

SOURCES OF VARIABILITY IN SEMI-ANECHOIC CHAMBER RADIATED EMISSIONS MEASUREMENT

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ABSTRACT

Investigations into the sources of variability in radiated emissions testing to CISPR 25[1] were conducted in a 6.7m x 3.7m x 3.2m semi-anechoic chamber. A large number of potential sources of variability were identified and experiments conducted to quantify the level of variability each potential source introduced to the measurement of radiated emission.

A commercial wide-band comparison noise emitter (CNE) was used as an emission source. Three different receiving antennae (Biconical, Log-Periodic-Biconical and Horn) were used to assess some of the emission variability due to different antenna structures. Other elements of variability examined include cable placement, effect of detector type and positional accuracy.

It is believed that this is the first reported quantified analysis of the effect of many of the investigated variables on radiated emission levels in a compact chamber. This study should enable higher precision results in semi-anechoic chamber radiated emission tests by appropriate control of emission variability within the test environment. Ultimately the data could improve specification writing for EMC radiated emissions testing.

BACKGROUND

The semi-anechoic chamber used for these investigations (figure 1) is primarily used for radiated emissions tests in accordance with European Directive 95/54/EC[2] and CISPR-25[1] standard for automotive modules. The chamber is relatively small (6.7m x 3.7m x 3.2m) and is lined with 50cm truncated cone absorbers.

CNE OUTPUT STABILITY

The output of a CNE is not static over small time scales as its output level fluctuates slightly about its nominal value at any specific frequency. This was quantified by making repeated conducted noise measurements at a fixed frequency (500MHz used here, table 1) using a spectrum analyser. The results illustrated that using a peak detector gives a high level of variability in the

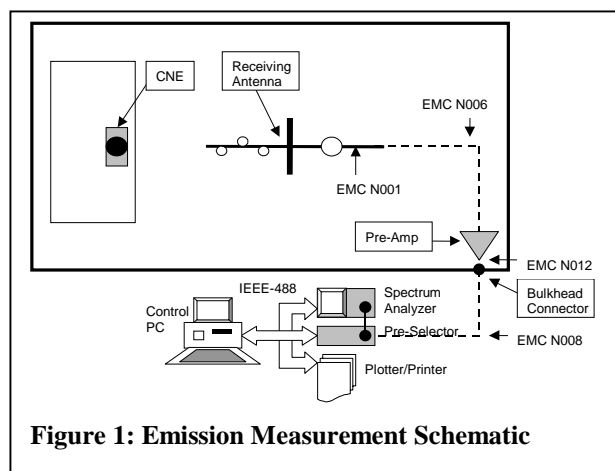


Figure 1: Emission Measurement Schematic

output spectrum, exhibiting $\pm 3.4\text{dB}$ at the required 95% confidence level.

The conducted emissions were also measured using an averaging technique, using a narrow video bandwidth (VBW=1Hz) and a long dwell time (dwell time=166ms). The result is considered pseudo-average as results were taken in dBuV (i.e. from a logarithmic scale, not linear). The data does illustrate the reduction in variability obtained using an average technique and for a 95% confidence level, $\pm 0.17\text{dB}$ variability should be achievable.

Statistic (dBuV base unit)	Peak Detect	Pseudo Average
Mean	78.20	70.89
Standard Deviation	1.6974	0.0795
Minimum	74.17	70.75
Maximum	84.00	71.00
Count	100	20

TABLE 1-CNE Output at 500MHz Using Different Detector Techniques

The main drawback of the averaging technique is the time required for measurement and this is also the reason for the lower number of results in table 1 using the average detector. The averaging technique requires more measurement time per data point and may only be

suitable for measurement where large anomalies are suspected or for calibration repeatability requirements.

CABLE CHARACTERISATION AND PRE-AMPLIFIER STABILITY

Errors due to different cables and the stability of the pre-amplifier were examined prior to the commencement of testing. These are sources of overall error but when controlled appropriately were proved not to be sources of variability. Any consistent gain error within the receiver system is compensated in the final result.

RADIATED EMISSION SPECTRUM

The recommended CNE antenna for 30MHz to 1GHz is a 100mm monopole and this was used with a 20dB BNC attenuator. The attenuator is required to prevent low frequency signal compression within the receiver chain, the value being selected after experiments with multiple attenuators and transmitting antennae. The standard receiver chain in the semi-anechoic chamber consists of a log-periodic-biconical antenna (Bi-Log), 3dB matching pad, 1m ferrite shielded cable mounted along the antenna boom, pre-amplifier, pre-selector and finally the spectrum analyser under PC control (figure 1).

