the conclusion of installation procedures for the GTEM!. They are also performed at the factory for all factory assembled GTEM! cells. If the GTEM! is to be installed by an ETS-Lindgren representative, then the on site VSWR measurement is the responsibility of the representative. Determination of continued performance to specified parameters may be ensured by periodic re measurement of the VSWR. This could detect changes in performance parameters that would signal unacceptable performance. The VSWR measurement should be performed on a schedule as recommended by the customer's Quality Engineering. The default time period between such evaluations (this is not a calibration) is six months.

Finger Stock Gasket

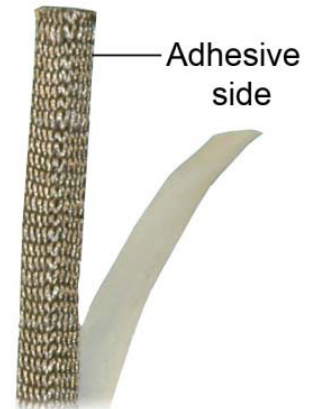
A large amount of finger stock is used in the construction of the GTEM!. Some of this finger stock is accessible in the normal course of GTEM! operation. Periodic visual inspections must be made to determine if there is need to clean the finger stock, or to replace it if damaged. Replacement finger stock for the doors is available from the factory; replacement finger stock for the connector panels and the load board access panels is also available.

Finger stock gasket (2 rows)



Part #890471

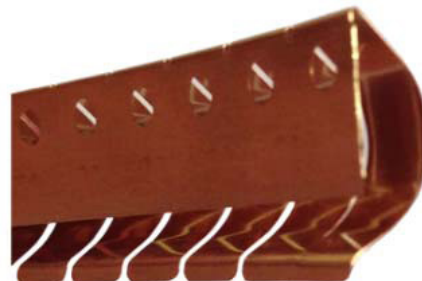
Foam gasket



Part #890645



Side View



Back View

Cleaning Finger Stock

To clean finger stock, use an aerosol lubricant to loosen the debris, and then low pressure air or another aerosol to remove the excess lubricant. Alternatively, a soft rag may be used to remove dirt and excess liquid from the finger stock.

Installing New Finger Stock Gasket

CAUTION

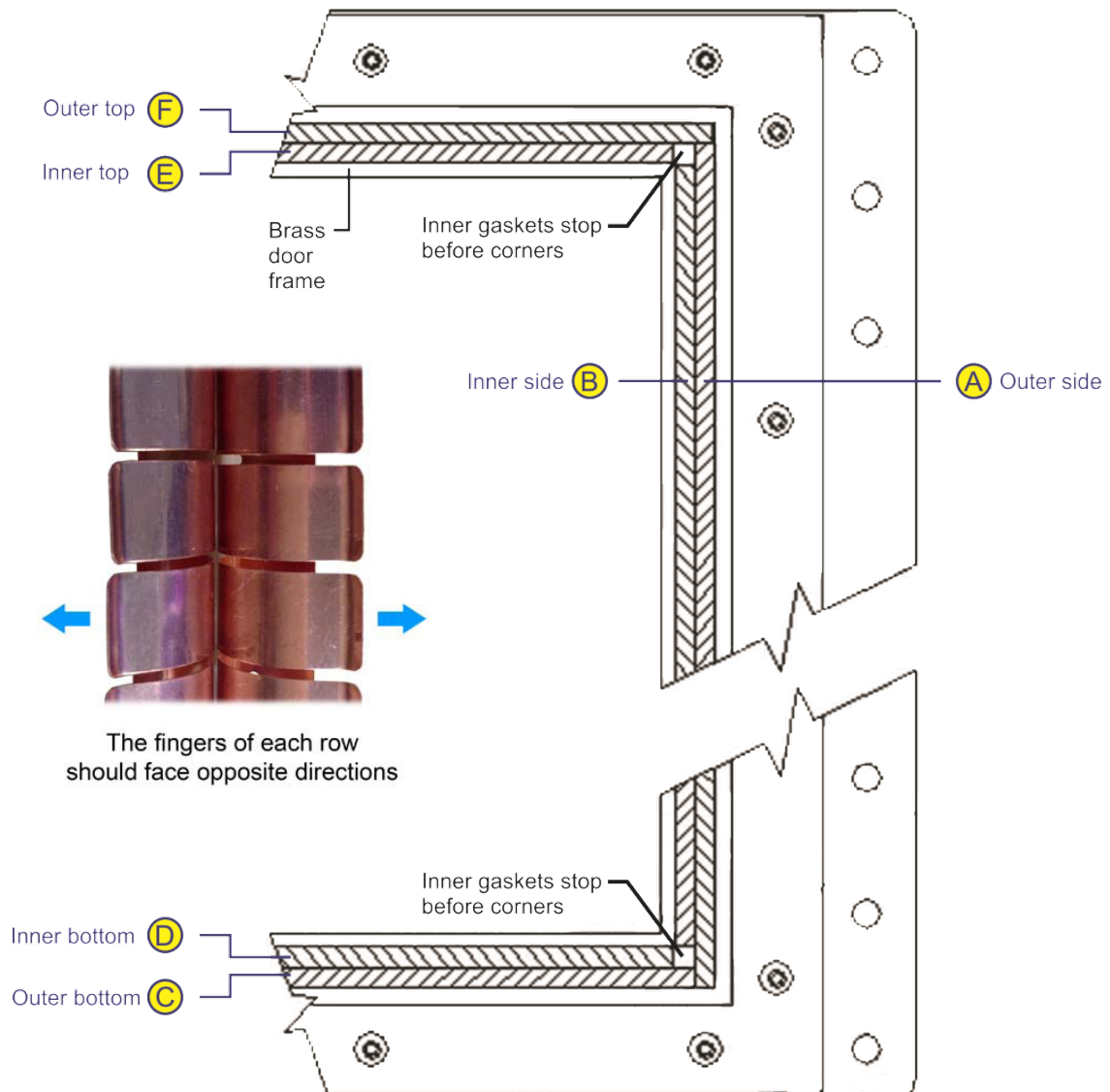
To create lengths of finger stock gasket you may gently bend the gasket with your fingers until it breaks. Breaking it creates sharp edges; carefully handle and trim sharp edges.



Before replacing finger stock gasket, remove the old finger stock gasket (see page 17) and then replace the foam gasket, if required (see page 17).

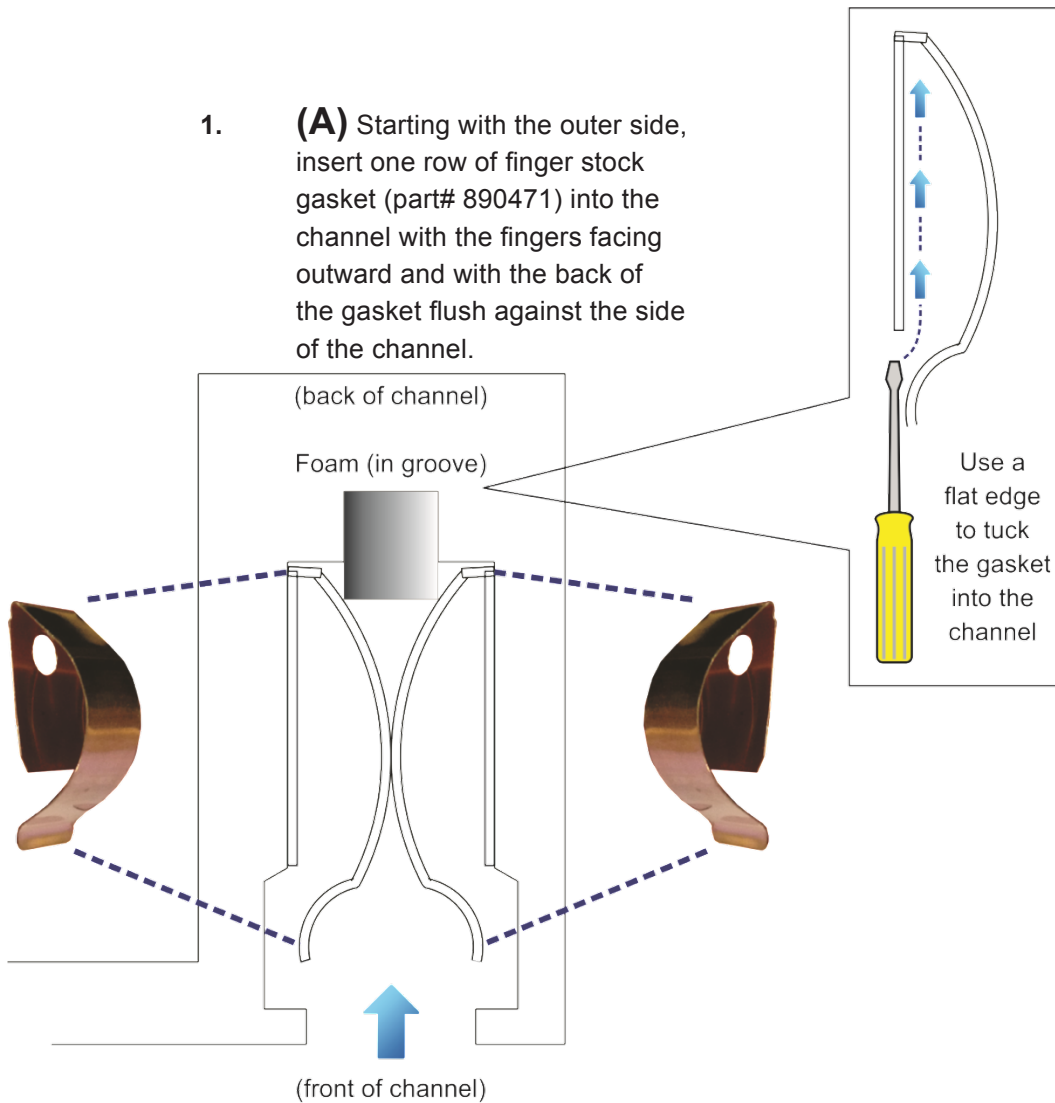


Follow the steps to install the gasket in the order shown, from **(A)** to **(F)**.





Make sure to install the finger stock gasket properly at the corners, as shown. See *Tips* on page 17 for additional information.



Insert finger stock into channel with fingers facing outward

2. **(B)** Insert the second row of finger stock gasket into the inner side. You may use the flat edge of a screwdriver or another type of flat edge to tuck the gasket
3. **(C)(D)(E)(F)** Repeat steps 1 and 2 for the bottom and top until two rows of new gasket is installed around the entire perimeter of the channel into the channel.
4. Verify that both gaskets are seated completely into the sides of the channel. Use a thin lubricant such as WD 40® or LPS 2® on the gaskets. After spraying the lubricant onto the gasket wipe off excess from the brass frame and door paint. Clean and lubricate the knife edge of the door where it meets the channel. Apply lubricant once a month or more often, as necessary

Removing Old Finger Stock

1. From one end of a row of finger stock gasket, grab a finger with needle nose pliers and gently pull it out and through the opening. Hold the end out.
2. While holding the end out, use a screwdriver to pry the next few fingers away from the channel. Continue to hold the end out.
3. Slide a wide, thin blade behind and down the entire strip to move all the fingers out, and then pull to completely remove the row of gasket.
4. Repeat steps 1–3 to remove all rows of finger stock gasket.

Removing and Replacing Foam Gasket (If Required)

After removing all old finger stock gasket, inspect the foam gasket to make sure it is recessed in the groove located at the back of the channel. If it is not recessed, replace it with new foam gasket (part# 890645). The new foam gasket is 5 mm (0.2 in) square; the old foam gasket was 6.3 mm (0.25 in) square.

- **To remove the foam gasket**—Grab one end with needle-nose pliers and gently pull the gasket out from the groove. There is adhesive on the side of the gasket facing the groove.
- **To install new foam gasket**—Place the gasket into the groove with the adhesive side facing the groove. Do not twist the gasket and do not place the gasket to the side of the groove where it will interfere with the finger stock gasket.

Tips

Correct assembly at corners	The top outer row must extend to both corners. The outer side rows should extend from the bottom corners to meet and support the outer top rows. The outer bottom row should extend to meet the outer side rows in the bottom corner.
Alignment of gasket fingers	The doors should be centered within 0.75 mm (0.03 in). The ideal dimension between the male frame and female frame is 26.9 mm (1.06 in). It should not vary more than 1.5 mm (0.06 in) around the door.
Shifting of finger stock gasket	The inner top and bottom rows may shift over time, breaking at the corners. The inner side row and bottom and top inner rows should never extend past any corner.
Proper seating of foam gasket	The finger stock gasket must be seated completely into the channel or it will break when closing the door. If the foam gasket is poorly assembled and improperly seated, it can interfere with the seating of the finger stock gasket. Replace foam gasket if not seated properly.

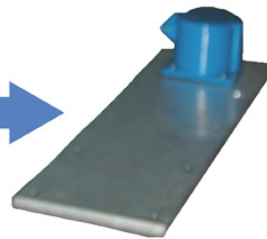
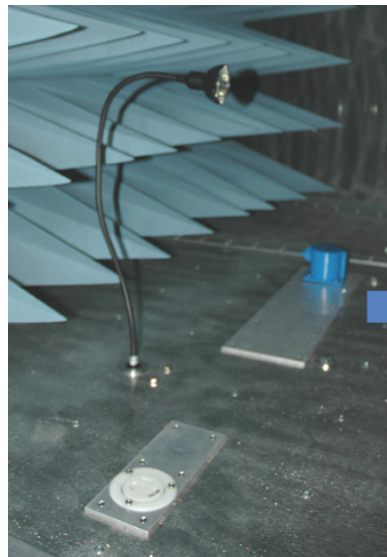
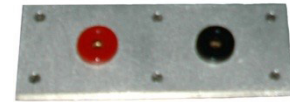
Air Vents

The air vents on the Model 5400 Series must be checked to make sure that free airflow exists to ensure optimum cooling. A small soft brush or low pressure air may be used to clean the honeycomb.

Floor Connector Panels

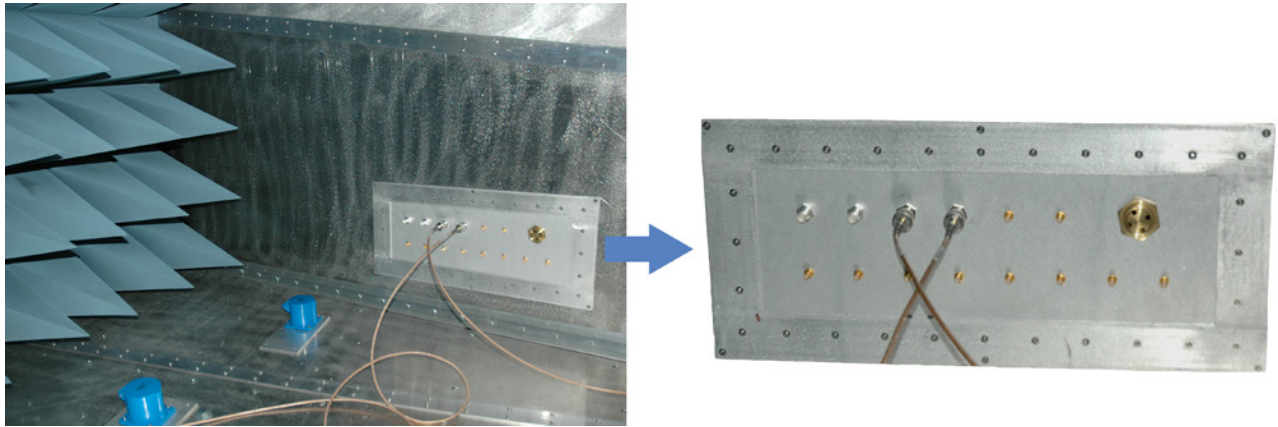
The connector feed through panels in the floor of the GTEM! will attract small particles of dirt or other debris. Inspection of their continuity on a periodic basis is necessary to ensure continued shielding. To inspect for an accumulation of dirt, the panels should be removed and the opening and the flange should be inspected and any accumulated dirt or debris removed. The finger stock must be inspected at this time, and cleaned or replaced if required.

See page 15 for information on replacing and cleaning finger stock gasket.



Connectors

The RF and other connectors are mounted in floor and side wall positions. Periodic examination of these connectors for damage will prevent use of a connector with damaged pins or other connections, assuring proper operation of the connectors. Protect these connectors when they are not in use.



Absorber Tips

While RF absorber is typically resilient to normal wear, it is possible for absorber tips to become damaged. They may be easily replaced with almost any contact cement or with rapid curing epoxy cement. If the tips are too damaged to reuse, they may be replaced by cutting off the entire tip at a point where the absorber body is about 10 cm by 10 cm, and then replacing the entire tip. Extra absorbers are available from the factory.

Absorber tip protectors are installed on some GTEM! cells where personal access inside is expected. These tip protectors are cut from block expanded polystyrene. They will protect the tips from casual contact. Extra or replacement tip protectors are available from the factory.

