Application Note # 34A
The ARCELL - Immunity and Emissions Testing

The ARCell is a passive shielded enclosure in which to place an EUT (equipment under test) in order to test it for radiated immunity (radio frequency energy affects equipment) or radiated emissions (equipment produces radio frequency energy). It offers a unique combination of features which facilitate the addition of peripheral (active) components to create a complete test system. The resulting configuration offers a practical, easy startup, easy to run facility for evaluation and pre-compliance radiated immunity and radiated emissions testing.

The ARCell test system is most appropriate for groups that are developing electronic equipment to which regulatory radiated immunity specifications apply, or which must be able to function and operate safely in moderate Radio Frequency (RF) field environments. These applications include regulatory EU and military requirements, automotive and medical environments. These cells are targeted to offer this testing capability to development groups in evaluating electronic hardware at various stages in the development process. Early experimental evaluation helps to promote an awareness of the technical issues involved in creating compliant products. While these cells are primarily selected for radiated immunity testing, they also offer a convenient and quiet site for radiated emissions testing, avoiding the site-dependent and time-dependent ambient interference problems commonly encountered when testing is conducted in open areas.

This Application Note is intended to supplement the current ARCell product specifications, which provide the detailed product description. Refer to these product specifications for technical characteristics of the ARCell and the ARCell Test Systems. Contact AR RF/Microwave Instrumentation for special configuration or performance requirements.

The ARCell

The interior of each ARCell enclosure lined with a radio frequency absorbing material creates a self-contained semi-anechoic enclosure which includes field launching/receiving devices. An internal log periodic antenna acts as a launching/receiving device in each cell. Three cell sizes are offered ranging from floor standing to room size. In the two larger cells, the launching/receiving device can be rotated to provide vertical or horizontal polarization as is usually required for both immunity and emissions testing. In the smaller cell, the polarization is vertical, and balanced parallel plate TEM (transverse electromagnetic) transmission lines are used at the lower frequencies. In these cells, which accommodate smaller EUTs, horizontal polarization is simulated by re-orienting the EUT.

The absorber material used inside the cells is selectively applied carbon impregnated foam. It is hidden from view and protected from damage by rugged covering materials. The launching/receiving devices that reside in the cell are in fixed positions and similarly hidden from view and protected from damage. The fixed location and protection eliminate variations in measurements due to changes in the placement of antennas and mechanical damage to the absorbing material. The absorber material has been selectively applied to create a practical level of field uniformity.

These cells are used by installing the EUT in the designated test area on a small non-conducting table or stand. The EUT is re-oriented during testing to enhance its likely susceptibility or emissions as appropriate. The EUT is connected and used as close to its normal application as practical, within the space constraints of the cell. Expected problem configurations would be checked. The ARCell size determines the maximum EUT size that can be tested.

The smaller cells are ideal for pre-compliance and evaluation testing during product development. They occupy little lab floor space yet permit testing of most PC board sizes and many complete small unit electronic assemblies. The larger cells accommodate larger assemblies up to the size of a one meter cube. Cell floors are rugged and support at least 500kg (1100 lbs) when the load is spread uniformly.
The cell size just right for an application is selected based on the largest EUT to be tested, so the user buys only the test space needed.

ARCell selection is based on EUT size. Refer to AR RF/Microwave Instrumentation's current ARCell product specifications for size, additional selection criteria and recent performance enhancements.

ARCell	TC2000C	TC3000B	TC4000B**
Max. EUT Size (each side)	50.0 cm (19.7 in.)	100.0 cm/side (39.3 in.)	100.0 cm/side (39.3 in.)
Door Opening (H x W)	112.0 x 83.0 cm (44.1 x 32.7 in.)	180.0 x 100.0 cm (70.9 x 39.4 in.)	180.0 x 100.0 (70.9 x 39.4 in.)
Frequency Range	10 kHz – 2.7 GHz	*27 MHz – 4.2 GHz	*27 MHz – 4.2 GHz

* Select optional bowtie antenna to test in the 27 – 80MHz frequency range.
** More interior space allows the TC4000B to accommodate testing at three meters, the test distance preferred in IEC1000-4-3 from 80 to 1000MHz.

The recommended maximum EUT size limit listed above for each cell takes into consideration the dimensions of the area of uniform field (for immunity testing) and access door opening. Slightly larger EUTs may be installed with reduced uniformity (TC2000C –70 cm cube). The relative enclosure size of each cell is shown below, along with the approximate location of the door to the user access area.

