ANNEX TO NPL CERTIFICATE FOR BICONICAL AND SHORT DIPOLE ANTENNAS

This annex applies to biconical antennas of dipole tip-tip length of approximately 1.4 m that are specified to cover all or part of the frequency range 20 MHz to 300 MHz. It also applies to short dipole antennas whose resonant frequency is approximately 80 MHz and that are specified for use over the frequency range 30 MHz to 80 MHz. It is therefore of similar length to a 1.4 m biconical antenna whose which resonates at approximately 75 MHz. An dipole-type antenna is most sensitive to effects of mutual coupling in the region of its resonant frequency.

Antenna Factor

Where the antenna factor has been given for a specific configuration above a ground plane (including free-space), the associated uncertainties only apply when the antenna support structure, including the input cable, does not cause significant reflections which would affect the received signal. If there are any significant sources of reflection the user should asses the resulting uncertainty and treat it as an additional uncertainty term. For calibration purposes the free-space condition is achieved by mounting the antenna vertically polarised at a height above the ground plane at which mutual coupling is negligible.

Where there is a sharp resonance in the antenna factor the uncertainty given in the certificate does not apply. At the frequency where the resonance causes a deviation of greater than 1 dB from the overall trend of the data, the magnitude of the increased uncertainty can be estimated from the height of the spike on the antenna factor graph. The affected range can be taken as ± 1.5 % of the centre frequency. Because the data is sampled at discrete points the maximum error may be much larger than that shown in the antenna factor graph.

The antenna factors are valid at the measurement height for any separation distance from the source exceeding one wavelength. For shorter distances the change in antenna factor with distance becomes significant and additional uncertainty would therefore be introduced. When the antenna is used for emission testing at a distance of 3 m from an equipment under test, whose size does not exceed that of the biconical antenna, there is an estimated increase in uncertainty of ± 0.3 dB in the range 55 MHz to 100 MHz, which is caused by mutual coupling of the antenna to the EUT. Below 100 MHz the antenna is in the near-field of the EUT and though the field magnitude will be correctly measured there will be additional uncertainty if the field strength were extrapolated to a greater distance. For extrapolation to a distance of 10 m, which is effectively in the far-field, this uncertainty is estimated to be ± 0.2 dB at 100 MHz increasing to ± 1 dB at 30 MHz.

In order to measure the absolute E-field at different heights and polarisations above the ground plane it is necessary to know the antenna factor at each height and polarisation. However, since many calibrations would be required, a viable alternative is to use a single calibration of free-space antenna factor, AF_{FS}. Because AF_{FS} is approximately the average of AF at all heights in the range 1 - 4m, the uncertainty in using AF_{FS} is less than using AF measured at a fixed height. For example, biconical antennas are often calibrated horizontally polarised at a height of 2m above a ground plane. The additional uncertainty is caused by coupling of the antenna with its image in the ground plane which results in a change in the input impedance. For vertical polarisation there is no additional uncertainty for heights above 1.5 m, but between 1 m and 1.5 m the additional uncertainty is ± 0.7 dB in the range 55 MHz to 100 MHz. For horizontal polarisation, at heights above 1 m, the antenna factor may differ from the quoted values by up to ± 0.5 dB in the range 20 MHz to 50 MHz, and by ± 1.5 dB in the range 50 MHz to 100 MHz, and by ± 1 dB in the range 100 MHz to 300 MHz. The values for horizontal polarisation can be reduced by 0.5 dB for antenna heights above 2 m. The above variations are representative; the exact variation will vary slightly according to each antenna design.

If the antenna is used in an unlined screened room the use of these antenna factors may not give the absolute value of field strengths, but a calibration provides an essential check that the antenna is working properly. The antenna factors can be used to compare measurements made in an identical setup using a different antenna of the same type.

During height scans, with the antenna vertically polarised, there will be an additional uncertainty caused by the directivity of the vertical radiation pattern. In normal use, signal maxima on a 10 m range occur for antenna heights below 2.5 m and the error here will be negligible. However, for a 3 m range the received signal could decrease by more than 1 dB.