Shielded Viewing Windows (Optional)

The shielded viewing windows are fabricated from an acrylic plastic material or toughened glass. Cleaning may be performed with a plastic cleaner or standard window cleaner. In both cases, make sure to limit run off onto the GTEM!.



GTEM! Cleaning

Overall cleaning of the GTEM! inner and outer surfaces may be performed by the use of standard non abrasive cleaners. Periodic cleaning of the interior with a vacuum cleaner will reduce the possibility of debris build up in the connector panel area.

Load Boards

Load boards should not require maintenance, other than periodic inspection and cleaning of contact surfaces to prevent the occurrence of any film or corrosion. Any foreign substance that is found on the boards or connector surfaces should be removed.

3.0 Specifications

Physical Specifications

	Model 5402	Model 5405	Model 5407	Model 5411
Outer Cell Dimension (LxWxH):	L: 1.4 m (4.7 ft) W: 0.75 m (2.5 ft) H: 0.5 m (1.7 ft)	With base: L: 3.0 m (9.8 ft.) W: 1.6 m (5.2 ft) H: 1.7 m (5.6 ft) Without base: L: 3.0 m (9.8 ft.) W: 1.6 m (5.2 ft) H: 1.1 m (3.7 ft)	With base: L: 4.0 m (13.1 ft) W: 2.2 m (7.1 ft) H: 2.1 m (6.8 ft) Without base: L: 4.0 m (13.1 ft) W: 2.2 m (7.1 ft) H: 1.4 m (4.6 ft)	With base: L: 5.4 m (17.7 ft) W: 2.8 m (9.2 ft) H: 2.3 (7.5 ft)
Approx Cell Weight:	40 kg (88 lb)	250 kg (550 lb)	500 kg (1100 lb)	900 kg (2000 lb)
Door Dimension (WxH):	W: 160 mm (6.3 in) H: 230 mm (3.9 in)	W: 460 mm (18.1 in) H: 385 mm (15.2 in)	W: 686 mm (27.0 in) H: 747 mm (29.4 in)	W: 686 mm (27.0 in) H: 925 mm (36.4 in)
Max Septum Height:	250 mm (9.8 in)	500 mm (19.7 in)	750 mm (29.5 in)	1100 mm (43.3 in)
Highest Accuracy Transverse Test Surface in Center of Cell (WxH):	W: 76.2 mm (3 in) H: 76.2 mm (3 in)	W: 300 mm (11.1 in) H: 300 mm (11.1 in)	W: 400 mm (15.8 in) H: 400 mm (15.8 in)	W: 550 mm (21.5 in) H: 366 mm (14.3 in)
Distributed Load Rating:	N/A	250 kg (550 lb)	430 kg (950 lb)	750 kg (1650 lb)

Electrical Specifications



Characteristic frequency: Resistor absorber crossover frequency.

	Model 5402	Model 5405	Model 5407	Model 5411
Frequency Range:	RE TESTS ¹ 9 kHz–5 GHz RI TESTS DC – 20 GHz	RE TESTS ¹ 9 kHz–5 GHz RI TESTS ² DC – 20 GHz	RE TESTS ¹ 9 kHz–5 GHz RI TESTS ² DC – 20 GHz	RE TESTS ¹ 9 kHz–5 GHz RI TESTS ² DC – 20 GHz
VSWR (Typical):	Characteristic frequency: ≤1.75:1 All other frequencies: ≤1.50:1	Characteristic frequency: ≤1.75:1 All other frequencies: ≤1.50:1	Characteristic frequency: ≤1.75:1 All other frequencies: ≤1.50:1	Characteristic frequency: ≤1.75:1 All other frequencies: ≤1.50:1
Maximum CW Input Power:	100 W	250 W 400 W with optional blower	200 W 500 W with optional blower	1000 W
Input Impedance:	50 Ω	50 Ω	50 Ω	50 Ω
Feed Connector Type:	CW 7/16 DIN plug to N jack adapter	CW 7/16 DIN plug to N jack adapter	CW 7/16 DIN plug to N jack adapter	CW 7/16 DIN plug to N jack adapter
Shielding Effectiveness:	From internal E fields: 80 dB minimum 10 kHz–1 GHz	From internal E fields: 80 dB minimum 10 kHz–1 GHz	From internal E fields: 80 dB minimum 10 kHz–1 GHz	From internal E fields: 80 dB minimum 10 kHz–1 GHz

¹ Frequency range where OATS correlation demonstrated

² Low VSWR to $f \geq 20$ GHz; performance dependent on field uniformity tolerance

4.0 GTEM! Assembly

The Gigahertz Transverse Electromagnetic (GTEM!™) Cell is shipped in one or more plywood crates, or in certain circumstances, may be shipped partially assembled. Large GTEM! cells are shipped in multiple crates. The assembly drawings on pages 24-27 provide pertinent outer dimensions and floor space requirements for the Model 5402, Model 5405, Model 5407, and Model 5411.

The Model 5400 Series is designed for easy assembly. Typically, only standard hand tools are required.

The Model 5402 and Model 5405 are normally shipped fully assembled. Due to the size of the shipping crates for the Model 5405 or size of the standard factory assembled subassemblies, it may be necessary to ship in smaller sections. In this case, a factory technician or authorized ETS-Lindgren installer will perform the installation. This should be arranged at the time of the order.

The Model 5407 and Model 5411 are shipped partially assembled or unassembled. A factory installer or authorized ETS-Lindgren installer will perform the installation.



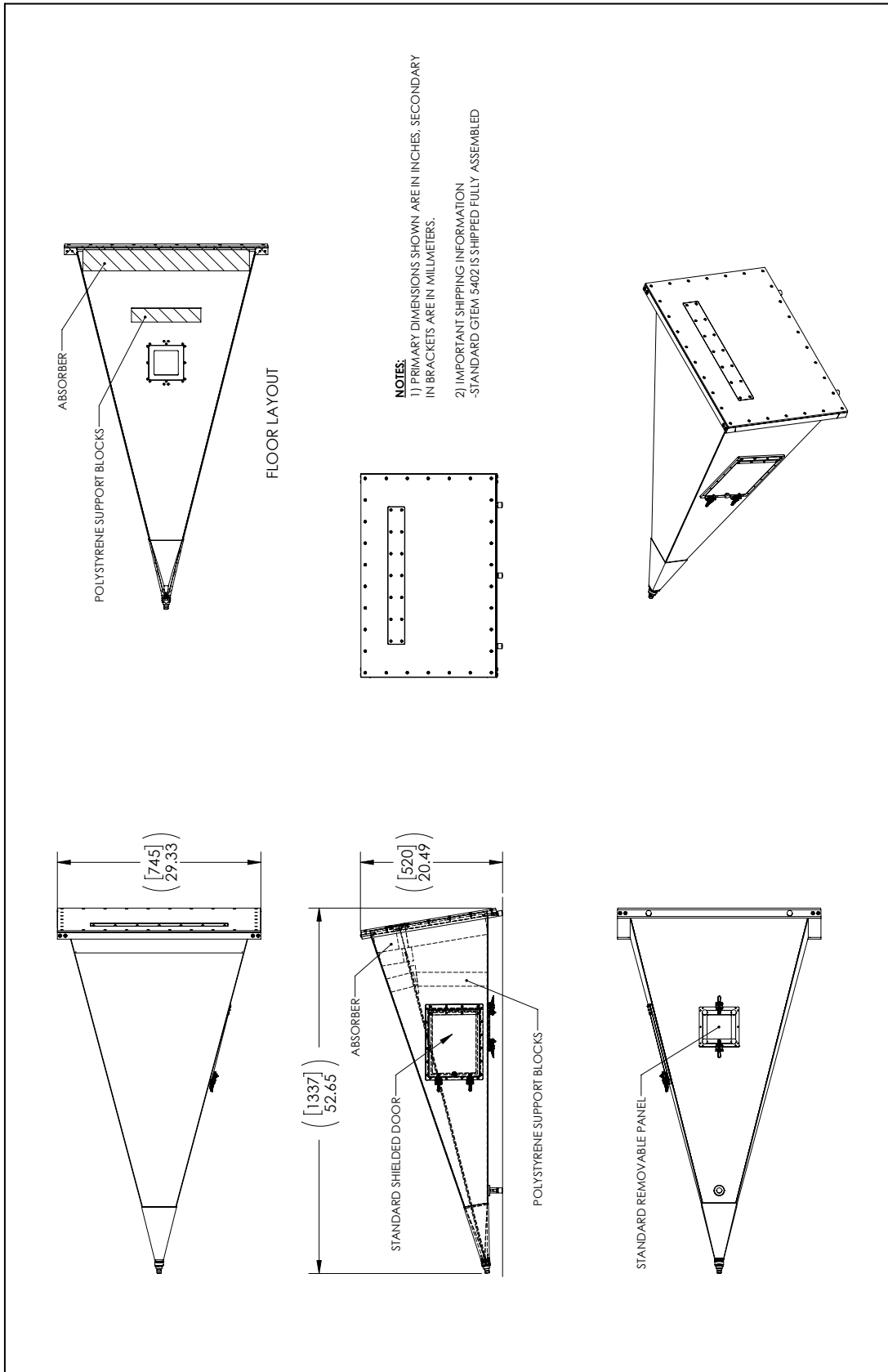
The Model 5407 and Model 5411 are shipped with a comprehensive installation manual. For complete information on uncrating, assembling, and installing, see the installation manual shipped with the Model 5407 and Model 5411.



After GTEM! assembly is complete, **DO NOT** remove polystyrene blocks from inside the GTEM!. Polystyrene blocks provide dielectric structural support.

While installation and calibration by the customer is possible, it is recommended that a qualified ETS-Lindgren installer provide those services.

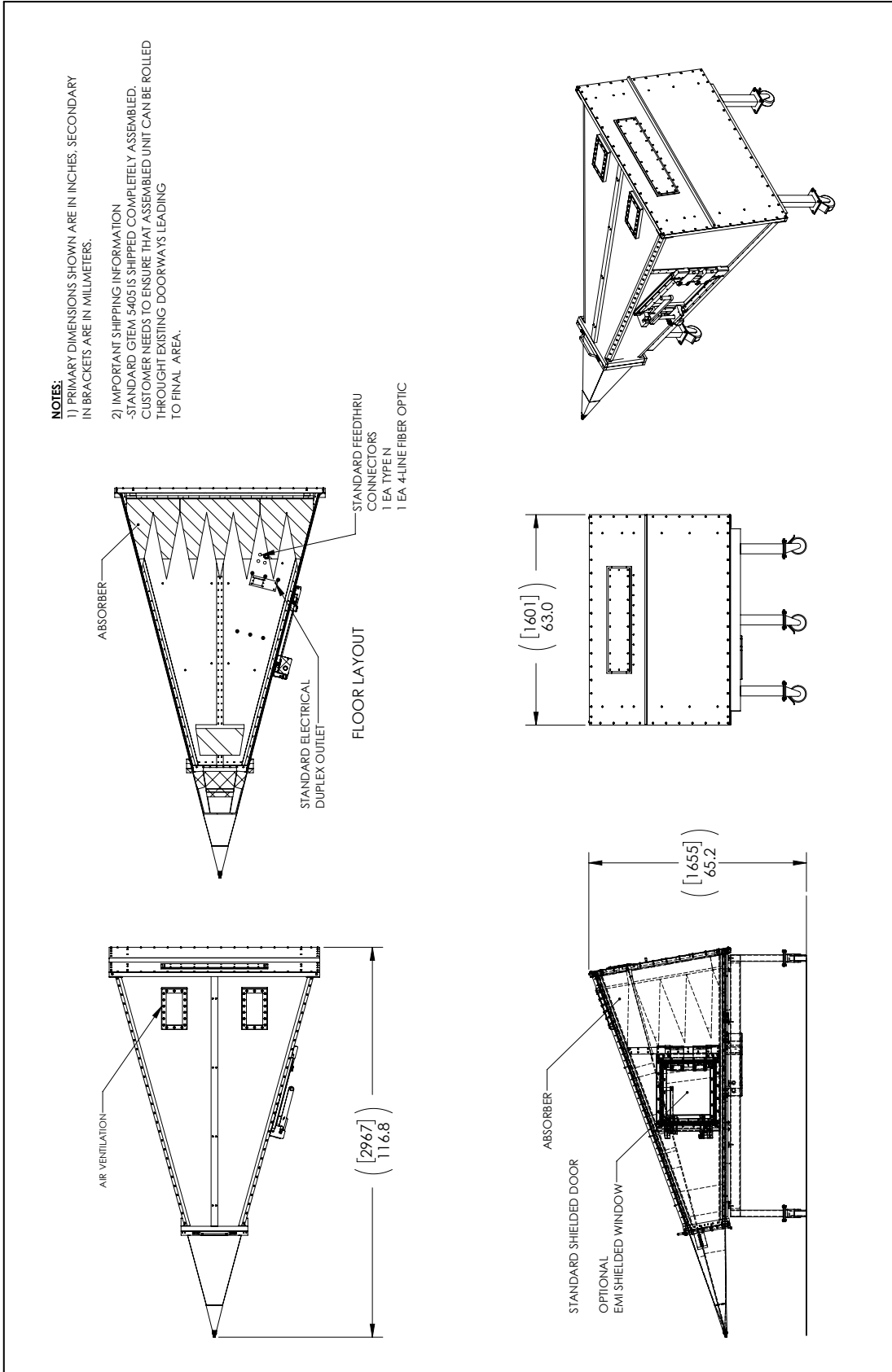
Model 5402 Assembly Drawing with Outer Dimensions



DO NOT remove polystyrene blocks from inside the GTEM!. Polystyrene blocks provide dielectric structural support.



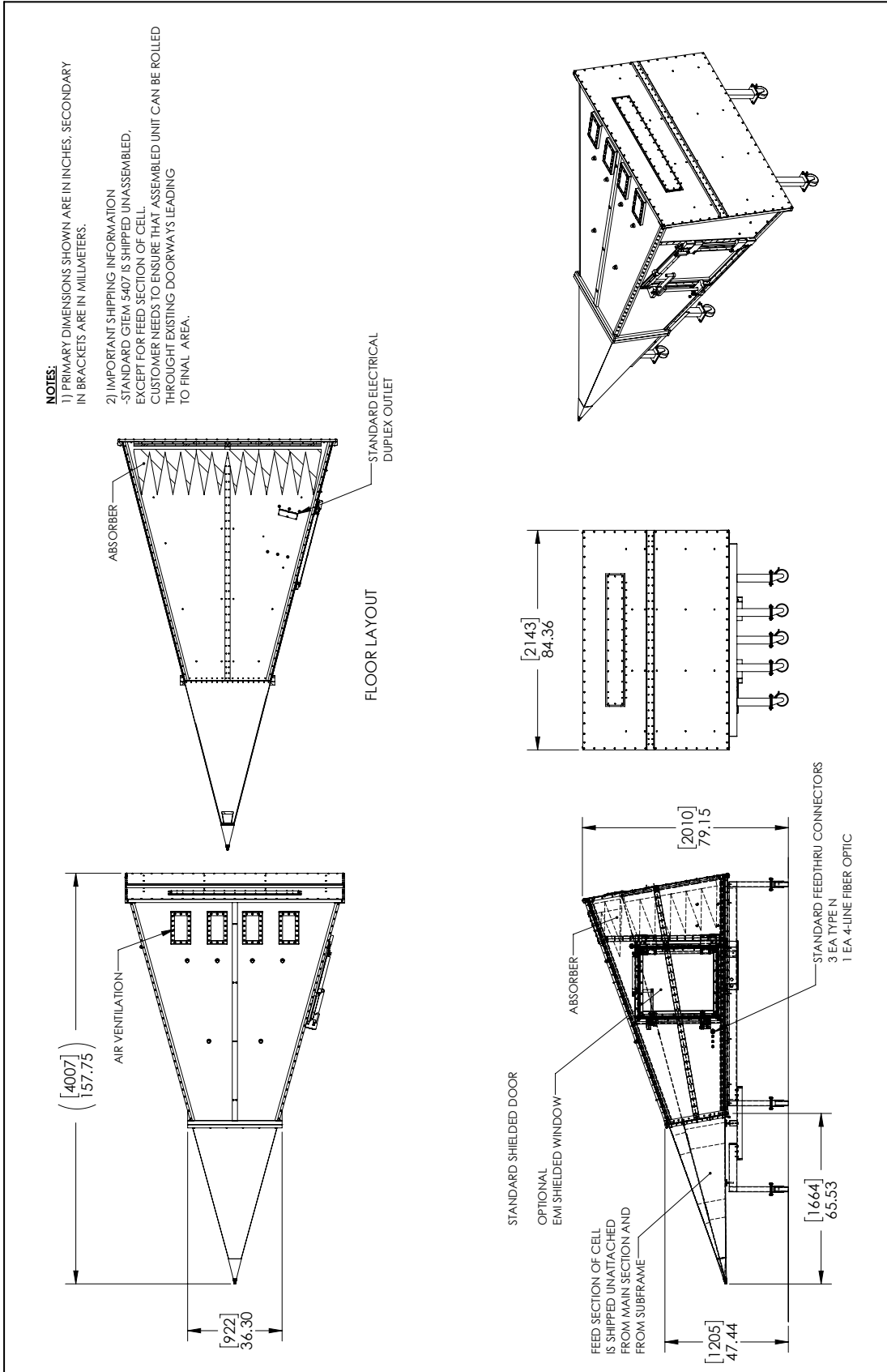
Model 5405 Assembly Drawing with Outer Dimensions



Polystyrene support blocks not shown.
DO NOT remove polystyrene blocks from inside the GTEM!. Polystyrene blocks provide dielectric structural support.