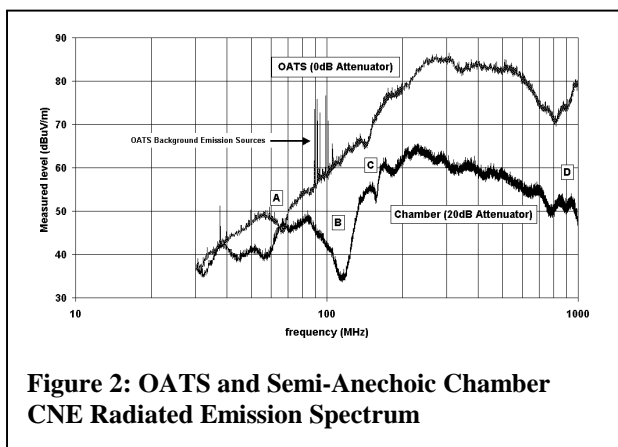


Figure 2: OATS and Semi-Anechoic Chamber CNE Radiated Emission Spectrum

The results can be compared to those obtained from an open area test site (OATS) when the CNE was externally calibrated (figure 2). The OATS results do not include the 20dB attenuator and only peak detect measurements were available, but the topography of the spectra is comparable.

The variability (exhibited as abrupt level changes or features) appears greater in the chamber, most likely due to reflections since the cones are not perfect absorbers, particularly at low frequencies. The higher frequency topography (above 200MHz) is similar with the 20dB attenuator accounting for the signal strength difference.

The 20dB attenuator on the CNE does increase the antenna to ground plane distance and this is the most probable cause of the higher frequency topographic differences. There are several specific features that are labelled in figure 2;

Feature A: Low Frequency Topography (<100MHz)

Feature B: 115MHz Absorption Peak

Feature C: 156MHz Discontinuity

Feature D: High Frequency Topography (>800MHz)

CABLE POSITION

The position of the cable to the rear of the antenna was examined, the cable being taken in-line with the antenna boom to the rear wall. At the rear wall the cable was positioned via 4 routes; 1) vertically then horizontally to the pre-amp, 2) horizontally on the front edge of the cones, 3) horizontally in the trough of the cones, 4) horizontally behind the rear wall absorbers.

The different cable routes resulted in insignificant measured variation in emission level, except for route 1 that exhibited some shift at feature B (115MHz absorption peak). In general it would appear that the positioning of the cable at the rear wall produces insignificant levels of variability, provided the cable run is perpendicular to the polarisation of the transmission source.

RECEIVING ANTENNA EFFECTS

The frequency spectrum was examined further by use of different antennae to separate antenna and transmission effects from each other. The low frequency range (20MHz to 240MHz) was examined using a Biconical antenna and the high frequency range (200MHz-1GHz) using a Horn antenna.

The low frequency results (figure 3) illustrate close correlation in topography between the Bi-Log and Biconical antenna measured emission level. There are some differences in the low frequency topography (feature A), this is believed to be primarily due to the physical proximity of the biconical sections of the Bi-Log antenna and the ground plane table. Feature B is still present but the frequency is shifted slightly from 115MHz using the Bi-Log to 104MHz using the Biconical antenna. Another significant feature change is the 156MHz discontinuity (feature C) which is not observed at all with the Biconical antenna.

The frequency shift of feature B is related to the quarter wavelength of the biconical elements of the Bi-Log and Biconical antennae ($\lambda=2.84\text{m}$ and $\lambda=2.68\text{m}$ respectively). The lack of this feature in the OATS result suggest that it

may be due to low frequency reflection from the chamber ceiling creating a resonance in the biconical antenna elements.