Balance Test

The balance of the antenna balun may be tested by mounting the vertically polarised antenna in a uniform vertically polarised electric field, and observing the difference in received signal when the antenna is inverted. Any change greater than 0.5 dB is caused by common mode current on the cable which is caused by an unbalance of the balun. It is important for this test that the cable hangs vertically behind the antenna in the usual manner. For this test there should be a horizontal distance of between 0.5 m and 2 m from the antenna element to the point at which the cable drops vertically. The cable should not move during the course of the measurements. An antenna is considered to have a good balun balance when the observed difference is less than ± 0.5 dB.

The inversion test is a qualitative measurement which reveals imbalance of the balun which, for some models of biconical antenna, can cause a large uncertainty in the measured field when the output cable is aligned parallel to the antenna elements. It is recommended that the user conducts tests of their own to quantify this effect in each particular measurement configuration. For antenna models with significant balun imbalance it is recommended that ferrite clamps are placed on the cable near the antenna input when the antenna is used for emission testing. Ferrite clamps on the output cable only provide a partial reduction of the braid current; a better solution is to use a perfectly balanced balun. The uncertainty of Antenna Factors is increased by the magnitude of balun imbalance.

Return Loss

The quoted antenna factors apply when the mismatch between the antenna and the receiver is attenuated. A well matched 10 dB attenuator is recommended. If no attenuator is used (and the receiver front-end attenuation is set to zero), the antenna factor can change by ± 1.4 dB at 30 MHz, assuming a receiver return loss of greater than 14 dB, an antenna return loss of 1 dB and a cable loss of 1 dB.

ARP958 Antenna Factor

Measurements at 1 m distance from an emitter is called for in MIL-STD-461D[1], which stipulates that procedure ARP958[2] is to be used for 1 m calibrations. It is necessary to distinguish between AF_{1m} and conventional AF which enables absolute E-field strength to be obtained from the voltage output of the antenna. ARP958 describes AF_{1m} as "apparent" antenna factor because it is derived from equations which do not take near-field terms into account. When AF_{1m} is used to measure absolute field strength an additional uncertainty term of ± 2 dB must be included. This only applies to the frequencies above 30 MHz, The uncertainty increases to ± 5 dB as the frequency is reduced from 30 MHz to 20 MHz.

ANSI Height Scan Method

The ANSI C63.5[3] procedure describes how the antenna factor may be measured over a ground plane by a height scanning three antenna method. For each measurement pair, one antenna is at a fixed height and polarisation, and the other is height scanned. The receiver is set to record the maximum measured signal during the scan. In the three pairings each antenna is measured twice, and if the customer supplies two antennas then one of the antennas is always allocated to the height scanning mount, and the other to the fixed mount. An NPL antenna is used for the third antenna which height scans for one pair and is fixed for the other pair. If the customer supplies one antenna it will be placed at the fixed height.

Where standards call for an ANSI calibration (e.g. for NSA measurements), NPL recommends the use of free-space antenna factors for the scanned antenna for measurements at 10 m separation because they agree well with 10 m ANSI antenna factors. However, at 3 m separation the ANSI antenna factors differ significantly from the free-space values, and therefore only the ANSI antenna factors should be used in order to comply fully with the NSA method described in ANSI C63.4:1992 and CISPR 16-1:1998.

References

[1] MIL-STD-461D, Requirements for the control of electromagnetic interference emissions and susceptibility, 1993, Department of Defence, USA.

[2] SAE ARP958:1992, Electromagnetic interference measurement antennas; standard calibration

method. Society of Automotive Engineers.

[3] ANSI C63.5-1998, American National Standard: Calibration of antennas used for radiation emission measurements in Electromagnetic Interference (EMI) control.

ANNEX TO NPL CERTIFICATE FOR BICONICAL-LOG/HYBRID ANTENNAS

Antenna Factor, general comments

The antenna factors are valid for any separation distance from the source exceeding one wavelength. For distances less than 10 m, the change in antenna factor with distance becomes significant when a fixed reference point on the antenna is assumed, and additional uncertainty would therefore be introduced. This is expanded in the section on Phase Centre.