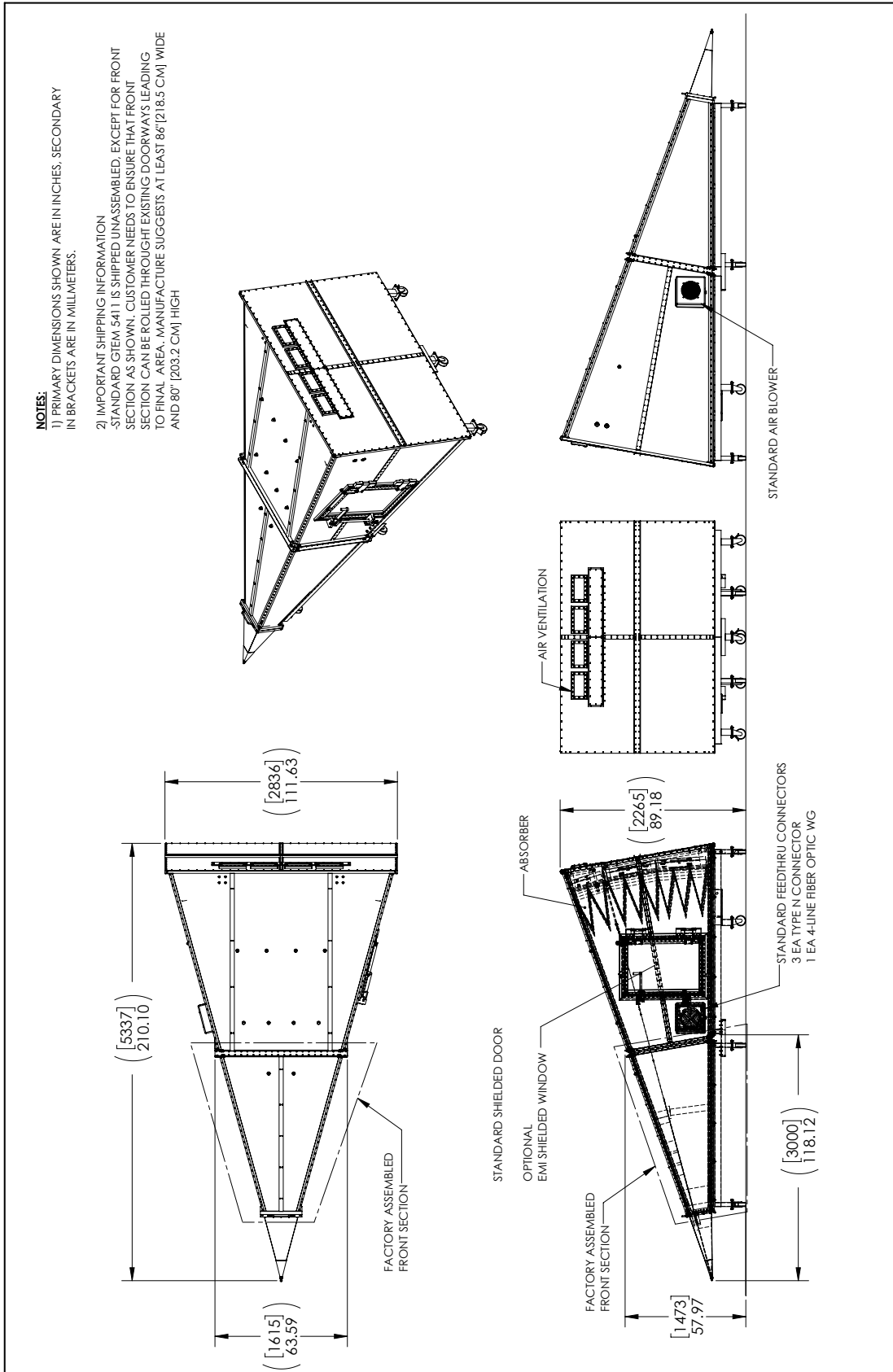
Model 5407 Assembly Drawing with Outer Dimensions



Polystyrene support blocks not shown. **DO NOT** remove polystyrene blocks from inside the GTEM!. Polystyrene blocks provide dielectric structural support.



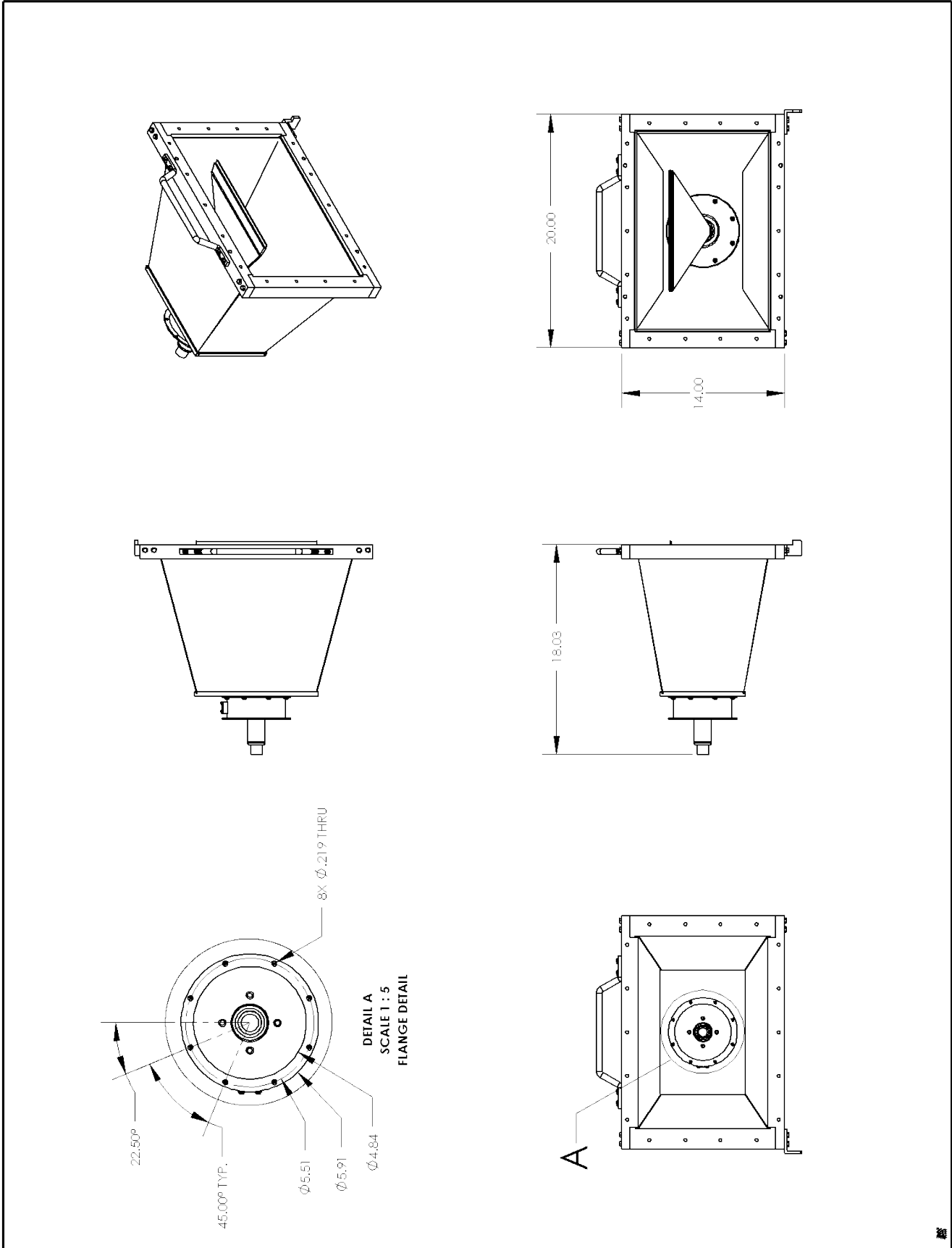
Model 5411 Assembly Drawing with Outer Dimensions

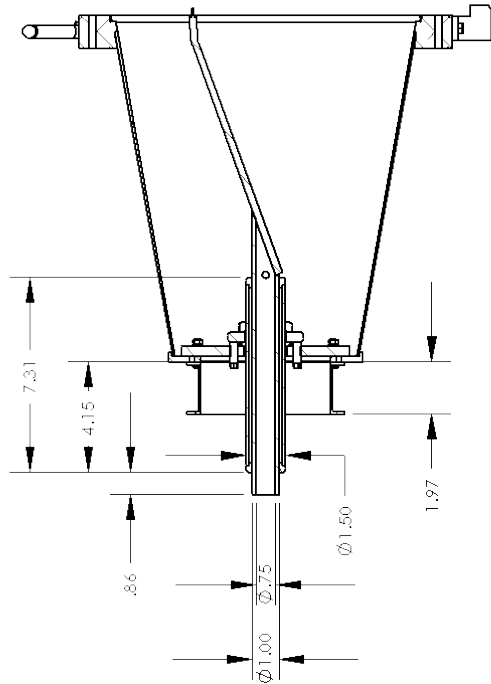
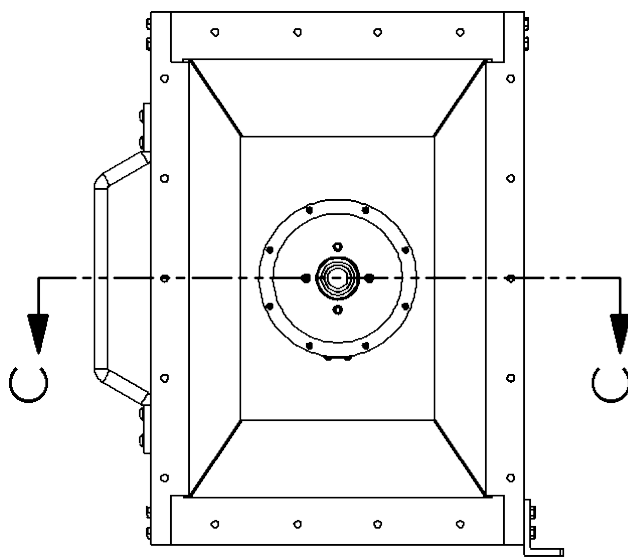


Polystyrene support blocks not shown.
DO NOT remove polystyrene blocks from inside the GTEM!. Polystyrene blocks provide dielectric structural support.

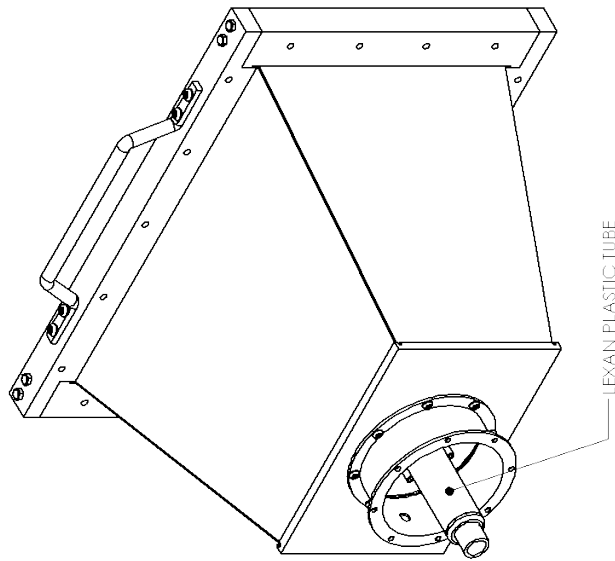
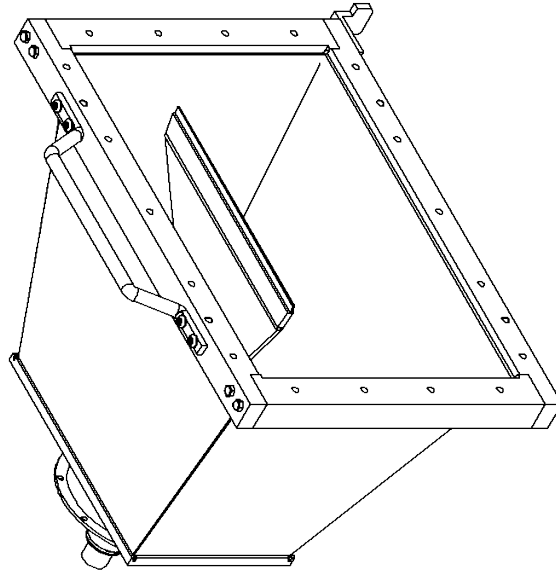


High Voltage Pulse Feed





SECTION C-C
SCALE 1 : 6



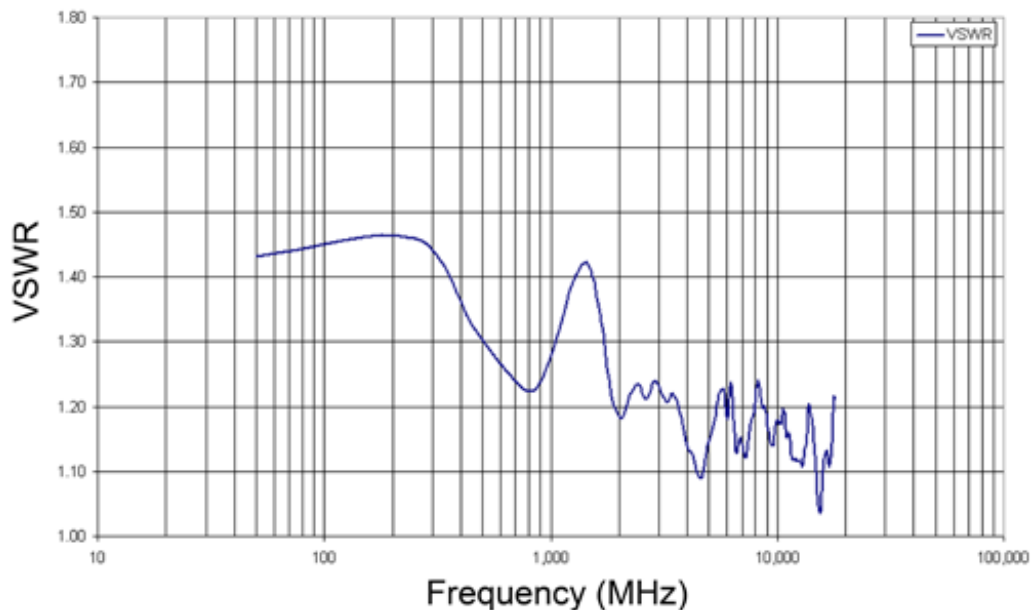
5.0 Measured GTEM! Performance

Several different measurable quantities exist that illustrate the performance of a Gigahertz Transverse Electromagnetic (GTEM![™]) Cell. Typical measurements are discussed in this section.

GTEM! Performance Qualification - VSWR

The Voltage Standing Wave Ratio (VSWR) of a terminated transmission line is a fundamental performance parameter. The value of the VSWR reading is a measure of mismatch; therefore, it completely defines the capability of a GTEM! to transfer power to or from interconnected 50 ohm RF test equipment. The VSWR is a qualifying measurement for GTEM! cells. Most GTEM! cells are pre-assembled at the factory and the VSWR verified at that time. Following is the VSWR of a typical Model 5407 measured with an HP8753C vector network analyzer.