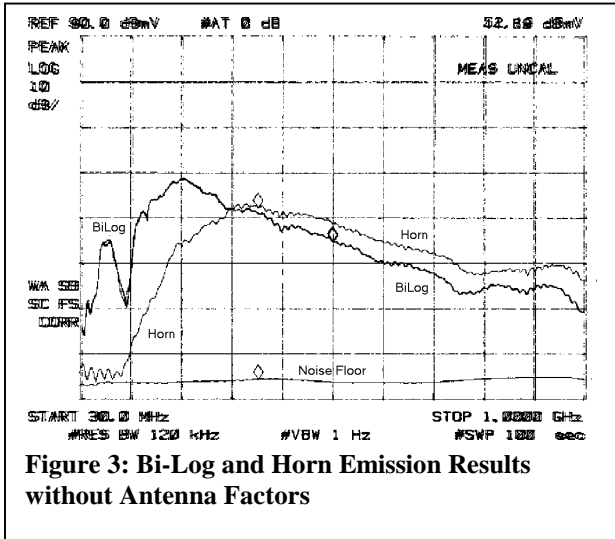


Figure 3: Bi-Log and Horn Emission Results without Antenna Factors

The feature C discontinuity is believed to be the biconical element gain cross over with the log-periodic elements of the Bi-Log antenna, hence its absence from the Biconical antenna results. This feature is a factor of the antenna and does not appear to shift, hence is not a potential

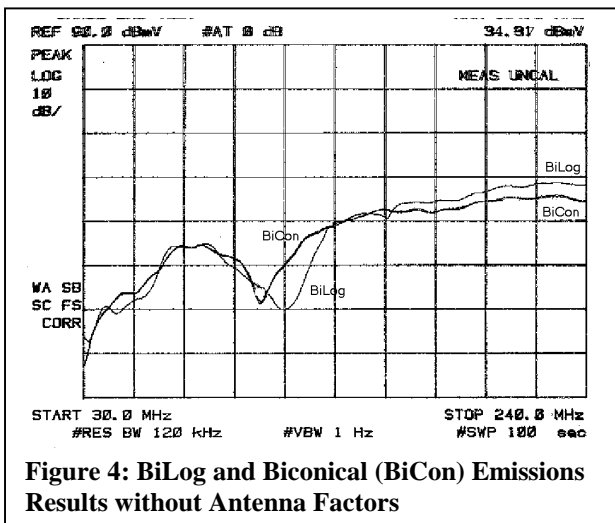


Figure 4: BiLog and Biconical (BiCon) Emissions Results without Antenna Factors

source of variability.

The high frequency range did not exhibit significant difference between the Horn and Bi-Log antennae over the recommended operating region of the Horn (400MHz-1GHz, figure 4). The horn is capable of receiving signals down to 240MHz, but its has a very high SWR at frequencies below 300MHz. It is inappropriate to compare to the Horn antenna received emission levels below 400MHz without antenna factor

correction. The results indicate that the higher frequency emission spectra topography and feature (D) are not influenced by the Bi-Log receiving antenna.

POSITIONAL ACCURACY OF ANTENNA

The placement of the receiving antenna is defined in CISPR-25 and 95/54/EC, with distance to source or ground plane table given a tolerance of $1m \pm 10mm$ in the CISPR-25 and $1m \pm 50mm$ in 95/54/EC. Lateral dimensions are not specified but a central arrangement is implied. Similarly the height above the floor and ground plane table are specified, but tolerances are not quoted. There are consequently several positional variabilities which are not defined. Assuming the emission level is related solely to distance from the source, these represent a calculated uncertainty of $\pm 0.08dB$ in the CISPR-25 set-up and $\pm 0.42dB$ in the 95/54/EC set-up.

The validity of the assumption that the uncertainty is dominated by the source-to-antenna distance was investigated by making measurements over relatively small positional offsets and estimating the effect over the allowable tolerance. Typical positional accuracy for those parameters without a tolerance was also estimated as $\pm 10cm$ for both height and lateral displacement (potential error induced with the particular tripod used if the polarisation is changed and boom height and tripod position are unmodified). A linear relationship was assumed to be sufficiently accurate approximation to the true relationship over the small displacements investigated here.

Changing the antenna-to-table distance produced signal level changes that a simple $1/distance$ calculation would produce (20dB/decade). The measured result of $\pm 0.075dB$ compares favourably with the calculated $\pm 0.086dB$ for the tolerance specified in CISPR-25.

Antenna height adjustment caused significant variability in emission level, particularly at the 115MHz feature and at the high frequency end of the test spectrum (figure 5). Using a positional error of $\pm 10cm$ there is a potential uncertainty of $\pm 1.0dB$ in the emission level and changes in the centre frequency of feature B can produce even greater emission signal level shift around its nominal 115MHz frequency. The change of frequency of the 115MHz feature and signal reduction with height supports the theory that this feature is due to interaction between the antenna and floor reflections. Lateral changes in the antenna position (towards a side wall) resulted in some minor changes in emission level. An analysis of contributing factors is complicated by the fact that the biconical elements and front high frequency elements of the Bi-Log are at different angular offset and

linear displacement from the source. Hence separate directional gain factors with frequency and displacement calculations for each element section would be required, similarly wall reflections will change with lateral displacement. When testing an automotive unit the difference would be much smaller as the emission source

offset could be either direct line-of-sight or tripod centred.