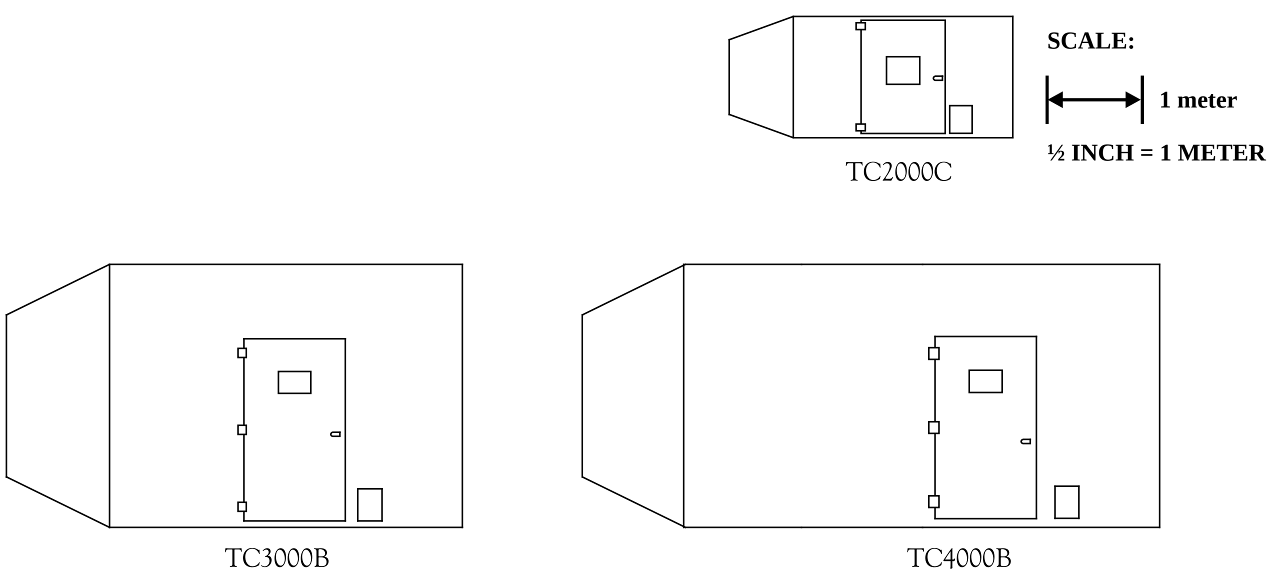


Figure 1: ARCell Diagrams

The smaller size is shipped assembled. The two larger sizes are shipped in kit form and are then fully assembled on the user site in a few days. More detailed installation information for each individual cell is available from AR RF/Microwave Instrumentation.
When planning a site, users should allow appropriate clearance for the cell and for access per the installation information. Check that doorways, elevators and other obstructions permit moving the cell into its targeted location(s).

Connections to the EUT
While some EUTs are self-contained (e.g. battery powered devices for emissions testing or battery powered devices with a visual or acoustical indication for immunity testing) most EUTs require connections to equipment outside of the ARCell. Some may even require mechanical activation during a test –a keyboard for example. These connections are typically; fiber optic (FO), status in/out, control in/out and power.

When making these connections, care must be taken during emissions testing so as not to permit excessive leakage of the RF signals from inside the cell, which may interfere with external electronic equipment or create a personnel hazard. Likewise, care may be needed to keep external fields from entering the cell if the EUT is unusually sensitive (such as in tests of radio receiving equipment) or if internal field levels must be kept low to facilitate observations during emissions testing. Although a thorough treatment of this subject is beyond the scope of this application note, some guidelines related to the ARCells follow. The first and most important step is to minimize the number of connections.

The best approach to providing needed connections are fiber optic (FO) cables (all information encoded as light signals) with physically small, shielded electronic/FO (or FO/electronic) converters located near or inside the EUT. A 2.2 cm ($^7/_8$ inch) diameter metal tube allows the FO cable to pass thru the cell wall. This tube acts as a "waveguide below cutoff" for frequencies in the cells' range. As long as no metal (electrically conducting) elements are passed thru the tube, significant (RF) energy does not pass.

Typically, field probes intended for measurement of moderate fields are supplied with FO links. Many standard digital interfaces (RS-232, GPIB, Parallel) and analog interfaces (NTSC, VIDEO) are supported by commercially available FO converters. Specialized instrumentation can be used to convert monitor points to FO signals or to create electrical control signals from FO signals. For mechanical activation, pneumatic actuators may be the best approach with air lines passed thru the same metal tube. Detailed visual analysis of an EUT might benefit from FO light transmitting viewers (light pipes). Alternatively, special battery operated television cameras with FO links can be used for real time monitoring.