Typical VSWR Measurement - Model 5407



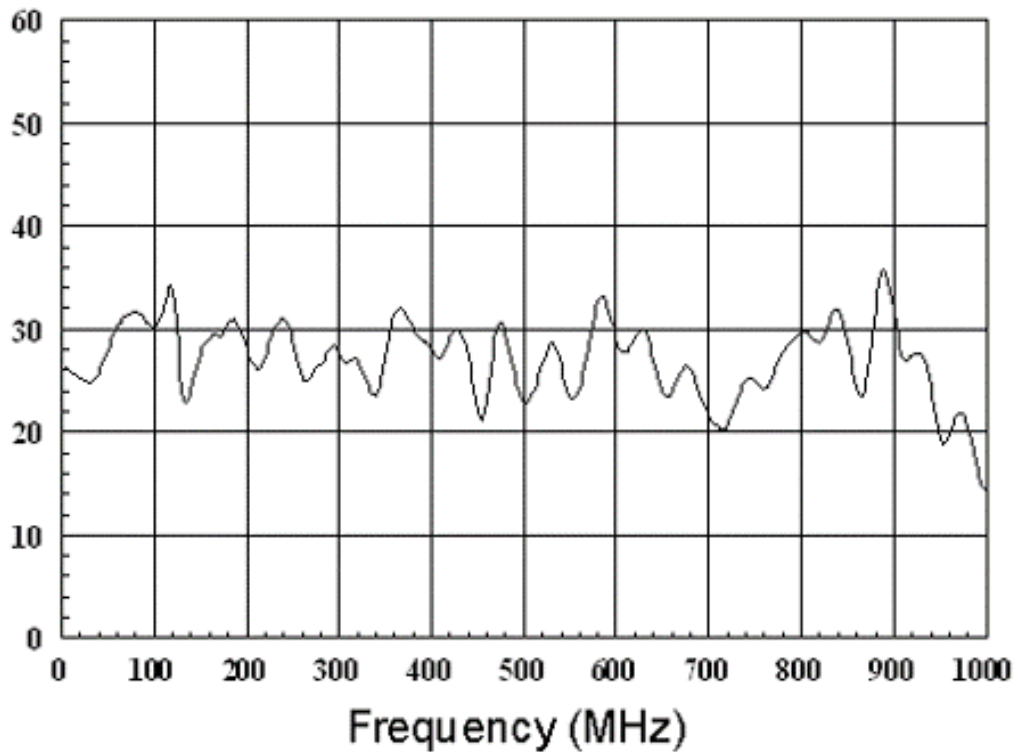
GTEM! Electromagnetic Field Response

E-Field Frequency Response

The E field frequency response is defined as the measurement of the electric field strength at a specific point in the GTEM! measured as a function of frequency and normalized to a constant forward input power.

Typical E-Field Frequency Response - Model 5407

Following is a typical Model 5407 vertical electric field frequency response normalized to 10 W constant forward power at a center point where the septum height is 80 cm (40 cm above the floor). At other locations electric field frequency response can vary by several dB.

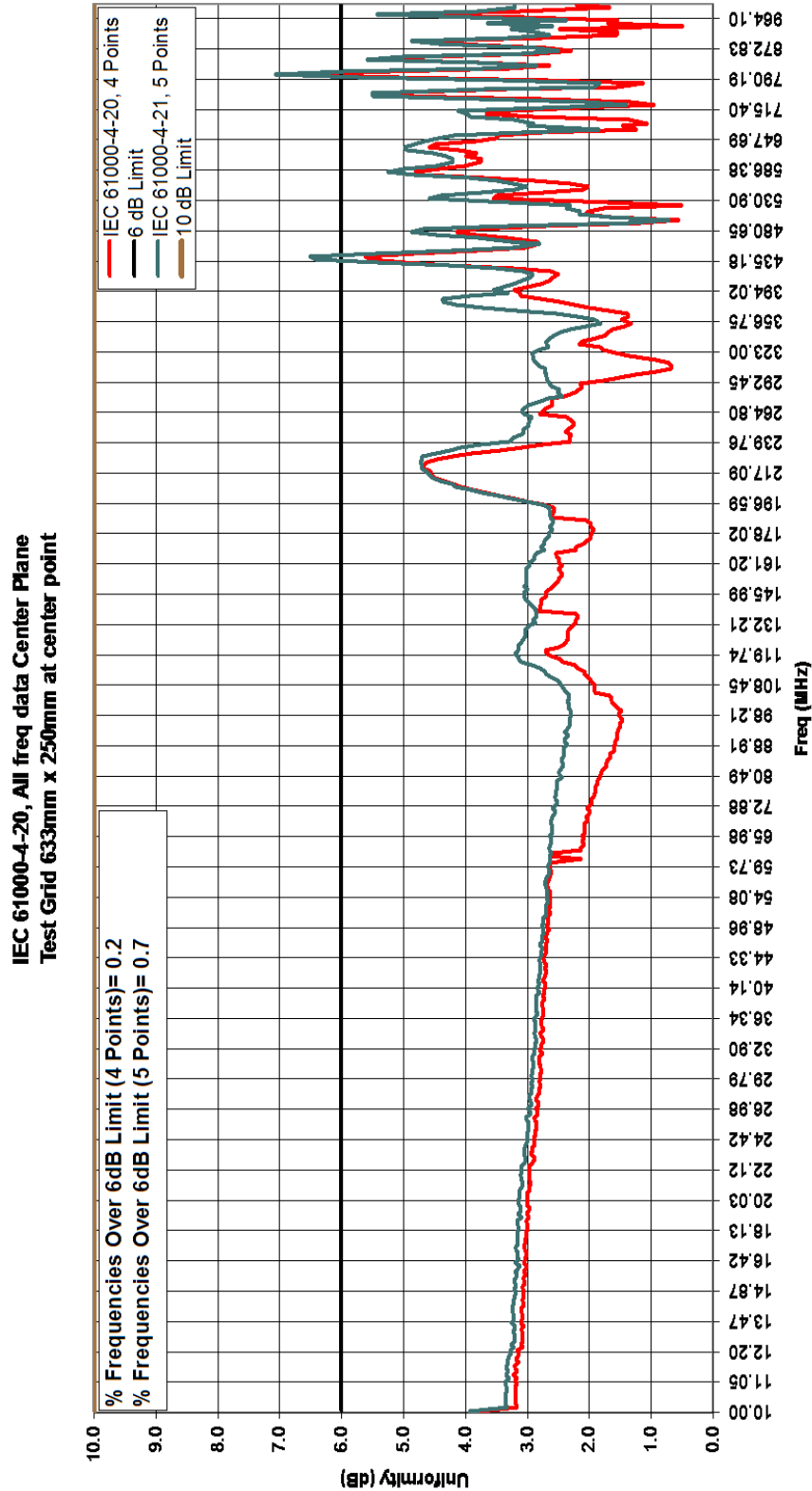


Electric Field Uniformity

The electric field uniformity of a GTEM! can be defined as the maximum difference in dB between measured electric field at various spatial locations on a plane perpendicular to the direction of propagation. According to the IEC 61000-4-20 standard, the uniform area to be measured and the minimum number of points depend on the size of the GTEM!. At each frequency, the reference location can be arbitrarily chosen; for example the center or bottom corner point of the calibration plane. After performing the plane calibration in the empty GTEM!, the Equipment Under Test (EUT) is inserted with the front face coincident with the calibration plane.

Typical Electric Field Uniformity - Model 5407

The electric field uniformity of a Model 5407 as measured according to EN 61000-4-20 is shown in the following. Five spatial points were measured in a 633 mm x 250 mm vertical/transverse plane centered at an 80 cm septum height. The standard allows 25% of the points to be omitted at each frequency; at least four of the five points fulfill the -0, +6 dB criteria as required.



Time Domain Reflectometer

The Time Domain Reflectometer (TDR) Measurement is an impedance measurement performed in the time domain. The advantage here is that distance information can be derived from the test and used to confirm the correct alignment of the septum and other cell components along the length of the cell. The TDR test is generally performed as standard at the factory on assembled cells.

GTEM! Shielding Effectiveness

The shielding effectiveness (SE) of a GTEM! is difficult to measure by conventional IEEE-299-type methods due to GTEM! size and flared walls. Alternative methods have been developed, for example: The primary technical issue is the choice of reference signal for the SE tests. Due to size constraints, normal antennas cannot be used to generate the signal inside the GTEM!. In addition, electric field intensity along the GTEM! can vary more than 20 dB from apex to load. For these reasons, a modified two antenna swept-frequency procedure was used to measure SE of the Model 5400 Series. In this method, power is input into the GTEM! as in a normal immunity test, and the receive readings of two loop probe antennas, one inside and the other outside the GTEM! walls, are compared. For the Model 5407, a >80 dB specification SE was verified with this method.

6.0 GTEM! Use

The intended use of the Gigahertz Transverse Electromagnetic (GTEM!™) Cell is for radiated immunity testing and radiated emissions testing. The following sections on GTEM! usage provide a general overview of these uses. Note that the test operator, as with any test facility, must plan and implement the testing of all devices thoroughly to ensure repeatable results.

Radiated Immunity Testing

Radiated immunity testing is conducted to ascertain if the Equipment Under Test (EUT) will respond to radiated energy in the electromagnetic ambient in a deleterious manner. The GTEM! provides an ideal facility for the accomplishment of such tests in a laboratory environment. Immunity testing is typically performed using either of the following techniques.

Substitution Method

This method uses the principle of calibrating the test volume. An E-field probe is positioned in the center of the test plane and the input power is increased until the required test field is measured. The input power is then recorded as a function of frequency to create an empty volume calibration file.

For the test, the field probe is replaced by the EUT and the forward power values of the calibration file are replayed while the device is monitored.

Direct Method

In this method the field probe and EUT are both placed in the GTEM! and the forward power increased until the required field is measured. This is repeated for each frequency as the EUT is monitored.

The test setup usually consists of the components shown in *Typical Automated Radiated Immunity Test Setup* on page 33.

Estimation of GTEM! RF Input Power Required for Given Field Strength

The standard RF power handling capability of the Model 5405 and Model 5407 is in excess of 200 W. The standard RF power handling capability of the Model 5411 is 1000 W. Greater voltage or power handling capabilities are possible if modified feed sections, load boards, or optional blowers are installed. Field intensities in excess of 200 V/m can be generated with sufficient CW power.

Estimation of the power required for obtaining a given field strength is easy. Using the parallel plate electric field approximation, the estimated field strength halfway between the septum and the floor of the GTEM! is given by the ratio of the RF voltage on the septum to the spacing of the septum above the GTEM! floor, or:

$$E(\text{Volts/meter}) = V (\text{Volts}) / h (\text{meters})$$

RF voltage is obtained from the drive power by the equation:

$$P_{in} (\text{Watts}) = V^2 (\text{Volts}^2) / Z_o (\text{Ohms})$$

Where P_{in} is input RF Power (Watts), V is RF voltage on the septum at height h , and Z_o is the GTEM! characteristic impedance (50 ohms).

Then a simple solution is:

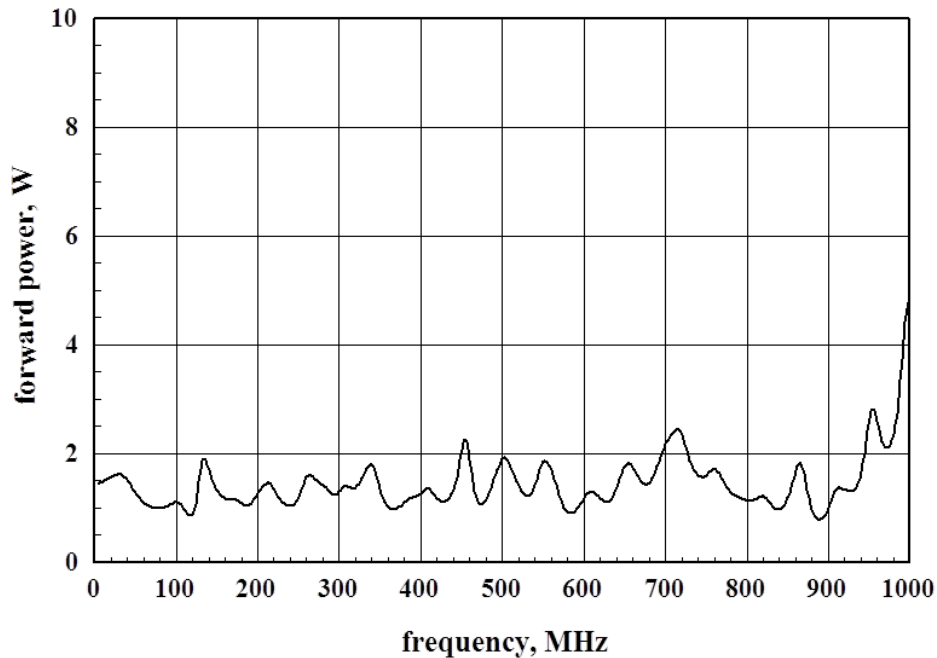
$$E = \left(\frac{1}{h}\right) (P \times Z_0)^{1/2}$$

$$P = (Eh)^2 / Z_0$$

The previous equations can be used for first order estimates of field strength given power, or power required for a given field strength. Power required calculated by this method is approximate, and actual power needed for a given electric field strength will vary versus frequency and location in the GTEM!.

Typical 10 V/m Power Required - Model 5400 Series

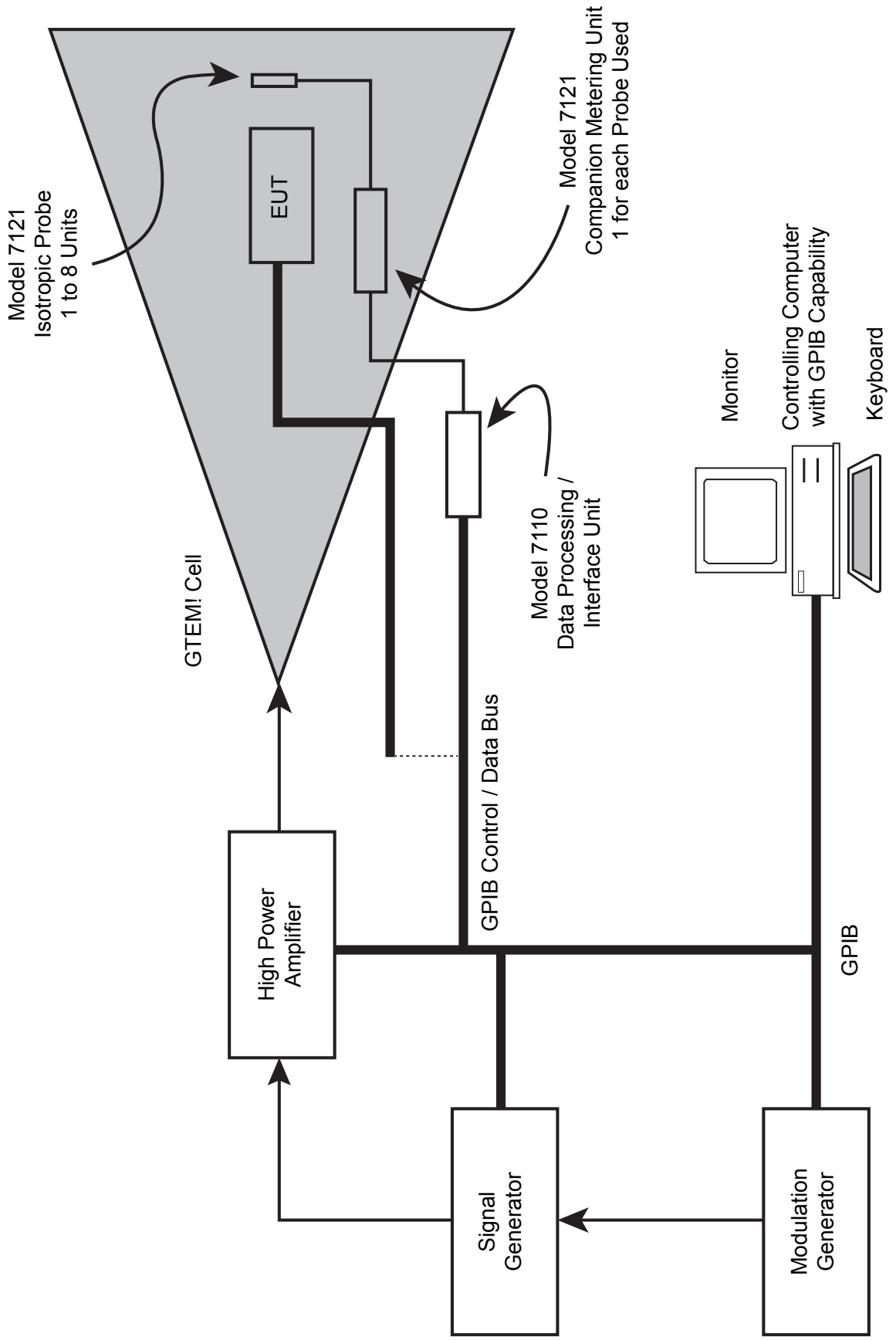
Following is the typical measured power required for 10 V/m at a 0.9 m septum height (40 cm height above floor and 80 cm septum height) in a Model 5400 Series.



Typical Automated Radiated Immunity Test Setup

Following is a typical setup for conducting radiated immunity testing using automated control techniques. Testing can be completely automated if it is possible to define a test signal response from the EUT, which can be sensed by the controlling computer. A signal generator is shown with an external modulation source so that the modulation characteristics can be matched, if desired, to signals internal to the EUT. The output of the signal generator is applied to the RF power amplifier, which in turn drives the GTEM!. Application of the signal to the GTEM! input produces the test signal between the septum and the floor of the GTEM!. Internal to the GTEM!, an optional broadband, high level isotropic probe monitors the level of the applied signal. An isotropic field probe may be used to sense the applied field at different locations and report actual electric field strength values.