The result from the direct line-of-sight horizontal angular offset suggests an uncertainty in measured results of $\pm 0.02\text{dB}$. This is consistent with the level that is estimated from increased linear displacement at 3.8° off centre tripod location and correlates with the linear displacement results observed above. Due to the relatively small displacements towards the side walls of the elements closest to the antenna tip negligible changes in reflections are observed.

Centring the tripod and moving the tip away from the source in a horizontal arc resulted in larger changes in the emission signal level than the line-of-sight experiment. The displacement of the elements from the source is reversed in that the elements closest to the tripod pivot point are moved least from their nominal position. However, the main factor that would change these results is the directional gain change that is exhibited at this angular offset that is not a factor in direct line-of-sight results.

The polar beam pattern chart for this antenna type suggests a relatively linear fall in signal gain per degree of angular offset over a $\pm 30^\circ$ range. The gain falling by approximately 1.5dB at 30MHz and 3dB at 1GHz, which coupled with increased displacement of the front high frequency elements account for $\pm 0.62\text{dB}$ uncertainty due to a horizontal angular misalignment of $\pm 3.8^\circ$.

The areas that exhibited the greatest change with vertical angle were at high frequencies and the 115MHz feature. The changes were larger as the antenna tip was raised towards the ceiling ($+14.5^\circ$), compared to being aimed towards the floor (-14.5°). This is consistent with the previous results for this feature as a floor related phenomenon.

The reduced change in emission level with the antenna targeted towards the floor suggests that a dipped antenna tip should result in reduced variability. Using the results obtained here and an angular variability of $\pm 3.8^\circ$, with a 0° nominal offset the positional variation at 115MHz is predicted to be $\pm 1.98\text{dB}$ and $\pm 1.05\text{dB}$ over the rest of the spectrum. The estimate for a -10° angular nominal position suggests that $\pm 3.8^\circ$ vertical offset would result in a $\pm 1.31\text{dB}$ variability at 115MHz and $\pm 0.79\text{dB}$ over the rest of the spectrum. Most of the variability due to vertical angular offset would be at the higher frequency end of the test spectrum.

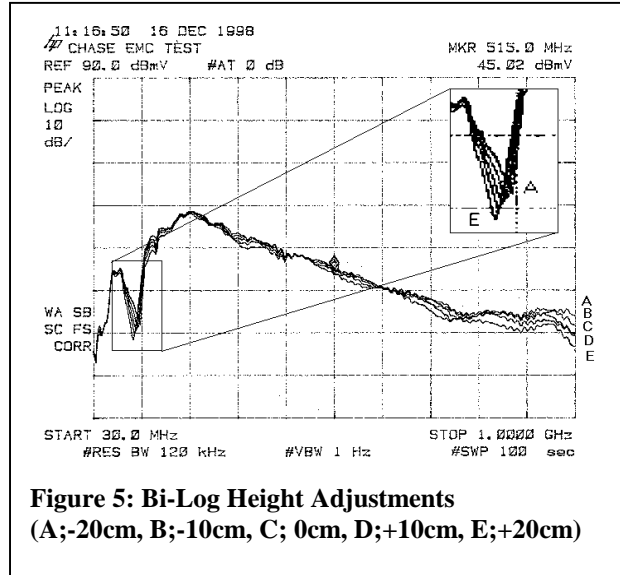


Figure 5: Bi-Log Height Adjustments (A;-20cm, B;-10cm, C; 0cm, D;+10cm, E;+20cm)

would be a cable harness, almost the length of the ground plane table, in this study the CNE acts as a point source.

The complexity of the lateral offset was illustrated in the appearance of multiple cross-over points in the spectrum, illustrating some signal increase with slight lateral movement and some signal loss, resulting from partial enhancement and cancellation at some frequencies and gain loss due to increased source-to-antenna distance. With a point source and $\pm 10\text{cm}$ lateral offset error the overall signal uncertainty would be $\pm 0.6\text{dB}$.