When the antenna is used for emission testing at a distance of 3 m from an equipment under test, whose size does not exceed that of the biconical antenna, there is an estimated increase in uncertainty of ± 0.3 dB in the range 50 MHz to 100 MHz, which is caused by mutual coupling of the antenna to the EUT (equipment under test). Below 100 MHz the antenna is in the near-field of the EUT and though the field magnitude will be correctly measured there will be additional uncertainty if the field strength were extrapolated to a greater distance. For extrapolation to a distance of 10 m, which is effectively in the far-field, this uncertainty is estimated to be ± 0.2 dB at 100 MHz and ± 1 dB at 30 MHz.

Where there is a sharp resonance in the antenna factor the uncertainty given in the certificate does not apply. At the frequency where the resonance causes a deviation of greater than 1 dB from the overall trend of the data, the magnitude of the increased uncertainty can be estimated from the height of the spike on the antenna factor graph. The affected range can be taken as ± 1.5 % of the centre frequency. Because the data is sampled at discrete points the maximum error may be much larger than that shown in the antenna factor graph.

If the antenna is used in an unlined screened room the use of these antenna factors may not give the absolute value of field strengths, but a calibration provides an essential check that the antenna is working properly. The antenna factors can be used to compare measurements made in an identical setup using a different antenna of the same type.

There is a further error arising from the directive nature of the antenna radiation, which is greater at the higher frequencies. In a normal height scan up to 4 m, on a 10 m range, the signal maximum can be reduced by up to 0.5 dB compared with that for a uniform radiation pattern. For a 3 m range this error could be up to 2 dB (given that the signal maximum is normally achieved at a height of less than 2.5 m).

The majority of LPDA (log-periodic dipole array) antennas have elements in echelon, which causes sensitivity to cross-polarised fields. This applies to the log part of a biconical-log/hybrid antenna. At the higher end of the operating frequency range of the antenna, the elements are short and the step between each half of one dipole element is pronounced. In the extreme case this can cause greater sensitivity to cross-polarised fields than co-polarised fields. The uncertainty in the antenna factor in the certificate may have been increased to reflect poor cross-polar rejection of the LPDA.

Antenna Factor, up to 200 MHz

In this frequency range the biconical-log/hybrid antenna has similar characteristics to a bicone antenna. In order to measure the absolute E-field at different heights and polarisations above the ground plane it is necessary to know the antenna factor at each height and polarisation. However, a viable alternative is to use the free-space antenna factor for every configuration which minimises the additional uncertainty incurred. The additional uncertainty is caused by coupling of the antenna with its image in the ground plane which results in a change in the input impedance. For vertical polarisation there is no additional uncertainty for heights above 1.5 m, but between 1 m and 1.5 m the additional uncertainty is ± 0.7 dB in the range 50 MHz to 100 MHz. For horizontal polarisation, at heights above 1 m, the antenna factor may differ from the quoted values by up to ± 0.5 dB in the range 20 MHz to 50 MHz, and by ± 1.5 dB in the range 50 MHz to 100 MHz, and by ± 1 dB in the range 100 MHz to 200 MHz. The values for horizontal polarisation can be reduced by 0.5 dB for antenna heights above 2 m. The above variations are representative; the exact variation will vary slightly according to each antenna design.

Antenna Factor, above 200 MHz

In this frequency range the biconical-log/hybrid antenna has similar characteristics to a LPDA antenna. If the antenna is used horizontally polarised during a height scan from 1 m to 4 m above a ground plane, the antenna factors may differ from the values quoted by up to ± 0.5 dB. This is because the input impedance of the antenna changes due to coupling with its image in the ground plane. This coupling is greatest at the lower frequencies where the wavelength is a larger fraction of the height above the ground plane. When the antenna is used vertically polarised, there is no significant coupling with the ground plane, but the cable should extend horizontally behind the antenna for at least 2 m before dropping to ground in order to minimise parasitic reflections.