The EUT is installed in the GTEM! in the approximate center of the test volume.



Monitoring of EUT performance is via a cable to any externally located monitor unit. Typical precautions must be taken, such as are used in shielded enclosure immunity testing with EUT performance monitors. An example would be grounding the shield of the cable to the performance monitor to the bottom of the GTEM!. Once the setup is complete, the signal generator is turned over the test frequency range while monitoring the performance of the EUT for response to the applied test signal. The levels of the test signal are adjusted by controlling the signal generator output while monitoring for the minimum field level at the location of the isotropic probe.

Note that the electric field strength and the sweep speeds are often set by the test requirements document(s). Care should be taken not to exceed specified sweep speeds. An additional factor is that, with the availability of automated testing, it is possible to sweep at the specification required speed without consideration of the performance of the EUT. If the EUT must be stepped through a number of modes at each frequency, then even slower sweep speeds may be needed.

Radiated Emissions Testing - General

In addition to immunity testing, the GTEM! may be used for radiated emissions testing. An item placed in the test volume under the septum can be evaluated for radiated emissions as easily and as simply as an immunity test is accomplished. By the reciprocity principle in electromagnetic theory, if the application of an RF voltage generates a field, then the introduction of a device that radiates a field in the volume under the septum will produce an RF voltage at the GTEM! input connector. The voltage produced will be proportional to the intensity of the radiated field.

The main development that brought the GTEM! forward as a practical radiated emissions device was the three position correlation algorithm (derived by Wilson et al. at ABB, based on results from NIST), which allowed the direct comparison of data taken in a GTEM! to data acquired on an Open Area Test Site (OATS). The GTEM! feed connector voltages produced by radiated emissions from the EUT at each of three orthogonal positions are measured. Then at each frequency, an equivalent set of dipole antennas that would produce the same voltages at the GTEM! connector are defined through computer computation. Once the equivalent antennas are defined, the field intensities for comparison to the given specification limit are computed from the set of equivalent dipoles at each frequency, given the separation and geometry of the test setup on an OATS.

The simplest GTEM! to OATS correlation algorithm uses three EUT positions. Various other rotation schemes have been described developed. Please contact ETS-Lindgren for additional details.

Radiated Emissions Measurements - Hardware Requirement

Measurement of radiated emissions requires the use of a frequency selective EMI meter or spectrum analyzer. For manual use, any calibrated receiver typically used for electromagnetic compatibility (EMC) measurements is acceptable as long as the test specification requirements for the measurement device are met.

EUT Orientation for Testing

Proper orientation of the EUT in three orthogonal axes is necessary to accurately perform radiated emissions measurements. To perform the EUT rotations, separate coordinate axes are defined for the GTEM! and the EUT.

The three reference orthogonal axes of the GTEM! are normally defined as:

- **Positive Z axis:** to the feed
- **Positive Y axis:** up
- **Positive X axis:** toward the right of the cell as seen from the apex

Note that this is a positive right rectangular coordinate system; X rotated into Y in a right handed sense gives a positive Z. In this discussion the uppercase letters X, Y, and Z represent the axes of the GTEM! , and the lowercase letters x, y, and z represent the EUT right axes.

The mathematical formulation of the GTEM! model for determining the OATS equivalent value of radiated emissions requires three measurements of voltage produced by the EUT in three orthogonal axes positions. In the rotation scheme, the three positions must be aligned with the axes of the cell as follows:

Position 1: GTEM! axes XYZ

EUT axes xyz

Position 2: GTEM! axes XYZ

EUT axes yzx

Position 3: GTEM! axes XYZ

EUT axes zxy

The EUT array, a personal computer system installed on a plywood panel per the requirements of ANSI 63.4 1992, is shown with the x, y, z EUT axes aligned with the X, Y, Z GTEM! axes. Note that the EUT and GTEM! axes are shown in alignment at the top, right sides, and bottom of *Typical EUT System Installed in Large GTEM!* on page 37. The circle with the dot at the center located at the bottom of the illustration represents the tip of the axis arrowhead pointing out.

In position two, the EUT is rotated so that the y axis aligns with the X axis, the z axis aligns with the Y axis, and the x axis aligns with the Z axis. *Typical EUT System Installed in Large GTEM! (90° Rotation)* on page 38 demonstrates the alignment of the GTEM! and EUT axes for this rotational position.

In position three, the EUT is rotated so that the x axis aligns with the X axis, the x axis aligns with the Y axis, and the y axis aligns with the Z axis. *Typical EUT System Installed in Large GTEM! (Additional 90° Rotation)* on page 39 shows the third position.

Measurement Procedure

The following general procedure should be used to perform radiated emissions measurements in a GTEM!. This procedure is written for manually performed measurements.

1. Install the EUT in the center of the test volume of the GTEM! with a reference orientation, as shown in *Typical EUT System Installed in Large GTEM!* on page 37 and as described previously for the first position.
2. Measure the RF voltages emanating from the EUT as a function of frequency over the desired frequency range. Depending on the measurement device used, either peak, quasi peak, or average measurements may be made. These measurements are collectively referred to as V_{xyz} versus frequency.
3. Rotate the EUT through two successive 90 degree rotations to the right, such that the x axis is replaced by the y axis, and so on, as shown in *Typical EUT System Installed in Large GTEM! (90° Rotation)* on page 38.
4. Measure the RF voltages emanating from the EUT as a function of frequency over the desired frequency range. These measurements are referred to as V_{yzx} versus frequency.
5. Rotate the EUT through further 90 degree rotations to the right, such that the y axis is replaced by the z axis, and so on, as shown in *Typical EUT System Installed in Large GTEM! (Additional 90° Rotation)* on page 39.

6. Measure the RF voltages emanating from the EUT as a function of frequency over the desired frequency range. These measurements are referred to as V_{zxy} versus frequency.



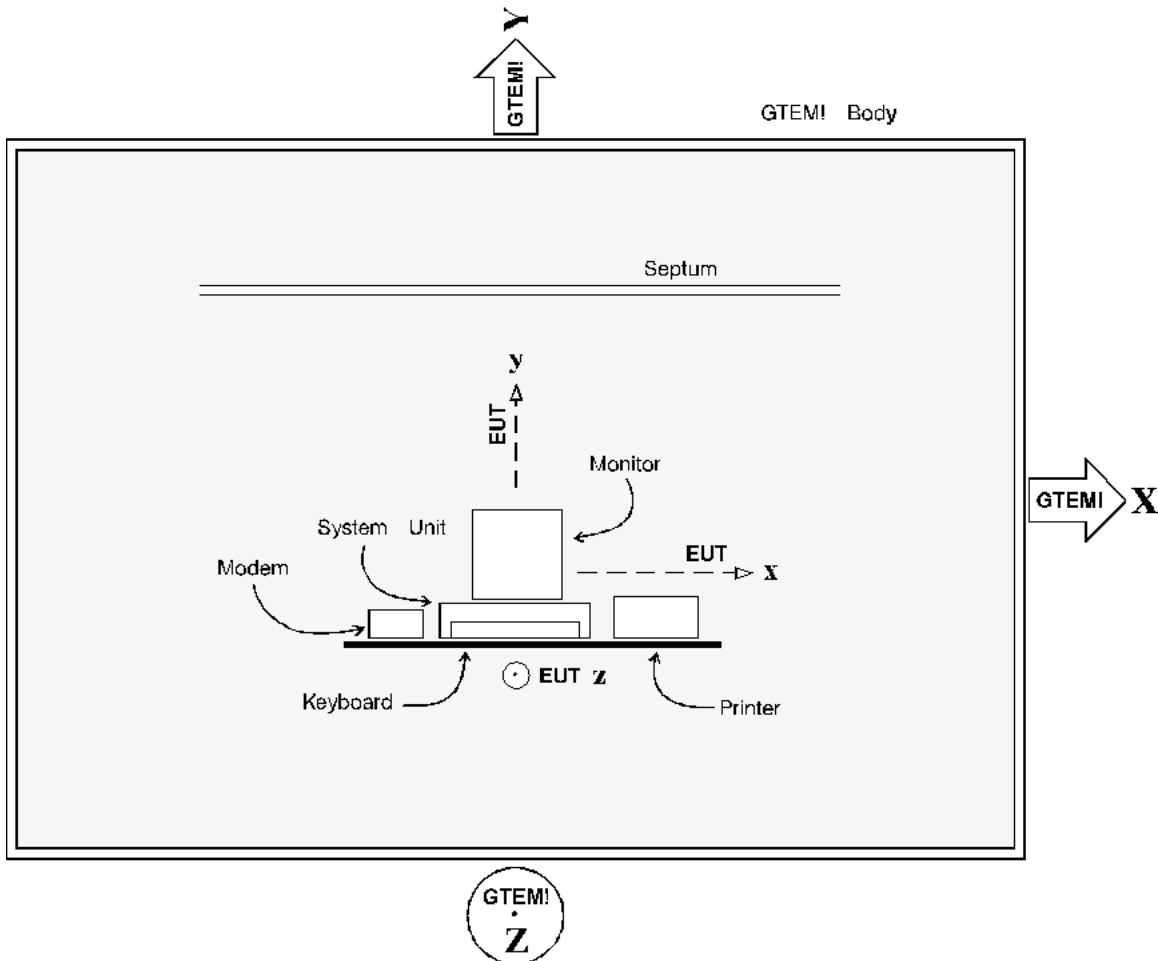
The detector selected (peak, quasi peak, or average) must be used for all three position measurements and the frequency of the measurements must be the same for all positions.

After completion of these measurements, the tester should have a matrix of measurements that consists of a frequency and three associated RF voltage measurements all made with the same detector function. A value for the noise measured at a given frequency where signal components were measured may be necessary to complete the measurement set.

To assist with the computation, you may download an MS DOS®-based utility program from the ETS-Lindgren website at www.ets-lindgren.com. This type of program should be used because the computations are too complex to be performed by hand in a reasonable amount of time.

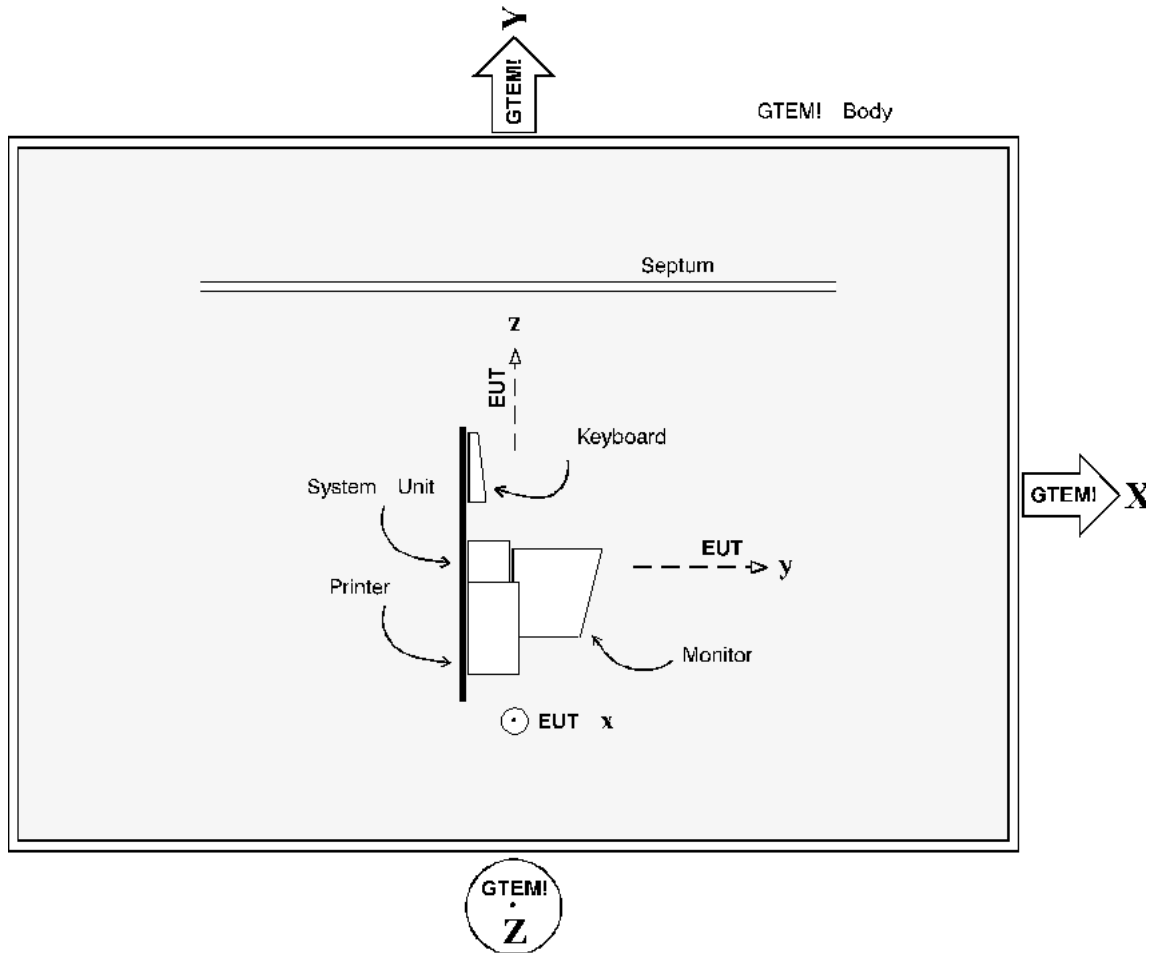
Typical EUT System Installed in Large GTEM!

This view is seen from the apex with GTEM! (X, Y, Z) and EUT (x, y, z) axes aligned for measurement of V_{xyz} .



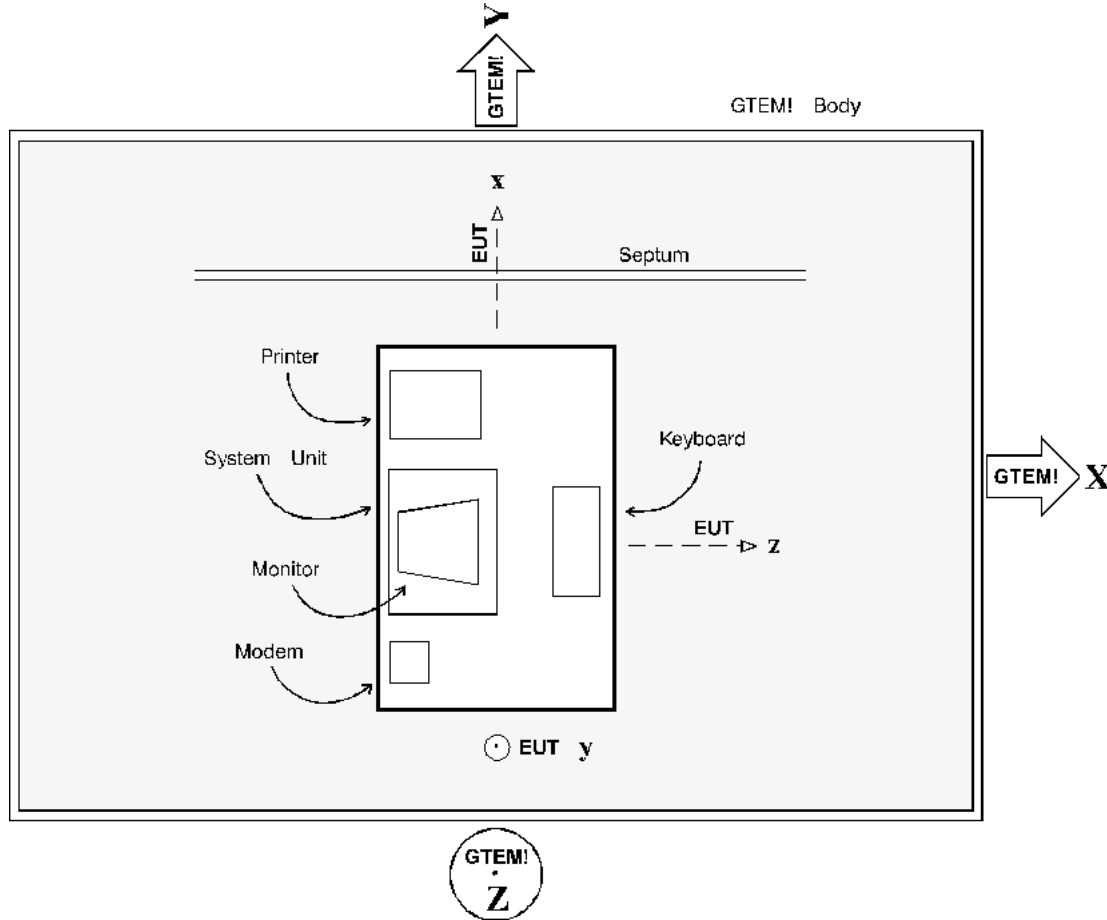
Typical EUT System Installed in Large GTEM! (90° Rotation)

This view is seen from the apex with GTEM! (X, Y, Z) and EUT (y, z, x) axes aligned for measurement of V_{yzx} .