Status and control signals which have not been converted to FO form should be waveshaped to slow their rise/fall times and then passed thru the cell walls via RF filters. The ARCell supports lightly filtered lines. Cables inside the cell which are not part of the item tested should be kept as short as possible.

AC power lines should pass thru the cell wall via RF filters. The ARCell includes a moderately effective single phase line filter with easy internal access via grounded IEC sockets. AC cables inside the cell which are not part of the items being tested should be kept as short as possible. If AC is not needed to operate the EUT or for internal cell lighting, it is recommended that it not be connected to the cell.

One Type N connector is provided to pass RF signals through the cell wall. Use only good quality double braid or solid shielded coaxial cables both inside and outside the cell.

Some EUTs require more wire or coaxial connections or improved isolation via filtering. To facilitate cell use with a large variety of EUTs, a removable access plate is provided for custom modification by the user. For example, an EUT requiring three phase power would require a three phase filter. This could be mounted externally to the access plate and wires fed via a short solid conduit. Select a filter with an inductor toward the interior of the cell.

In all cases, safety is a primary issue and care must be taken to comply with applicable electrical codes with careful attention to safety grounding (earthing) of the cell, and the chassis of any primary power AC filters.

Since internal RF field levels during immunity testing can reach hazardous levels, the RF input should not be applied to the cells with humans inside, with the access door open; with the access plate removed or if there are any signs of damage that might lead to excessive leakage. Since proper operating procedure requires positive disabling of the RF power source when the door is open, each cell offers a "door open" interlock line which should be connected to disable the RF source whenever the door is open. The larger cells which are walk-in size have an inside-the-door latch release mechanism to allow the careless, or those with mischievous associates, to make a graceful escape before the next immunity tests reduce their reproductive, visual, or cognitive capabilities.

With proper wiring and use of supplied filters, individuals outside of the cells are usually adequately protected from RF test fields. With proper application, the field at 1 meter from the cell is typically more than 60dB below the field applied in the test plane during immunity testing.

Heat from the EUT

The ARCells are large enough to transfer the heat of typical EUTs plus the applied RF power without concern. However, when the total of RF plus EUT power dissipated approaches the following levels, it is recommended that EUT temperature be monitored.

Cell	Monitor EUT temperature when total cell power dissipation exceeds:
TC2000C	1000 watts
TC3000B	2000 watts
TC4000B	3000 watts

Power levels based on approximately 20°C ambient temperature rise

If excessive temperatures are noted or if testing at a controlled temperature is required, steps should be taken to limit the temperature rise such as: shorten the test, add a fan inside to circulate the air, use cooling gas during the test or add forced ventilation thru the metal tube.

For greater power handling, the user access plate could be modified to add an EMI (honeycomb or equivalent) filter, and then a blower or ducted air added for increased cooling. Cooled air could be introduced into the cell but should not enter at a temperature below 10°C.

Calibration of Field for Radiated Immunity Testing

Calibration of the ARCell for radiated immunity testing is based on the approach provided in paragraph 6.2 of IEC 1000-4-3:1995. As applied to the ARCells, a uniform area is a hypothetical vertical plane in which the EUT and its wires can be fully illuminated by a field (down to a 0.5 meter square) with acceptably small field variations.

The uniform area is calibrated in an empty enclosure - without the EUT. It is calibrated using field sensors spaced a short distance from the field generating log periodic antenna and centered vertically between the balanced TEM transmission lines used in the two smaller cells at the lower frequencies. Calibration in the largest cell is performed with field sensors at approximately 3 meters from the field generator from 80-1000MHz. The location of the uniform area is identified by marking in each individual ARCell.