Phase Centre

When a LPDA is receiving E-field radiation the phase centre is the active part of the antenna at any given frequency. The active part of the antenna corresponds approximately to the position of the element whose length is equal to that of the equivalent resonant half wave dipole for the received frequency. The gap between the bicone component on a biconical-log/hybrid antenna and its LPDA part may also be considered as having a phase centre. This phase centre here is apparent to the user and is caused by the gradual shift of the complex current distribution from the LPDA part to the bicone part.

The quoted uncertainty in antenna factor is only valid when the phase centre is placed at the point at which the field is required to be measured. If the antenna position is not adjusted with frequency to make this condition true, a correction should be made to the measured field (at the phase centre position). This is valid in free-space conditions but there is additional uncertainty when applied to a LPDA above a ground plane. For distances of greater than one wavelength from the antenna a reduction of the field proportional to the inverse of the distance can be assumed, which means that in an anechoic environment a linear extrapolation may be used to adjust the field strength. The adjustment of antenna factor to a fixed reference point on the antenna is described later in the annex. For measurements made over a ground plane this correction has to be calculated using the difference in E_{Dmax} [1].

The NPL certificate contains an expression which allows the phase centre at any frequency to be calculated. This approximation is derived from some equations which govern LPDA antennas with triangular profiles (i.e. where the element tips form a straight line). Hence larger errors in the predicted phase centre will occur when these expressions are used for tapered antennas. The values for the constants, which are given in the NPL certificate are derived from the following equations :-

$$\delta = \frac{X_L \cdot L_H - X_H \cdot L_L}{L_L - L_H} \qquad Tan\alpha = \frac{L_L}{2*\left(X_L + \delta\right)}$$

$$X_F = \frac{71.2}{Tan\alpha} \cdot \frac{1}{F_{MHz}} - \delta$$

Where :

L_L and L_H = The lengths of two well spaced elements which reside towards the Low and High frequency ends of the LPDA respectively.

X_L and X_H = The distance from the tip to the same two elements.

If the above corrections are not feasible then an alternative strategy is available. This method, which may be applied in an anechoic chamber or near signal maxima during a height scan, uses a fixed phase centre, whose position is chosen in order to weight the incurred error evenly at either end of the operating frequency band. The fixed phase centre, X_{FIX}, is given by :-

$$X_{FIX} = \frac{1}{2} \cdot \left[X_{LOW} + X_{HIGH} \right]$$

The error incurred, U_E, at either end of the operating band is given by :-

$$U_E = \pm 20 * Log_{10} \left\{ \frac{R - \left[\frac{X_{LOW} - X_{HIGH}}{2} \right]}{R} \right\}$$

Where :- X_{LOW} = The phase centre of the low frequency operating limit.
X_{HIGH} = The phase centre of the high frequency operating limit.
R = The required separation to the EUT (i.e. 10 m or 3 m).

Between the last element on the LPDA and the bicone elements the best approximation to the phase centre is a linear extrapolation of frequency with distance along the central transmission line of the antenna. The assumptions are that the frequency of the longest LPDA element is calculated by converting its length to the corresponding resonant half-wave dipole frequency, and the frequency of the bicone element is given by the low frequency limit of the operating band.

For most common designs the calculated fixed phase centre (X_{FIX}) will be approximately half way between the actual tip of the antenna and the lowest frequency element. Thus, for simplicity, the reference point is often obtained by halving the distance from the tip to the back element.

Balance Test, (applies to frequencies up to 300 MHz)

The balance of the antenna balun may be tested by mounting the vertically polarised antenna in a uniform vertically polarised electric field, and observing the difference in received signal when the antenna is inverted. The change is caused by common mode current on the cable which is caused by an unbalance of the balun. It is important for this test that the cable hangs vertically behind the antenna in the usual manner. For this test there should be a horizontal distance of between 0.5 m and 2 m from the antenna element to the point at which the cable drops vertically. The cable should not move during the course of the measurements. An antenna is considered to have a good balun balance when the observed difference is less than ± 0.5 dB.