Typical EUT System Installed in Large GTEM! (Additional 90° Rotation)

The view is from the apex with GTEM! (X, Y, Z) and EUT (z, x, y) axes aligned for measurement of Vzxy.



Software Computations

The correlation algorithm software for the GTEM! performs the calculations as outlined in the following.

At each frequency, the three-position correlation algorithm:

- Performs a root sum of the squares summation of the three orthogonal voltages.
- Computes the total power emitted by the EUT as determined from the summation of the three voltages and the transverse electromagnetic mode (TEM) mode equations for the GTEM!.
- Computes the current excitation of an equivalent tuned, half wave Hertzian dipole when excited with that input power.
- Computes the field intensity at appropriate height intervals over the total, operator selected scan height, either one to four meters or two to six meters for both vertical and horizontal polarizations of the receive antenna when the equivalent turned resonant dipole is placed at an appropriate height over a perfect ground plane.
- Selects the maximum field strength (larger) value of the horizontal or vertical polarizations.
- Presents this maximum value for comparison to the chosen EMC specification limit.

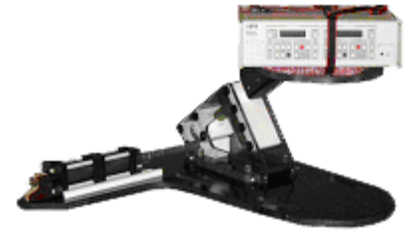
The GTEM! feed connector voltages produced by radiated emissions from the EUT at each of three orthogonal axes are measured, then at each frequency an equivalent set of fixed dipole antennas that would produce the same voltages at the GTEM! connector are defined through computer computation. Once these equivalent antennas are defined, the OATS field intensities are computed for the distances and height scans selected. The calculated OATS

data is then presented for comparison to actual OATS data if available based on an OATS emission limit. The accuracy of the measurement is of prime importance.

7.0 Ortho-Axis Positioner - Pneumatic (Optional)

The Ortho Axis Positioners for the Model 5405, Model 5407, and Model 5411 are air driven devices used to assist in positioning the Equipment Under Test (EUT) during EMC measurements.

The positioner is designed to automate the positioning of EUT inside the Gigahertz Transverse Electromagnetic (GTEM!™) Cell. A custom serial interface is used to control the movement of the positioner.



Position the Ortho Axis Positioner in the GTEM! as far back as possible, making sure to clear the absorbers and any floor penetration panels. The mounting platforms for the different models can support the following loads:

5405: Can support up to 4.5 kg

5407: Can support up to 4.5 kg

5411: Can support up to 20 kg

The EUT should always be positioned centrally and supported securely using the provided straps before the positioner is operated.

CAUTION

To prevent injury: Make sure that the positioner cannot be operated remotely while inside the chamber or mounting the EUT to the platform.

Operation

A control unit containing pneumatic control relays is to be mounted to the exterior of the GTEM!. Four pneumatic control lines connect the control unit to the positioner through four separate feed through fittings on the side wall of the GTEM!.

Inline flow control valves mounted on the air cylinders of the positioner regulate the speed of the positioner movement. The valves can be adjusted to increase or decrease the airflow. The unit is to be connected to a customer supplied air source. This air source will need to deliver a minimum of 1 CFM at 60 psi (30 psi for the Model 5405). It is important to have clean, dry air. We recommend the use of a 40-micron filter in close proximity to the installation.

A 12-volt DC wall mounted power supply provides the DC power to the control unit. It connects to the control unit through a two-pin receptacle on the side of the enclosure. A serial cable connects the control unit to the serial port in the computer. A nine-pin D-sub connector is mounted on the side of the control unit for this connection.

Place the positioner in the GTEM! so that the recess in the base plate fits over the center strip in the GTEM!. The mounting plate will be positioned in one of the three orthogonal positions within the GTEM! at each of the fixed positions.

The Ortho-Axis Positioner can be controlled through Hyperterminal or other control software. If using Hyperterminal, the settings must be as follows:

Baud:	9600
Data Bits:	8
Parity:	None
Stopbits:	1
Flow Control:	None

The commands to control the positioner are:

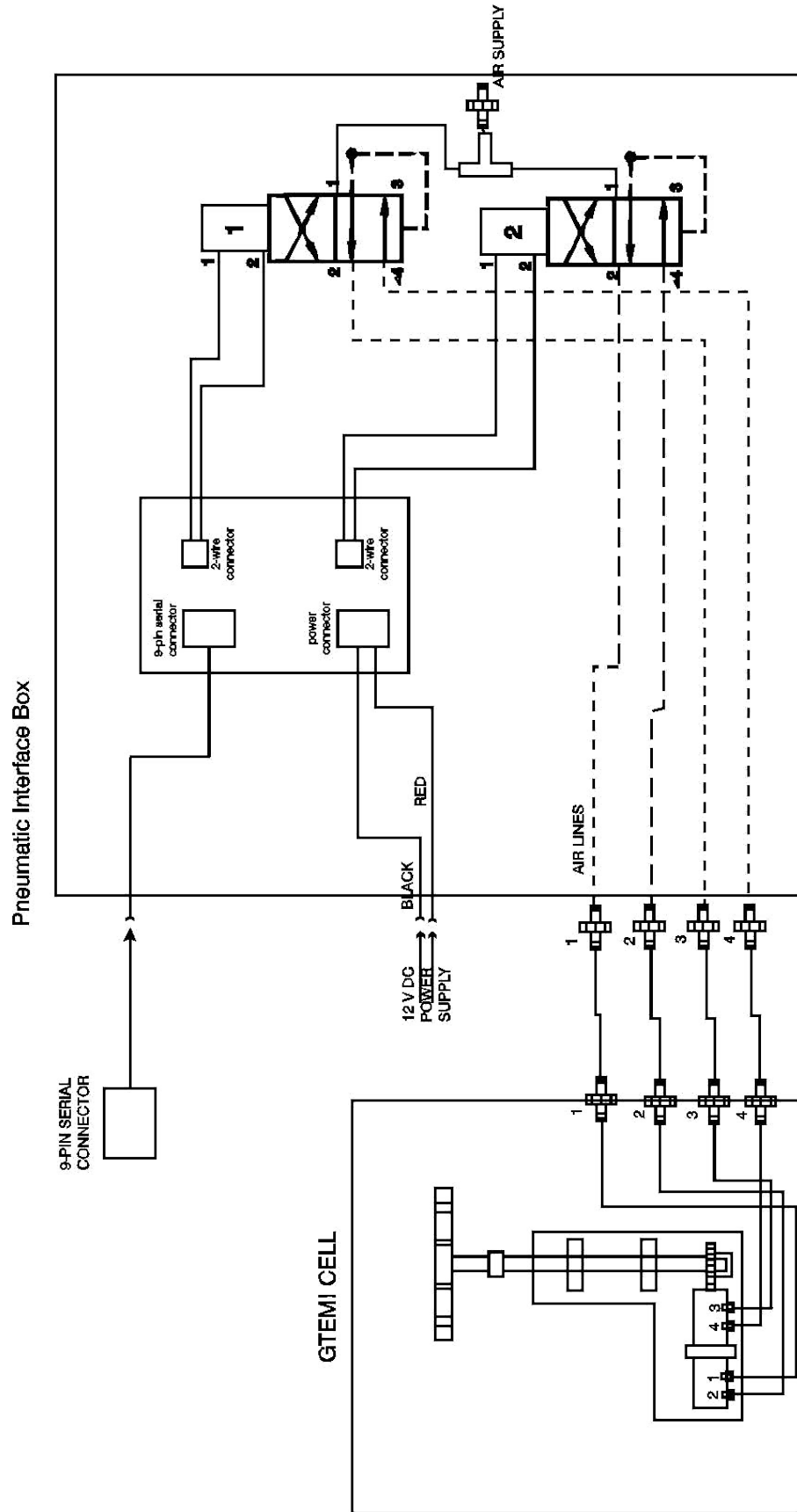
	Bit 01	Bit 02
Position 1	\$CB01	\$CB02
Position 2	\$SB01	\$CB02
or	\$CB01	\$SB02
Position 3	\$SB01	\$SB02

<p># - Transmitted on startup \$ - Used to denote commands * - The response for valid commands ER – The response for invalid commands SBxx = Sets corresponding Bit high – for example, \$SB01 CBxx = Clear corresponding Bit – for example, \$CB01 RBxx = Read corresponding Bit – for example, \$RB01 *1 if Bit is set *0 if Bit is clear RR = Resets the control unit – for example, \$RR</p>

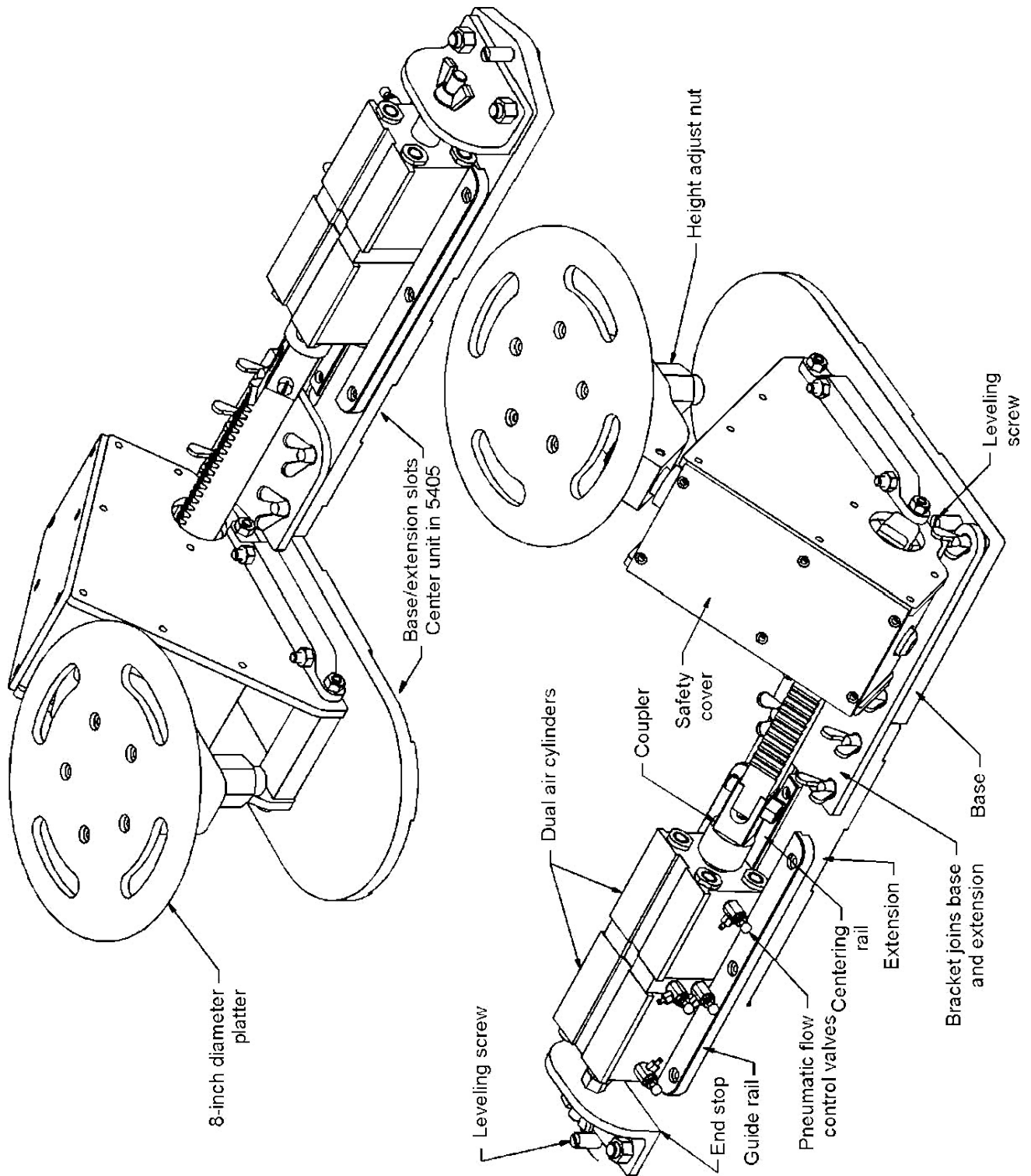


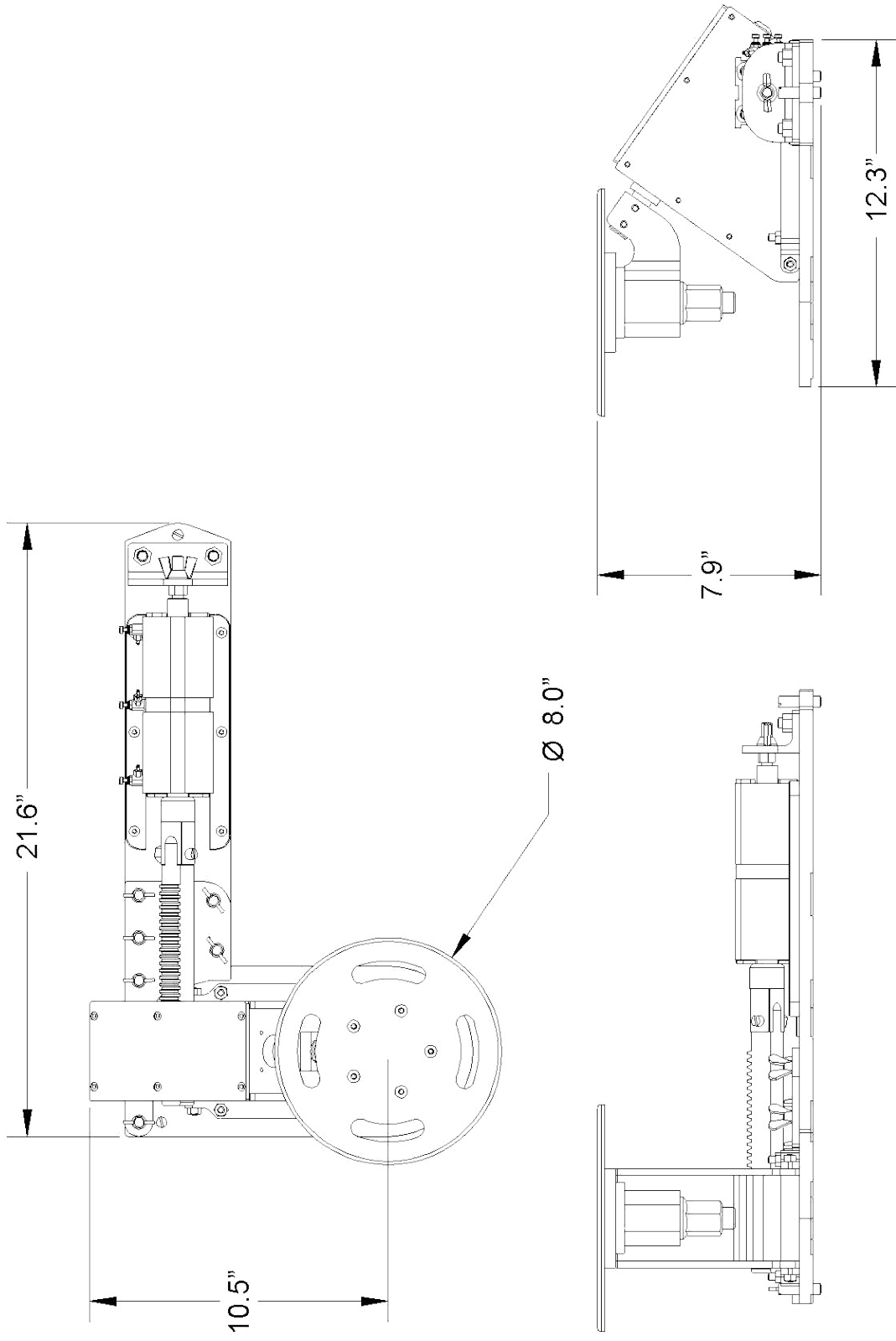
The term *positioner* can be used interchangeably with the term *manipulator*.