A field is considered uniform at a frequency if its magnitude over the defined area is within –0dB to +6dB of nominal value, over 75% of the surface. The tolerance is expressed as –0dB to +6dB to ensure that the field does not fall below nominal. In practice, some limited number of field measurement locations spread uniformly across the vertical plane is chosen and up to 25% of the measurements are discarded. The remaining 75% of the measurements - if within a 6dB envelope - determine the minimum RF input power required to generate the test field. Other calibration methods can be used which may meet specific user requirements or may require a lower RF input power

The formal IEC requirement for a 1.5 meter square test plane locates sensors in 16 positions on a 0.5 meter grid. ARCell calibration is typically performed as follows:

TC2000C 5 point

TC3000B 9 point

TC4000B 9 point

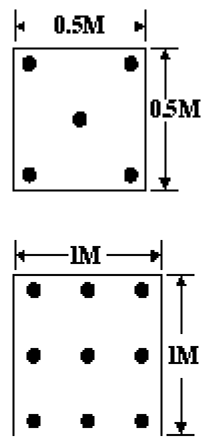


Figure 2: Typical probe locations in the test plane

A representative calibration process is:

1. Place the isotropic field probe in the correct location.
2. At 1% frequency steps, set input RF power level for 5 V/m field (or other known level) measured by the field probe.
3. Measure and record RF power input to the ARCell.
4. Repeat 1-3 for each of the 5 or 9 locations.
5. For the two larger cells, repeat 1-4 for each of the 9 locations with the antenna set for horizontal. (The ARCell antenna is re-oriented by rotating a handle inside the cell).

The array of data relating drive power and frequency at each test location is then converted to a calibration file. The data array is examined to select the best locations to be discarded with two objectives:

1. Obtain field uniformity
2. Minimize drive power required

The first priority in selecting discards is uniformity. If the measurement used 9 points, then discarding two points is only a 22% discard, so there is a disadvantage by applying the 25% discard criteria (to probe counts not evenly divisible by 4). To discard 3 points at each frequency may be considered excessive, so, as a practical measure, an allowance may be made for a third discard for 25% of the frequencies which brings the total discard to exactly 25%.

The second function of discarding measurements is to minimize the drive power required. This is not discussed in the IEC specification but is a practical approach to minimize the power rating required for the amplifier. If 2 points have not been discarded from a 9 point calibration, then the number of discards is increased to 2 by deleting the largest values (highest power) in the array. This has the effect of reducing the drive power required. Having discarded unwanted values the largest value (highest power) for each frequency is then increased by 6dB (when the calibration was done at 5V/m) and written into the calibration file. The calibration file consists of alternating frequencies expressed in Hz, and drive power in dBm to give 10 V/m stress value. (A similar approach is used for a 5 point calibration).

The exact procedure used is typically determined by the computer controlled calibration routine. Calibration software may use this or other alternative procedures to develop a calibration file.

When used to set other field levels during EUT testing, the input power is adjusted to produce the targeted field level. For example, to test at 3 volts per meter stress level, the input power is reduced by 20 $\log_{10} \frac{3V/m}{10V/m} = 10.5dB$ relative to the level in the calibration file.

Calibration of Cell for Radiated Emissions Testing

Calibration of the ARCell for radiated emissions testing is based on using a transfer standard from an open area test site (OATS). An OATS is the basic environment in which radiated immunity limits are defined for FCC requirements (FCC – Part 15) and EU requirements (EN 55022). Formal tests to these requirements are usually conducted with a receiving antenna located 3 meters or more from the EUT. Other specifications (MIL-STD-461D-1993 for example) perform tests at a 1 meter distance – and such tests are usually conducted in shielded enclosures to limit ambient interference. In spite of the use of a transfer standard for the calibration, emissions measurements of an EUT in the ARCell – as in other enclosures – will vary in their correlation to measurements on an OATS or other test environment depending on the enclosure characteristics and the specific emission pattern of the EUT.

Additionally, the various specifications provide specific requirements for equipment setup, some of which cannot be readily duplicated in an ARCell. While these significant practical limitations preclude the use of an ARCell for compliance emissions testing, it is considered to be a reasonable pre-compliance-test predictor of OATS performance. It offers a convenient, quiet environment for pre-compliance testing, or for evaluation of spectral emission frequencies in preparation for compliance testing.

The ARCell emissions calibration typically is carried out using a comparison noise emitter (CNE) designed by York University (York, UK) as a tool for comparing different OATS. The CNE (a stable broadband noise source feeding a short monopole antenna) is carefully calibrated on an OATS at a 10m test distance for use as a transfer standard.

To calibrate an ARCell, the calibrated CNE is moved to five different locations in the chamber. The locations are the center of a test circle in a horizontal plane plus four locations around the test circle.