The inversion test is a qualitative measurement which reveals imbalance of the balun which, for some models of biconical antenna, can cause a large uncertainty in the measured field when the output cable is aligned parallel to the antenna elements. It is recommended that the user conducts tests of their own to quantify this effect in each particular measurement configuration. For antenna models with significant balun imbalance it is recommended that ferrite clamps are placed on the cable near the antenna input when the antenna is used for emission testing. Ferrite clamps on the output cable only provide a partial reduction of the braid current; a better solution is to use a perfectly balanced balun.

Return Loss

The quoted antenna factors apply when the mismatch between the antenna and the receiver is attenuated. A well matched 10 dB attenuator is recommended. If no attenuator is used (and the receiver front-end attenuation is set to zero), the antenna factor can change by ± 1.5 dB at 30 MHz, assuming a receiver return loss of greater than 14 dB, an antenna return loss of 0.4 dB and a cable loss of 1 dB.

Height Scan

During a height scan from 1 m to 4 m during emission measurements there will be an additional uncertainty caused by the directivity of the vertical radiation pattern. On a 10 m range the signal maxima, for frequencies below 200 MHz, occur for antenna heights less than 2.5 m and the error here will be negligible; but for a 3 m range the received signal could decrease by more than 1 dB. Above 200 MHz the directivity is greater and on a 10 m range the signal maxima can be reduced by up to 0.5 dB compared with that for a uniform radiation pattern. For a 3 m range this error above 200 MHz could be more than 2 dB, given that the signal maximum is normally achieved at a height of less than 2.5 m).

Adjusted Antenna Factor

We can calculate an adjustment to the antenna factor, which extrapolates the field measured at the phase centre of the antenna to a defined reference point. The separation to the EUT has to be specified and the reference point on the antenna is often at the tip.

The adjusted antenna factor is commonly given for 3 m and 10 m separation, measured from the marked reference position or the mechanical centre of the antenna. If these 3 m and 10 m antenna factors are used for measurements other than at 3 m and 10 m respectively, the uncertainty will be larger than if the free space antenna factors are used, with correction for phase centre. The latter can be used for any distance exceeding two wavelengths without the need to increase uncertainty.

$$AF_{REF} = AF_{FS} + 20 * Log_{10}\left[\frac{R + X_F - X_{REF}}{R}\right]$$

Where :-

AF_{FS} = Measured free space antenna factor.
AF_{REF} = Antenna factor referenced to defined point on LPDA.
R = Separation from EUT to reference point on LPDA.
X_F = Position of phase centre from LPDA tip.
X_{REF} = Position of defined reference point from LPDA tip.

ANSI Height Scan Method

The ANSI C63.5[1] procedure describes how the antenna factor may be measured over a ground plane by a height scanning three antenna method. For each measurement pair, one antenna is at a fixed height and polarisation, and the other is height scanned. The receiver is set to record the maximum measured signal during the scan. In the three pairings each antenna is measured twice, and if the customer supplies two antennas then one of the antennas is always allocated to the height scanning mount, and the other to the fixed mount. An NPL antenna is used for the third antenna which height scans for one pair and is fixed for the other pair. If the customer supplies one antenna it will be placed at the fixed height.

Where standards call for an ANSI calibration (e.g. for NSA measurements), NPL recommends the use of free-space antenna factors for measurements at 10 m separation because they agree well with 10 m ANSI antenna factors. However, at 3 m separation the ANSI antenna factors differ significantly from the free-space values, and therefore only the ANSI antenna factors should be used in order to comply fully with the NSA method described in ANSI C63.4:1992 and CISPR 16-1:1999, [2].

References

[1] ANSI C63.5-1998, American National Standard: Calibration of antennas used for radiation emission measurements in Electromagnetic Interference (EMI) control.

[2] CISPR 16-1:1999, CISPR publication 16. Specification for radio disturbance and immunity measuring apparatus and methods, Part 1:1999 Apparatus, Central office of the IEC, 3 rue de Varembé, Geneva, Switzerland.