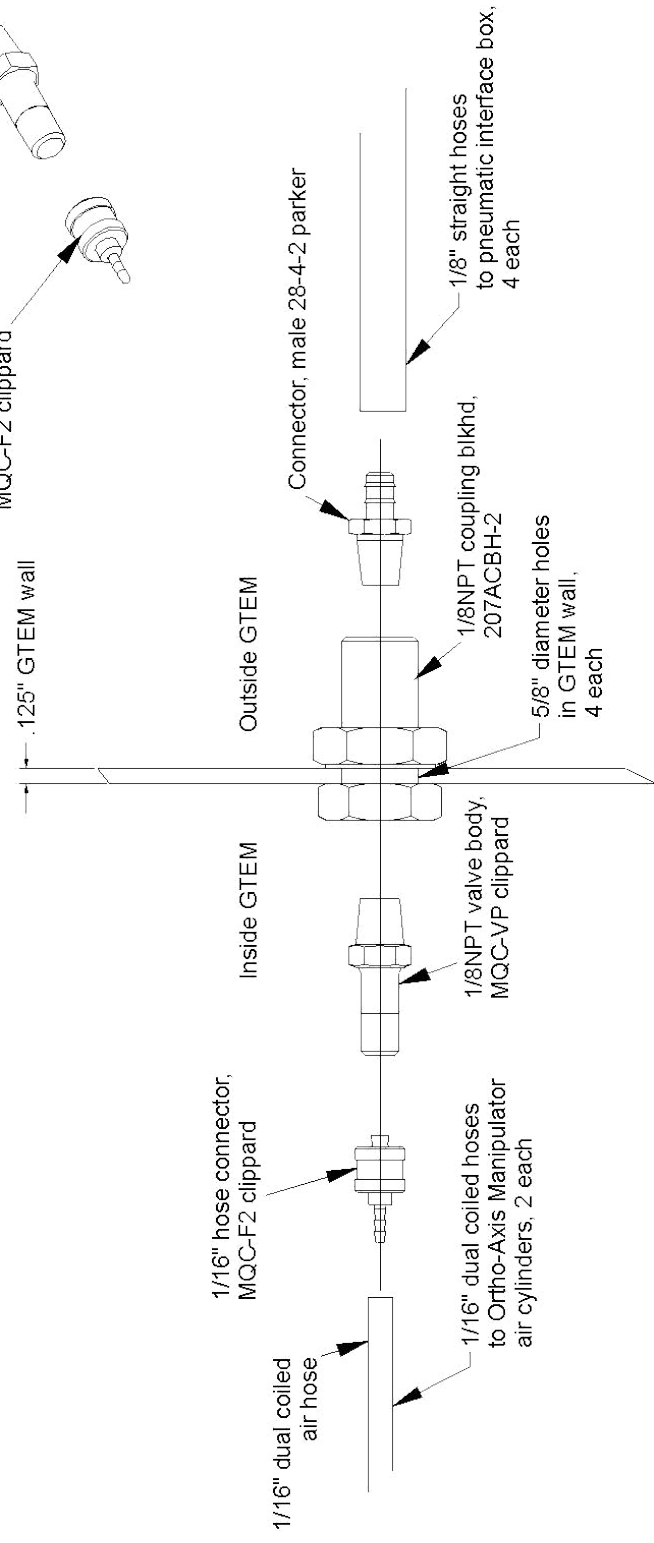
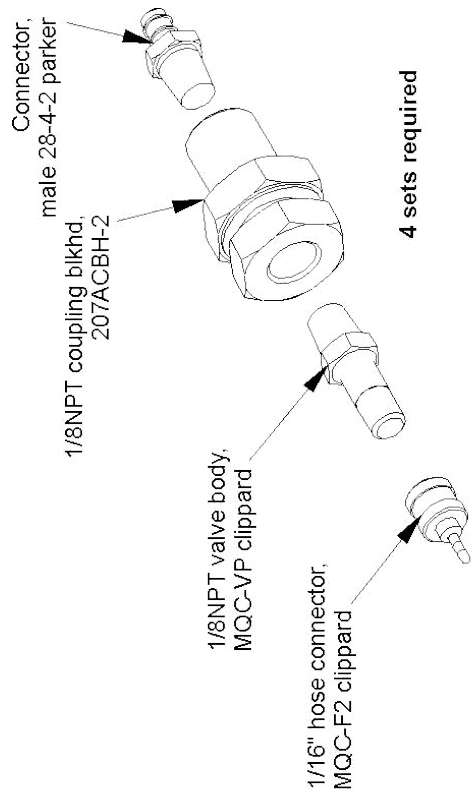
Functional Schematic

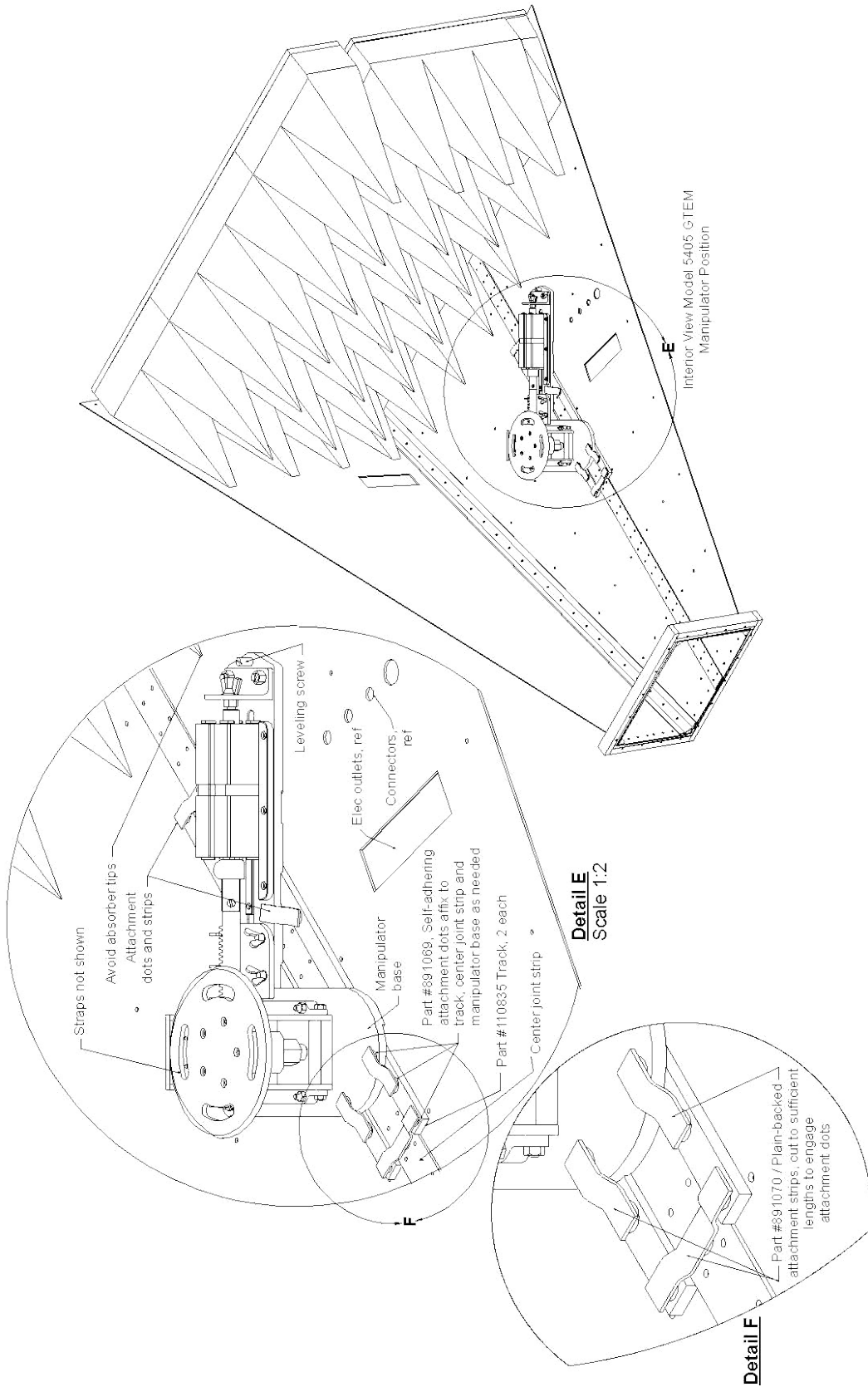


Ortho-Axis Positioner for Model 5405







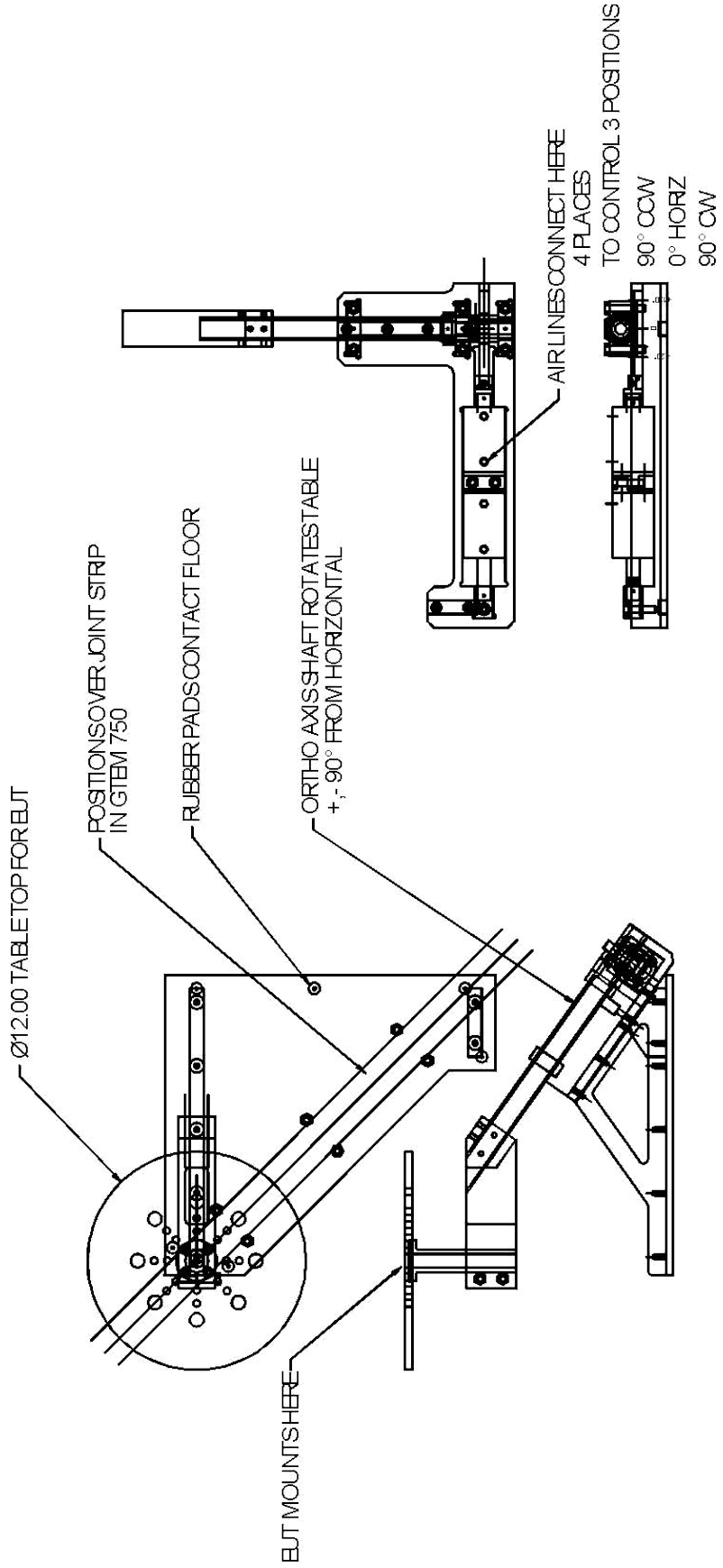


Interior View Model 5405 GTEM
Manipulator Position

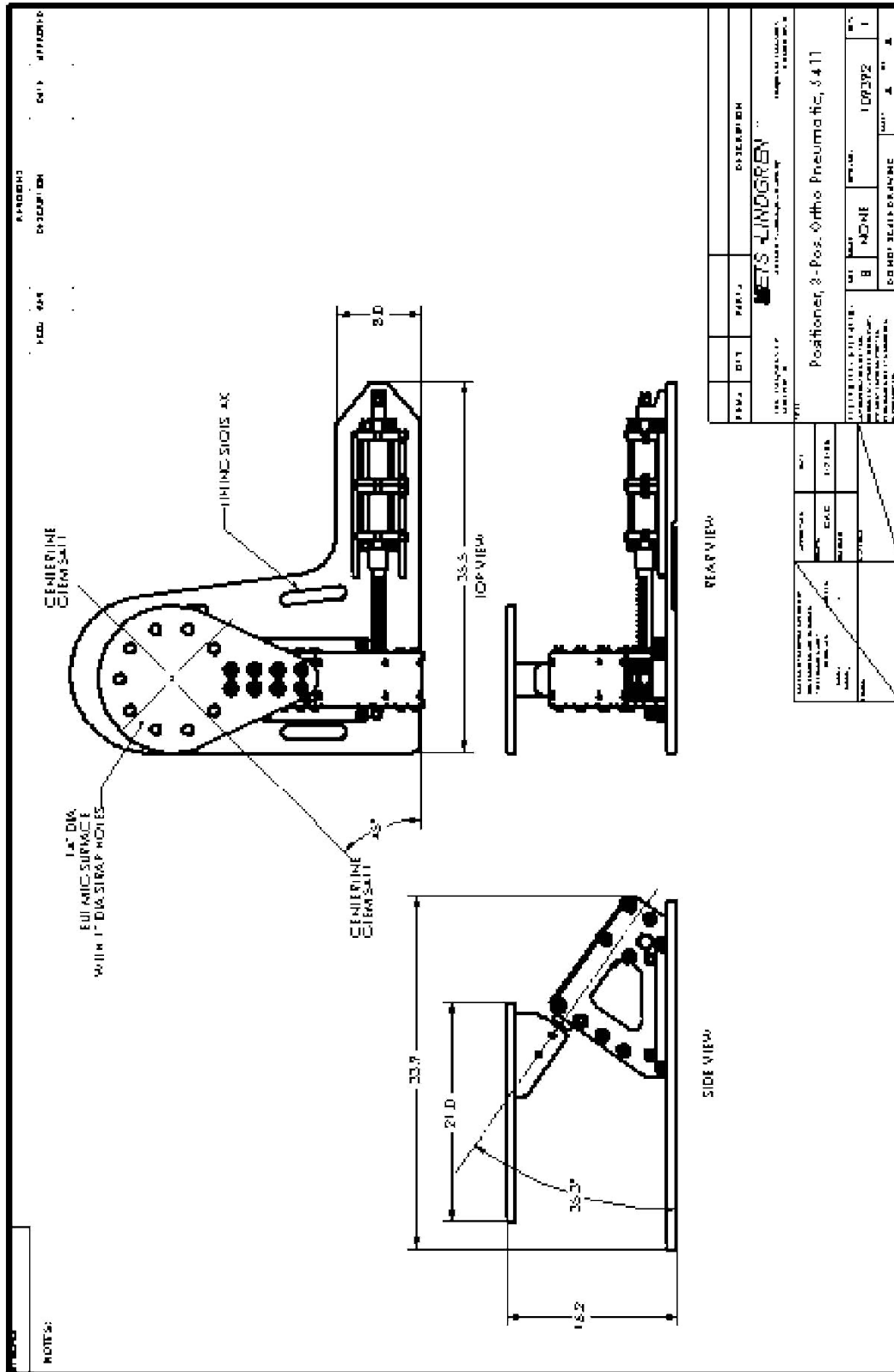
Detail E
Scale 1:2

Detail F

Ortho-Axis Positioner for Model 5407



Ortho-Axis Positioner for Model 5411



8.0 GTEM! Manual EUT Positioner (Optional)

Manual EUT positioners are designed for use with Model 5407 and Model 5411 to aid with the accurate positioning of the Equipment Under Test (EUT). The EUT positioner used in the Gigahertz Transverse Electromagnetic (GTEM!™) Cell facilitates rapid testing of the EUT using not only the standard three position test procedure, but nine, twelve, twelve-plus-four, and other test procedures that are needed to provide near-field measurements and to characterize special EUT.

Electromagnetic compatibility (EMC) measurements in the GTEM! require that the EUT be measured in at least three orthogonal positions. This is necessary to ensure that enough data is collected to predict or correlate the performance of the EUT to measurements on an Open Area Test Site (OATS) or in a semi anechoic chamber. Whether measuring the EMI emissions or immunity of EUT, tests must be made in several positions. Positioning the EUT for each measurement can be done manually, but this can be time consuming and can require two or three people to reposition the EUT inside the GTEM!. Not only does changing the EUT position take time, but also supplies of low-permittivity dielectric materials are needed to support it in each measurement position. The time to manually position the EUT can be the major part of the total test time when nine or more positions are needed.