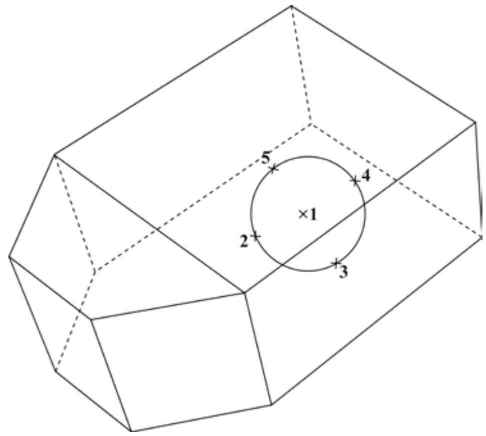


Figure 3: Position 2 is located in the vertical uniform area defined for immunity testing.

Emissions Calibration Locations

The test circle is 1 meter in diameter for the two larger cells and 0.5 meters in diameter for the TC2000. For each location, the RF signal level sensed by the ARCell transducer(s) [antenna(s)] is measured. Five or ten sets of data are obtained.

A representative calibration process is:

1) Place CNE in the correct location
2) Measure and record the ARCell output RF level (dBµV) using the test calibration bandwidth (BW) or an available BW and BW correction factors. A suitable spectrum analyzer or receiver is used to measure the RF level. Repeat for a total of 101 frequencies over the range of 30 –1000MHz.
3) Repeat 1-2 for each of the 5 locations
4) For the two larger cells, repeat 1-3 with the ARCell antenna and CNE set for horizontal

The vertical/horizontal results at each frequency are typically averaged (in dBµV) and adjusted by the CNE calibration data to give a table of correction factors. When these factors are added to the received level (dBµV), the result is the value (dBµV/m) which would have been measured on a 10meter OATS. Separate vertical and horizontal calibrations are produced for the two larger cells.

The variation between the maximum and minimum values in the calibration data at any frequency is typically less than 8dB at 75% of the frequencies - but can rise to 15dB or more at a few frequencies.
Other methods of processing the measured data may be used. The exact procedure used is typically determined by the computer controlled calibration routine. Calibration software may use this or other alternative procedures to develop the correction factors.

Connection to the ARCell

The ARCell has two <u>required</u> external connections. For immunity testing, RF power must be supplied to the RF (Type N) connector. This RF is routed to the log periodic antenna field transducer inside the ARCell. To route the RF to the alternate transducer (balanced TEM lines in the two smaller cells or bowtie antenna in the two larger cells) for low frequency testing, the user applies +12VDC to a second adjacent connector (Type BNC). Refer to ARCell product specifications for amplifier power requirements vs. field level.

These same connectors are used for emissions testing. The RF power source used for immunity testing is disconnected and a spectrum analyzer (with preamplifier, if needed, or a receiver) is connected to the RF connector. The user supplies +12VDC to the second (BNC) connector for low frequency emissions testing.

For testing from 27-80MHz in the two larger cells, it is also necessary to put the bowtie antenna into the cell and to attach an internal RF connector. The bowtie location is identified by marking within the ARCell.

Immunity Testing

Testing for radiated immunity is the principal function for which the ARCells were designed. The preceding description of the cells, connections and field calibration offers a very basic insight into use of the cell and its features. This guidance, together with detailed ARCell product specifications, can help the potential user to determine how to use external instrumentation to meet his testing needs. User needs vary- from a very basic set of external instrumentation (RF signal generator, RF amplifier) that might be used for manual only testing of battery powered EUTs with built in fault alerts, to more extensive instrumentation for semi-automatic testing, exercising, monitoring, EUT reorientation, data recording, and report preparation. The optimum choice is determined by the user's test workload and budget.

Some testing applications give preference to using field probe(s) to measure and control the level of the field during a test of the EUT. This approach offers an alternative methodology and a handy approach to continuous sweep testing. By adding field probe(s) and probe controller, a closed loop field leveling system can be implemented. In this case the immunity calibration file is not needed.

An example of a commercially offered set of instrumentation for immunity testing is shown in the system block diagram below. It describes the logical elements and signal flow in a fully configured FS2010 system based on the TC2000C cell. This system, plus systems using the other cell sizes are offered by AR RF/Microwave Instrumentation for immunity testing.