ANGULAR ATTITUDE OF ANTENNA

The angular offset of the receiving antenna is another positional variable that is unspecified in the CISPR-25 and 95/54/EC procedures. Implicit in the standard is that the antenna and source (unit under test) are perpendicular to each other and square with the chamber.

The angular offset was examined in the horizontal plane for both direct line-of-sight and tripod centre positioned angular offset, and vertically angled towards the ceiling and towards the floor. Although more difficult than the linear positional accuracy to tolerance, an estimate based on polarisation changes without realignment suggested a $\pm 3.8^\circ$ angular variation could be observed in both the horizontal and vertical planes, the horizontal angular

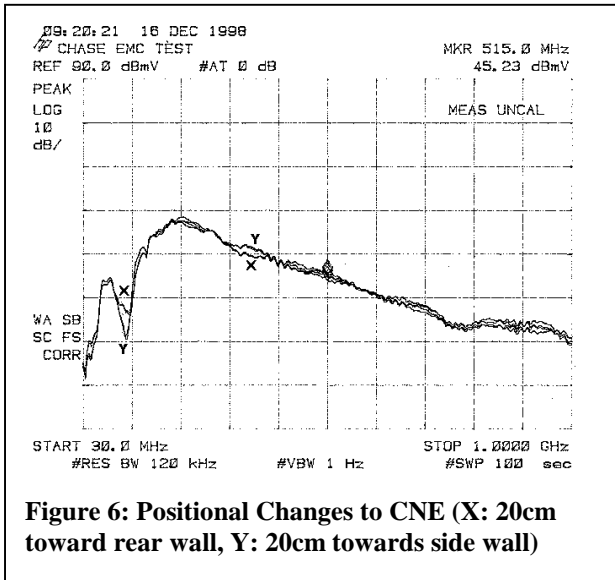


Figure 6: Positional Changes to CNE (X: 20cm toward rear wall, Y: 20cm towards side wall)

POSITIONAL ACCURACY OF CNE

The positional accuracy of the CNE is representative of the positional accuracy of a unit under test and this is specified either to the edge of the ground plane table (10cm±1cm, 95/54/EC) or directly between source and receiving antenna (CISPR-25).

The CNE was checked for symmetry and angular offset, negligible change in emission level was observed suggesting that axially the CNE is symmetrical and acts as expected as a point source.

With lateral movement towards the side walls the change in emissions signal strength was small over the displacements used (up to 20cm from nominal). The resulting changes in emission signal strength were consistent with distance increase changes predicted by calculation, at the small angles used within the beam width of the receiving antenna. This result suggests negligible variability due to lateral positioning of the CNE and also supports the previous suggestions that beam width (polar gain variation) is the main source of the variation with horizontal angular displacement of the receiving antenna.

Moving the CNE towards the rear wall resulted in a much greater shift in emissions level across the whole frequency spectrum (figure 7). The 115MHz feature (and lower frequencies) has raised levels and at high frequency (800MHz-1GHz) the level is also generally higher. The typical level shift was +3dB over a 20cm displacement, with the 115MHz feature being raised by as much as +7dB and its centre frequency increasing to 125MHz.

The increased source-to-receiving antenna distance would predict a signal loss of 1.58dB. The signal increase is therefore believed to be due to reduced cancellation from floor reflections. The beam incident on the floor from the CNE monopole is significantly reduced as the CNE is moved towards the rear wall (blocked by the ground plane table). This is undoubtedly not a linear effect, since there will still be the signal loss due to increased source-to-receiving antenna distance and eventually the floor cancellations will be small compared to the source-to-receiving antenna distance loss.

Typical CNE and test unit positional variability (±1cm) could result in approximately ±0.35dB emission level variability across the frequency range, with variability at the 115MHz feature of ±1dB in signal level and ±1MHz in peak frequency. This peak frequency change and increased variability at the 115MHz feature further supports the premise that this anomaly is due to floor reflections/interaction with the lower element of the biconical section of the Bi-Log antenna.