EUT Positioner Platform Apparatus

The positioner platform apparatus consists of a cradle with EUT turntable (top turntable), and a cradle support frame also with turntable (bottom turntable). Rotation is possible in three axes: the bottom turntable azimuth axis perpendicular to the floor of the GTEM!, the top turntable azimuth axis perpendicular to the bottom of the cradle, and the cradle horizontal tilt axis. The positioner for the Model 5407 is shown in *Manual EUT Positioner – Model 5407* on page 52. The positioner for the Model 5411 is similar in physical appearance and is sized to fit the recommended test volume of the larger test cell. The EUT turntable includes holes for anchor points to secure the EUT during testing. The positioner is constructed of low-permittivity wood and non metallic fasteners to minimize perturbation of the electromagnetic fields.



The term *positioner* can be used interchangeably with the term *manipulator*.

9.0 Manual EUT Positioner Operation Theory

Measurements in a GTEM!

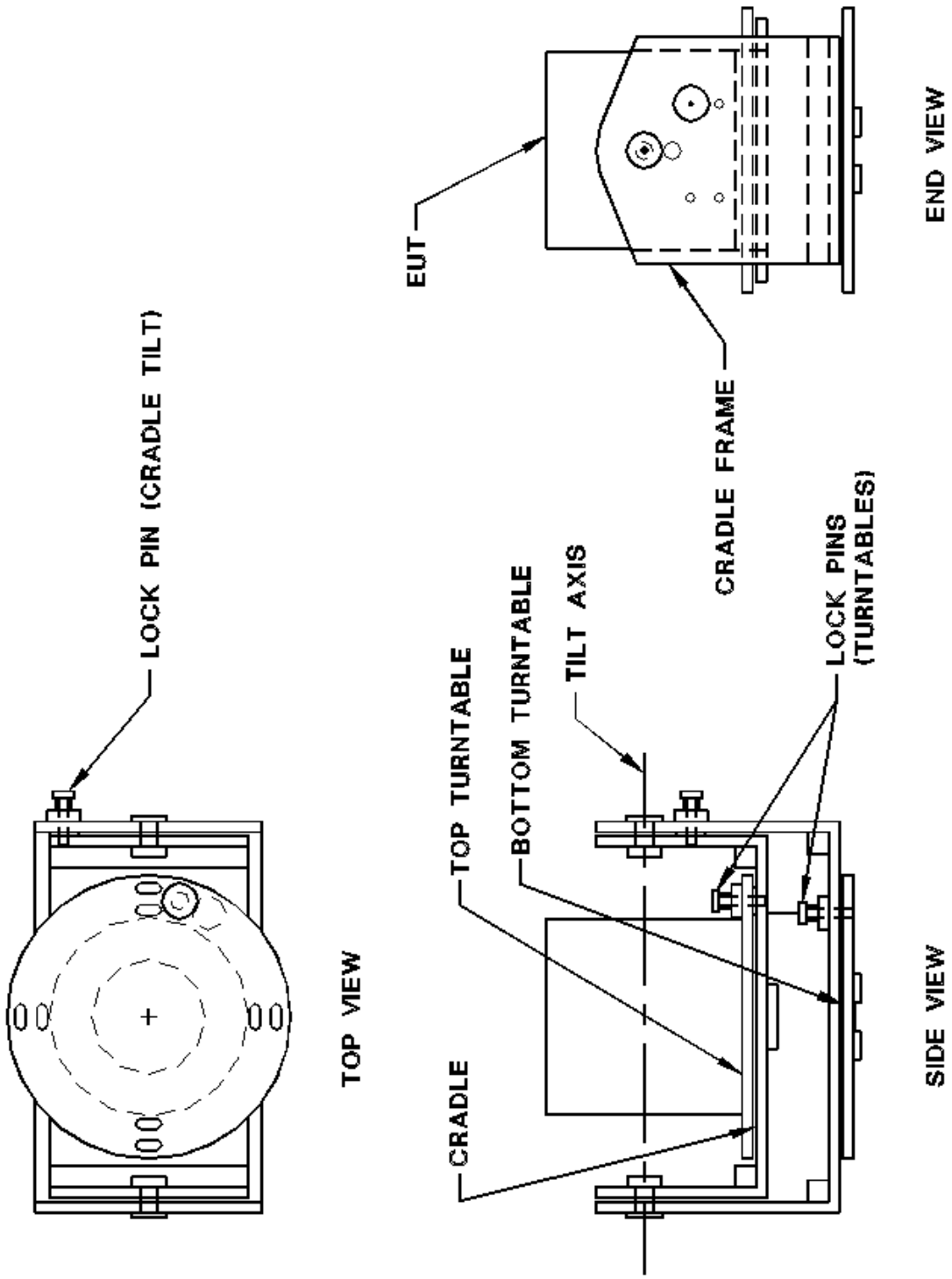
A Gigahertz Transverse Electromagnetic (GTEM![™]) Cell may either receive or transmit; thus electromagnetic interference (EMI) measurements in a GTEM! may be of either emissions or immunity. Among emissions measurements are far field, near field, and some special measurements. To predict the performance of the Equipment Under Test (EUT) during measurements of emissions on an Open Area Test Site (OATS), the emissions must be measured in a specific set of positions in the GTEM!. Predictive EUT performance on an OATS by making measurements in a GTEM! is also called correlation, and the mathematical process is often called the correlation algorithm.

Far-Field Measurements

Simplified far field measurements may be made of EUT in a GTEM! to predict or correlate OATS measured emissions. These measurements are usually made to show compliance to standards, such as CISPR 22 or FCC Part 15, in which it is only necessary to know the maximum E field versus frequency within a specified range of heights at a certain distance. For example, FCC tests for home computers search heights from one to four meters above the ground at a distance of three meters over the frequency range of 30 MHz to 5 GHz. These simplified measurements require emissions to be measured with the EUT in only three orthogonal positions. This is called the three measurement, three input correlation algorithm. The main simplifying assumption in this algorithm is that the EUT has gain no greater than a dipole; for example, a dipole radiation pattern.

Near-Field Measurements

Near field measurements may be made of EUT in a GTEM! to correlate emissions over the frequency range of 9 kHz to 30 MHz. This is called the nine measurement, nine input correlation algorithm, and requires measurement of emissions with the EUT in nine positions. The EUT is assumed to be much smaller than a wavelength in the largest dimension, a reasonable assumption below 30 MHz for EUT that will fit into a GTEM!. While this algorithm was originally intended for near field measurements below 30 MHz, it also works well for far field measurements above 30 MHz and should be valid from 9 kHz to 5 GHz.



Special Measurements

Special measurements are sometimes required because the EUT may have gain greater than a dipole, in which case the radiation pattern may be cardioid or other unidirectional pattern. Above about 500 MHz, some EUT may have an incidental unidirectional pattern because of the way they are constructed, but others have a unidirectional pattern because they are intentional transmitters with a built in antenna. Two algorithms may be used depending on what one wants to know about the EUT. The simplest one is the 12 measurement, sorted three input correlation algorithm, and the other one is the 12+4 position correlation algorithm. In both of these algorithms, the EUT is viewed as a cube and measurements are taken of the emission from each face in both polarizations. The 12 measurement, sorted three input correlation is used when it is not necessary to know anything about the shape of the radiation pattern of the EUT. It is often used to test small telecom terminal equipment, such as cellular telephones, up to 10 GHz. It is valid from 30 MHz to at least 10 GHz. The 12+4 position correlation algorithm is used to estimate the shape of the radiation pattern of the EUT. It is valid from 30 MHz to 5 GHz.

Immunity Measurements

Immunity measurements may be made in the GTEM! to satisfy standards such as MIL STD 462 or IEC 61000 4 20. If the shape of the radiation (sensitivity) pattern of the EUT is unknown, then the front, back, and both sides must all be exposed to the test signal in both horizontal and vertical polarizations. To do this, eight positions must be tested so that the four usually vertical sides of the EUT are tested in both polarizations facing the apex of the GTEM!. If the operator already knows that only one side (for example, the back) of the EUT is sensitive to external electromagnetic fields, then the testing can be reduced to exposing only the one sensitive side to the apex of the GTEM! in both polarizations.

Installing the Positioner and EUT

Position the cradle turntable, base turntable, and cradle tilt to the 0 degree marks. For the Model 5407, place the positioner such that the grooves straddle the center seam strip. The suggested start position is with the cradle side plates perpendicular to the center longitudinal seam, and spaced approximately 20 cm from the absorber tips. Place the EUT on the cradle turntable and secure it with non metallic cords or rope. Polystyrene blocks may be placed under the EUT for elevation before securing. For the Model 5411, place the positioner so that the unit is positioned approximately 20 cm from the absorber tips. Center the positioner along the longitudinal axis of the GTEM!. Rubber feet will help maintain the position during testing.

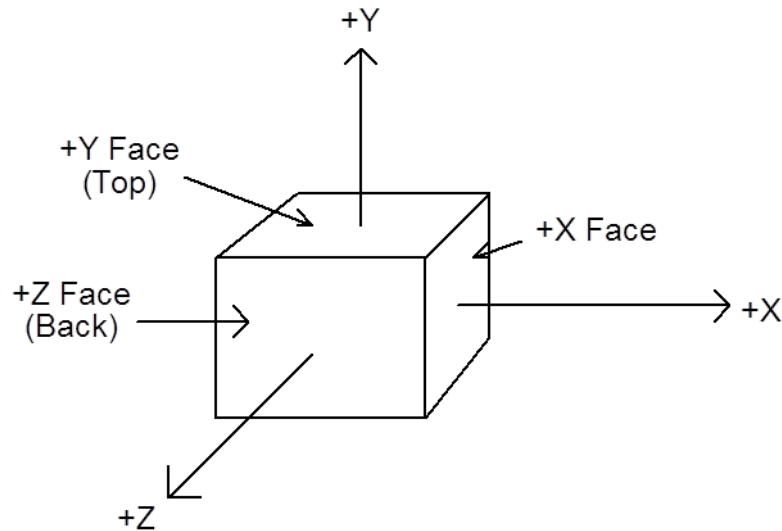
Naming the EUT Faces

For the purpose of this discussion, consider the EUT as a cube. The following illustrates a three dimensional Cartesian coordinate system with a cube centered on it. The face from which a positive axis emerges is named for that axis; for example, **+X** is the face of the cube from which the positive X axis emerges. Name the front of the EUT **-Z** and the back **+Z**. Looking at the **+Z** face (the back), name the right side **+Z** and the left side **-X**. Name the top **+Y** and the bottom **-Y**.



The term *positioner* can be used interchangeably with the term *manipulator*.

EUT as a Cube on Cartesian Axes Showing Names of Faces



This is the coordinate system for the EUT. Note that the three orthogonal positions of the EUT exchange the EUT coordinates relative to the GTEM! coordinates. The first position is identified as **XYZ**, the second as **YZX**, and the third as **ZXY**; the voltages measured at the apex of the GTEM! in the three positions are called **V_{xyz}**, **V_{yzx}**, and **V_{zxy}**.

EUT Positions

Emissions tests all require sets of positions, which are built on the basic three orthogonal positions needed by the three measurement, three input correlation. Immunity tests require positions based on the test standard; these are not necessarily extensions of the basic set of three orthogonal positions.

Sets of Positions Needed

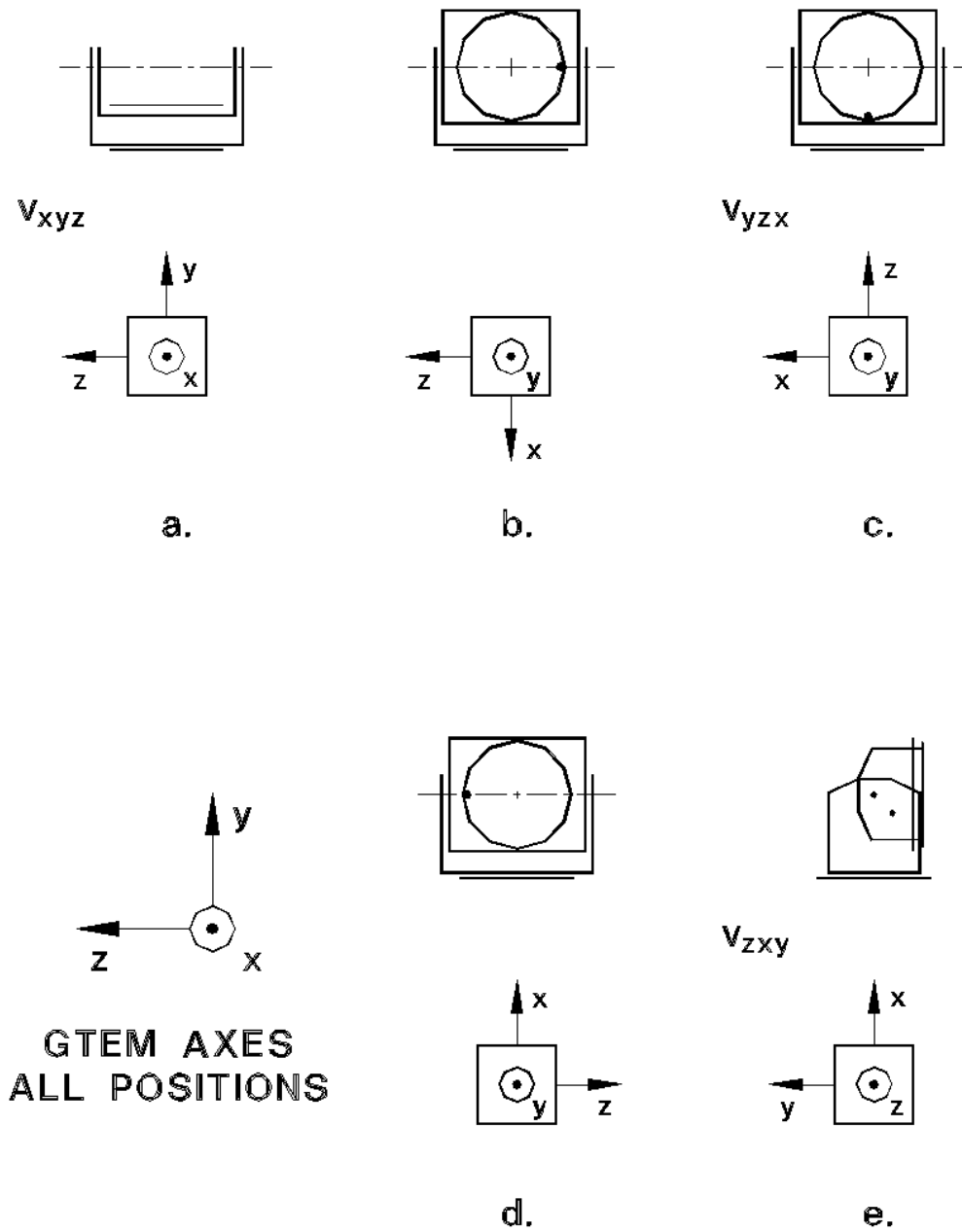
For the three measurement, three input correlation, any set of three orthogonal positions can be used. A typical rotation series is as follows.

For the Model 5400 Series with the door on the right side (looking from the apex), position the positioner with the 0 degree mark pointing toward the right side of the door. Secure the EUT to the top turntable.

See *Manual EUT Positioner Positions for Three Position Emissions Test – Model 5400 Series* on page 55 for these steps:

- **a**—Shows a schematic of this arrangement as seen looking in the door. This is the first test position used to measure **V_{xyz}**.
- **b**—Release the cradle tilt lock pin and swing the cradle away from the door to the 90 degree tilt position. The EUT x axis now points down, as shown.
- **c**—Rotate the top turntable to 90 degrees (as shown), and measure **V_{yzx}**.
- **d**—Rotate the top turntable to the 180 degree position.
- **e**—Rotate the bottom turntable to 90 degrees and measure **V_{zxy}**.

Manual EUT Positioner Positions for Three-Position Emissions Test - Model 5400 Series



For the nine measurement, nine input correlation, at each of the measurement positions shown in figures x, x, and x, rotate the bottom turntable +45 degrees and take additional voltage readings. For the 12 measurement, sorted three input correlation, and for the 12+4 position correlation, contact the factory for the suggested mini positioner positioning. The 12 measurement, sorted three input correlation eliminates the assumption of gain no greater than a dipole, and can be used to do tests in which the power at the dipole terminals need to produce the same emission level measured from the EUT. The 12+4 position correlation estimates the directivity, and thus the gain of the EUT, then uses this estimated gain in the three measurement, three input correlation.

Appendix A: Warranty

See the *Product Information Bulletin* included with your shipment for the complete ETS Lindgren warranty.

Duration of Warranties for Model 5400 Series

All product warranties, except the warranty of title, and all remedies for warranty failures are limited to two years.

Product Warranted	Duration Warranty Period
Model 5400 Series Gigahertz Transverse Electromagnetic (GTEM! TM) Cell	2 Years

Results of Statistical Analysis

The general results of the statistical analysis are shown in the following tables.

Table 11: Correlation of Data from the First Three Dipole Measurements and the First Two Personal Computer Measurements

Coefficient	Dipole I (Tables 1, 2, 3)	PC 1 (Tables 4 & 5)
R	0.941	0.988
a	-2.36	+3.30
b	+1.00	0.95