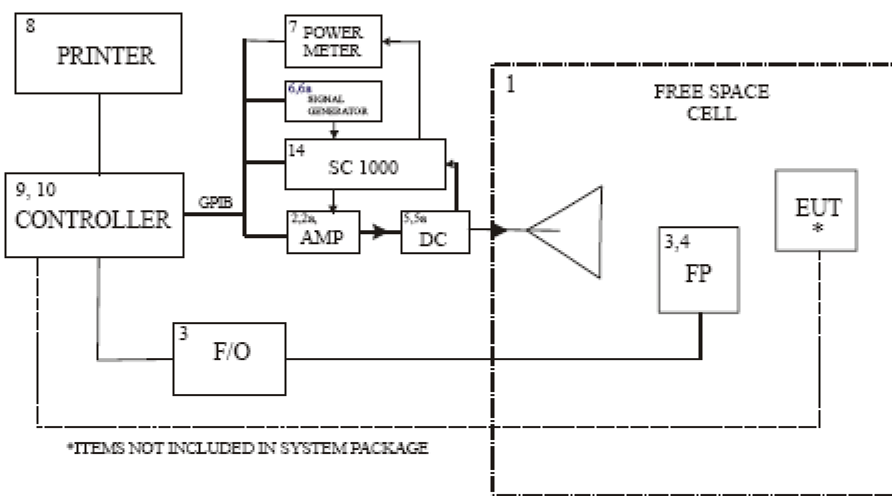


Figure 4: FS2010 System Block Diagram – Immunity Testing (Calibration shown dotted)

When fully configured with signal generator, computer, immunity test software and calibration files for the specific cell, a typical application of the system is to:

1) Setup a test. User sets up the required test parameters such as start/stop frequency, log or linear sweep, stress level, depth and frequency of AM modulation or pulse modulation, and sets up response monitoring. Test frequencies should be selected to match the frequencies of calibration. When smaller steps are selected, a linear interpolation of the two adjacent values is applied.
2) Run a test with the unit in a fixed orientation over a cell frequency range compatible with the instrumentation (amplifier and RF synthesizer may limit the range of a single pass).
3) Monitor and record levels on a number of analog and digital EUT response lines. Control or reset EUT via digital control lines.
4) Limit RF field level based on preset response on one sensitive response line. Since the field strength reduction is recorded during the test, the field strength provides a powerful graphic indication of the degree of failure- in terms of depth in stress voltage and breadth in frequency.
5) Communicate over standard interfaces, RS-232 to an EUT, or IEEE-488 to test equipment which may be exercising /monitoring the EUT in synchronization with the testing.
6) Use existing run values for fast repeat of a test. Test at other EUT orientations.
7) Generate test report.

Emission Testing
Testing for radiated emissions is a secondary function for the ARCells. The preceding description of the connections and emissions calibration offers a very basic insight into the use of the cell and its features. This guidance, together with detailed ARCell product specifications can help the potential user to determine how to configure external instrumentation to meet testing needs. User needs vary – from a very basic set of external instrumentation (RF preamplifier and spectrum analyzer or receiver) that might be used for manual only testing of self exercising EUTs, to more extensive instrumentation for semi-automatic testing, exercising, EUT reorientation, data recording and report preparation. Some applications may require only a comparison of emissions to those of a reference product. In this case, the emissions calibration file is not required.

When selecting a spectrum analyzer or receiver, the user should select one with the features applicable to the test requirements. Key features include pre-detection bandwidth, detection system characteristics (AM, FM, etc.) and post detection processing selections such as quasi-peak and average. For use in an automated test system, a suitable standard I/O port is needed (GPIB / IEEE-488). As was the case with immunity testing, the optimum equipment choices for emissions testing are determined by the user's test work load and budget.

The immunity test instrumentation offered by AR RF/Microwave Instrumentation is an example of a commercially offered set of instrumentation designed to economically compliment the ARCell and be re-configurable for emissions testing. Description of typical operation for emissions testing will serve to further illustrate use of the cell.

The system block diagram for emissions testing shown below describes the logical elements and signal flow in a fully configured FS2010 system based on the TC2000C cell.