ANNEX TO NPL CERTIFICATE FOR 200 MHz to 2 GHz HORN ANTENNAS

Antenna Factor

The antenna factors are valid for any separation distance from the source exceeding one wavelength. For shorter distances the change in antenna factor with distance becomes significant and additional uncertainty would therefore be introduced.

Where there is a sharp resonance in the antenna factor the uncertainty given in the certificate does not apply. At the frequency where the resonance causes a deviation of greater than 1 dB from the overall trend of the data, the magnitude of the increased uncertainty can be estimated from the height of the spike on the antenna factor graph. The affected range can be taken as ± 1.5 % of the centre frequency. Because the data is sampled at discrete points the maximum error may be much larger than that shown in the antenna factor graph.

If the antenna is used in an unlined screened room the use of these antenna factors may not give the absolute value of field strengths, but a calibration provides an essential check that the antenna is working properly. The antenna factors can be used to compare measurements made in an identical setup using a different antenna of the same type.

Return Loss

The antenna factors quoted apply when the mismatch between the antenna and the receiver is attenuated. A well matched 6 dB attenuator is recommended. For example, if no attenuator is used and the receiver front-end attenuation is set to zero, the antenna factor can change by typically ± 0.3 dB, assuming a receiver return loss of greater than 14 dB, an antenna return loss of 10 dB and a cable loss of 3 dB.

ARP958 Antenna Factor

Measurements at 1 m distance from an emitter is called for in MIL-STD-461D[1], which stipulates that procedure ARP958[2] is to be used for 1 m calibrations. It is necessary to distinguish between AF_{1m} and conventional AF which enables absolute E-field strength to be obtained from the voltage output of the antenna. ARP958 describes AF_{1m} as "apparent" antenna factor because it is derived from equations which do not take near-field terms into account. When these antennas are calibrated to SAE ARP958, the method calls for two identical antennas to be mounted with their faces 1 m apart. These horn antennas have aperture dimensions of 0.94m x 0.68m and there is substantial mutual coupling between them, which shows as an oscillation in a plot of antenna factor against frequency. When one of these antennas is used for EMC testing, the object being tested is unlikely to present the same mutual coupling. Approximately 2 dB of additional uncertainty should be allowed for.

References

[1] MIL-STD-461D, Requirements for the control of electromagnetic interference emissions and susceptibility, 1993, Department of Defence, USA.

[2] SAE ARP958:1992, Electromagnetic interference measurement antennas; standard calibration method. Society of Automotive Engineers.

ANNEX TO NPL CERTIFICATE FOR LOG-PERIODIC DIPOLE ARRAY ANTENNAS

Antenna Factor

The antenna factors are valid for any separation distance from the source exceeding one wavelength. For distances less than 10 m, the change in antenna factor with distance becomes significant when a fixed reference point on the antenna is assumed, and additional uncertainty would therefore be introduced. This is expanded in the section on Phase Centre.

Where there is a sharp resonance in the antenna factor the uncertainty given in the certificate does not apply. At the frequency where the resonance causes a deviation of greater than 1 dB from the overall trend of the data, the magnitude of the increased uncertainty can be estimated from the height of the spike on the antenna factor graph. The affected range can be taken as ± 1.5 % of the centre frequency. Because the data is sampled at discrete points the maximum error may be much larger than that shown in the antenna factor graph.

If the antenna is used horizontally polarised during a height scan from 1 m to 4 m above a ground plane, the antenna factors may differ from the values quoted by up to ± 0.5 dB. This is because the input impedance of the antenna changes due to coupling with its image in the ground plane. This coupling is greatest at the lower frequencies where the wavelength is a larger fraction of the height above the ground plane. When the antenna is used vertically polarised, there is no significant coupling with the ground plane, but the cable should extend horizontally behind the antenna for at least 2 m before dropping to ground in order to minimise parasitic reflections, particularly at the lowest frequency of operation of the antenna.

If the antenna is used in an unlined screened room the use of these antenna factors may not give the absolute value of field strengths, but a calibration provides an essential check that the antenna is working properly. The antenna factors can be used to compare measurements made in an identical setup using a different antenna of the same type.