GROUND PLANE OFFSET

The ground plane table position within the chamber is

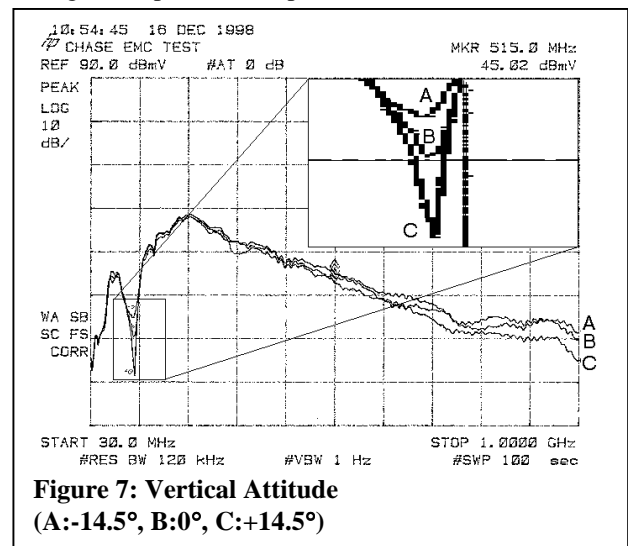


Figure 7: Vertical Attitude (A:-14.5°, B:0°, C:+14.5°)

relatively fixed at the rear wall and laterally central to the room. The lateral position is not specified within the test procedures and no tolerance on rear wall positioning is given.

Although the table in general is static, as test units are loaded/unloaded some accidental movement can occur, primarily pushing the table toward the rear wall and offset from the lateral centre. Examination of the earth strap fixing on the table used suggested the maximum offset was 5mm towards the rear wall and 25mm lateral

offset, the straps forcing this to occur in an arc left or right of centre.

This shift in the centre position produced a relatively large shift in the measured emission level of 0.3dB across the emission spectrum. This is much larger than would be predicted due to distance changes and indicates some form of coupling between antenna and table is probably responsible for this magnitude of shift.

SUMMARY

The positional variability identified can be assigned typical distribution profiles and summed (root sum square, RSS) to estimate the total system variability (table 2). This indicates that emissions from a CNE measured with a fixed, well calibrated and low drift receiving system, when using a peak detect method variability within the semi-anechoic chamber is likely to be ±3.72dB, whereas with an average detect method this falls to ±1.52dB. The 115MHz anomaly is the worst area and this feature exhibits variability of ±4.33dB and ±2.69dB for peak and average detect methods respectively.

The identified sources of variability can have tighter tolerances or changes to the specification to reduce system uncertainty. For example placing the antenna at an angle of -10° (i.e. towards the floor) significantly reduces the system variability to ±3.63dB using peak and ±1.30dB using the average detector techniques.

CONCLUSION

The measured variability within a semi-anechoic chamber resulted in relatively good emission measurement uncertainty compared to the calculated value of ±6dB reported for OATS by White & Mardiguian [3]. This uncertainty can be easily improved by appropriate tolerancing of test specification parameters.

REFERENCES

1. CISPR-25: 1995, "Limits and methods of measurement of radio disturbance characteristics for the protection of receivers used on board vehicles."
2. European Directive 95/54/EC, "...relating to the suppression of radio interference produced by spark ignition engines fitted to motor vehicles."
3. D. White & M. Mardiguian, 1982, "Errors in EMC Compliance Testing and Their Control", *IEEE Int Symp on EMC*, p226-231
4. C. Zombolas, "Radiated Field Strength Measurements at Open Area Test Site: Inconsistent Results when Determining Compliance with 10m Limits at a Test Distance of 3m", <http://www.emcnet.com/papers/radem/htm>
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Source	Uncertainty (dB)	Assumed Distribution	Normalised Value (dB)	Comment
Peak Detector	3.40	normal	3.40	Standard Test Method
Average Detector	0.17	normal	0.17	Calibration Test Method
Bi-Log Horizontal Angle	0.02	rectangular	0.02	line-of-site (±3.8°)
	0.62	rectangular	0.72	off-centre (±3.8°)
Bi-Log Vertical Angle	1.05	rectangular	1.21	from level (±3.8°)
Bi-Log Lateral Alignment	0.06	rectangular	0.07	±10mm to side wall
Bi-Log to Table Error	0.01	rectangular	0.01	±10mm
Bi-Log Height Error	0.10	rectangular	0.12	±10mm
CNE to Table Error	0.00	rectangular	0.00	angular variability
	0.06	rectangular	0.07	±10mm to/from side
	0.35	rectangular	0.40	±10mm to/from front
Ground Plane Offset	0.30	rectangular	0.35	without floor fixings

RSS (Peak Detector)	3.72
RSS (Average Detector)	1.52

TABLE 2- Typical Test Set-Up Variability (±10mm positional accuracy, ±3.8° angular accuracy)