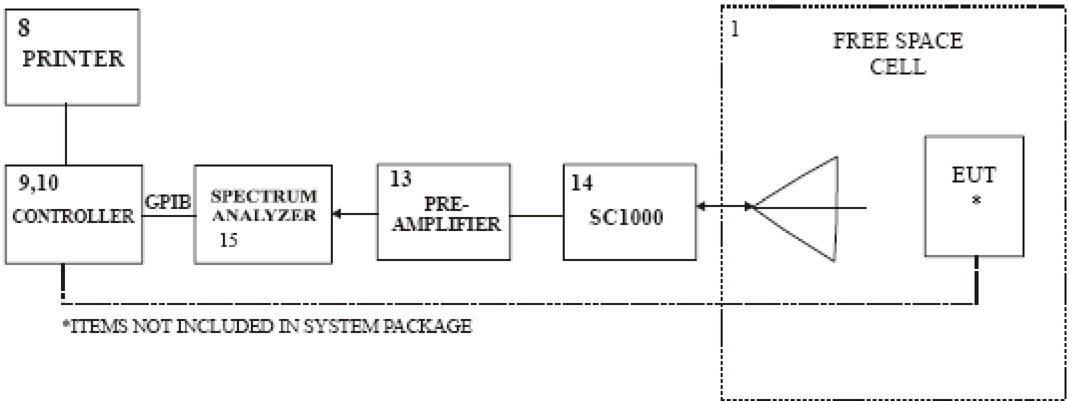


Figure 5: FS2010 System Block Diagram – Emission Testing

When fully configured with RF preamplifier and spectrum analyzer or receiver, computer, emissions test software and calibration files for the specific cell, a typical application of the system is to:

1) Setup a test: User sets up required test parameters such as start/stop frequency and post detection processing
2) When quasi-peak detection has been selected, the control program divides the test frequency range into 101 equal segments. Each of these segments is quickly examined with the spectrum analyzer in a peak reading mode. The frequency of the largest signal in each segment is selected, the analyzer is set to zero span and quasi-peak, and the signal is measured. This results in a quasi-peak scan being completed in approximately 5 minutes. When smaller frequency test steps are selected, a linear interpolation of the two adjacent values in dB is applied. Note that other algorithms for measurement are available in the FS2010 system.
3) Communicate over standard interfaces, RS-232 directly to EUT or IEEE-488 to test equipment which may be exercising/monitoring the EUT in synchronization with the testing.
4) Use existing run values for fast repeat of a test. Test at other EUT orientations.
5) Generate test report.

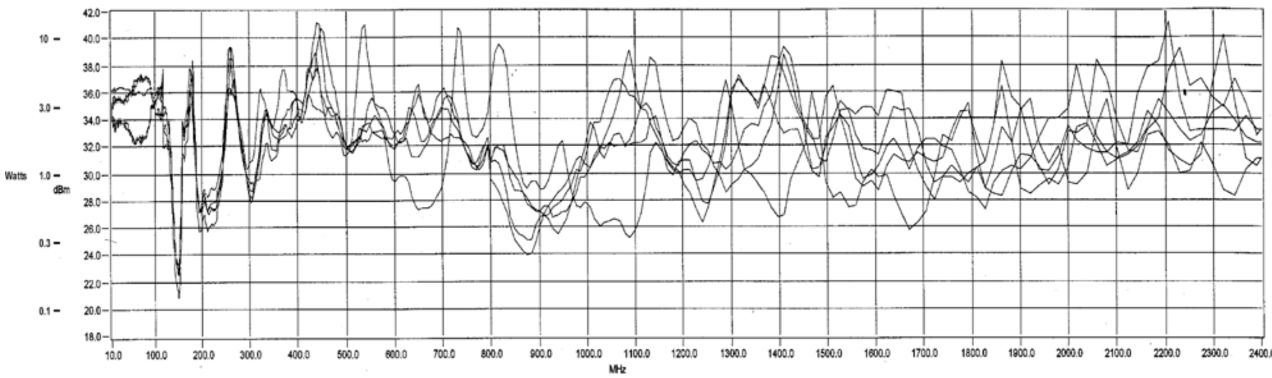
If a specific emission level is found to be close to a limit, additional steps may be taken to obtain improved correlation to OATS – the assumed reference site. Most important is to rotate the EUT and to look for the maximum received level at each frequency of interest. This is a process normally performed during an OATS test. In addition, to simulate the usual antenna elevation adjustment in an OATS test, it is important to re-position the EUT to obtain the maximum received level. (This is in place of raising and lowering the receive antenna which would be done in an OATS test, and is used to ensure that the received signal has not been nulled due to reflections). Recommended re-positioning is diagonally across the test space. The spectrum analyzer's peak hold mode is typically used to store the maximum level while rotating and re-positioning the EUT and this measured level is used to refine the field level value at the test frequency.

Cell Performance Data

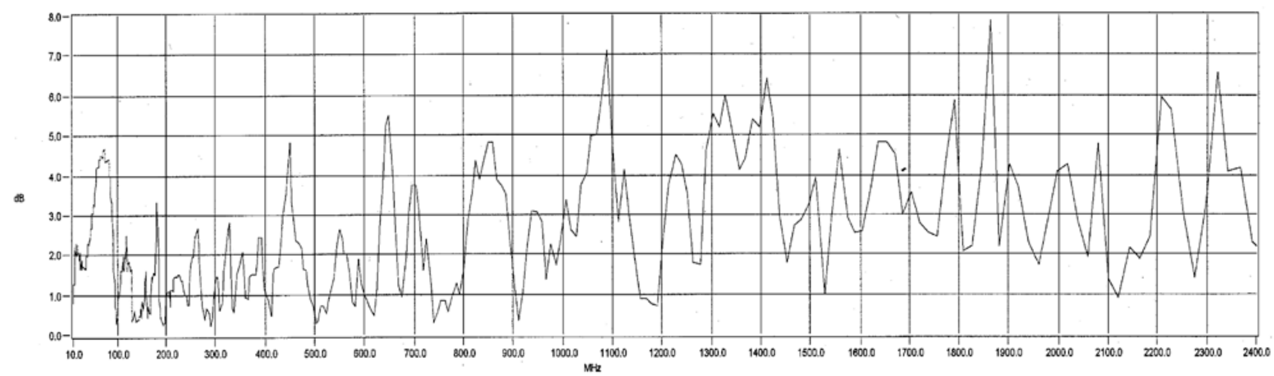
The following graphs of measured data are provided for those seeking additional insight into the RF performance of the ARCell. Data is for ARCell TC2000, S/N 21975. Contact AR RF/Microwave Instrumentation for results of ongoing developments to important field uniformity, increase frequency range, increase efficiency and field level.

IMMUNITY

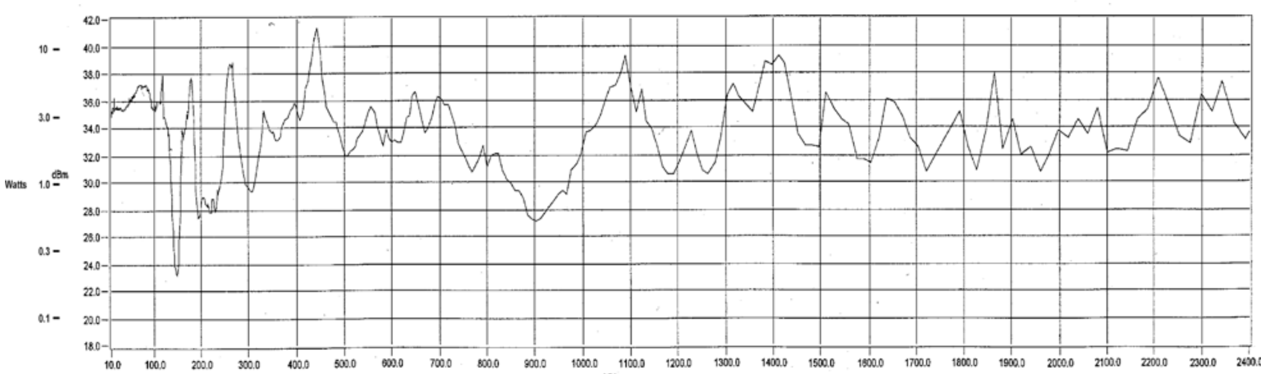
1) Example of input power to create a constant field of 10V/m CW at five locations in a test plane from 10MHz – 2.4GHz in one percent steps. These measurements were actually taken at a convenient field level between 3 and 10V/m and normalized to a 10V/m field. The log periodic antenna data is used at frequencies above 130MHz and the balanced parallel plate TEM lines data is used below 130MHz.



2) Example of input power variation (maximum minus minimum) after discard of up to 25%.



3) Example of plot of calibration table showing RF input power needed to produce a 10V/m CW –0, +6dB field.



Summary – The ARCells and Test systems

The ARCells constitute a family of passive shielded enclosures that offer a unique combination of features useful in experimental evaluations of radiated immunity and radiated emissions of moderate sized objects, up to 1 meter per side.

The ARCell's test systems compliment the cell to offer an economical series of practical easy startup, easy run facilities for experimental evaluation and pre-compliance radiated immunity and radiated emissions testing. These test systems cover a wide range of cost/performance applications for radiated EMC testing.
The larger ARCells offer a radiated immunity testing enclosure at a lower cost than traditional anechoic or semi-anechoic chambers – though the ARCells have moderate but distinct EUT size limitations.
In addition to this application note, potential users should refer to the ARCell and AR Test Systems product specifications; the test requirements (regulatory or environmentally required), ARCell installation information, and current AR price lists in order to select an appropriate configuration.