There is a further error arising from the directive nature of the antenna radiation, which is greater at the higher frequencies. In a normal height scan up to 4 m, on a 10 m range, the signal maximum can be reduced by up to 0.5 dB compared with that for a uniform radiation pattern. For a 3 m range this error could be up to 2 dB (given that the signal maximum is normally achieved at a height of less than 2.5 m).

The majority of LPDA (log-periodic dipole array) antennas have elements in echelon, which causes sensitivity to cross-polarised fields. At the higher end of the operating frequency range of the antenna the elements are short and the step between each half of one dipole element is pronounced. In the extreme case this can cause greater sensitivity to cross-polarised fields than co-polarised fields. The uncertainty in the antenna factor in the certificate may have been increased to reflect poor cross-polar rejection of the LPDA.

Phase Centre

When a LPDA is receiving E-field radiation the phase centre is the active part of the antenna at any given frequency. The active part of the antenna corresponds approximately to the position of the element whose length is equal to that of the equivalent resonant half wave dipole for the received frequency.

The quoted uncertainty in antenna factor is only valid when the phase centre is placed at the point at which the field is required to be measured. If the antenna position is not adjusted with frequency to make this condition true, a correction should be made to the measured field (at the phase centre position). This is valid in free-space conditions but there is additional uncertainty when applied to a LPDA above a ground plane. For distances of greater than one wavelength from the antenna a reduction of the field proportional to the inverse of the distance can be assumed, which means that in an anechoic environment a linear extrapolation may be used to adjust the field strength. The adjustment of antenna factor to a fixed reference point on the antenna is described later in the annex. For measurements made over a ground plane this correction has to be calculated using the difference in E_{Dmax} [3].

The NPL certificate contains an expression which allows the phase centre at any frequency to be calculated. This approximation is derived from some equations which govern LPDA antennas with triangular profiles (i.e. where the element tips form a straight line). Hence larger errors in the predicted phase centre will occur when these expressions are used for tapered antennas. The values for the constants, which are given in the NPL certificate are derived from the following equations :-

$$\delta = \frac{X_L \cdot L_H - X_H \cdot L_L}{L_L - L_H} \qquad Tan\alpha = \frac{L_L}{2 * (X_L + \delta)}$$

$$X_F = \frac{71.2}{Tan\alpha} \cdot \frac{1}{F_{MHz}} - \delta$$

Where:

L_L and L_H = The lengths of two well spaced elements which reside towards the Low and High frequency ends of the LPDA respectively.

X_L and X_H = The distance from the tip to the same two elements.

If the above corrections are not feasible then an alternative strategy is available. This method, which may be applied in an anechoic chamber or near signal maxima during a height scan, uses a fixed phase centre, whose position is chosen in order to weight the incurred error evenly at either end of the operating frequency band. The fixed phase centre, X_{FIX}, is given by :-

$$X_{FIX} = \frac{1}{2} \cdot \left[X_{LOW} + X_{HIGH} \right]$$

The error incurred, U_E, at either end of the operating band is given by :-

$$U_E = \pm 20 * Log_{10} \left\{ \frac{R - \left[\frac{X_{LOW} - X_{HIGH}}{2} \right]}{R} \right\}$$

Where :- X_{LOW} = The phase centre of the low frequency operating limit.
X_{HIGH} = The phase centre of the high frequency operating limit.
R = The required separation to the EUT (i.e. 10 m or 3 m).

For most common LPDA designs the calculated fixed phase centre (X_{FIX}) will be approximately half way between the actual tip of the antenna and the longest element. Thus, for simplicity, the reference point is often obtained by halving the distance from the tip to the back element.

Return Loss

The antenna factors quoted apply when the mismatch between the antenna and the receiver is attenuated. A well matched 6 dB attenuator is recommended. For example, if no attenuator is used and the receiver front-end attenuation is set to zero, the antenna factor can change by typically ± 0.3 dB, assuming a receiver return loss of greater than 14 dB, an antenna return loss of 10 dB and a cable loss of 3 dB.

Adjusted Antenna Factor
For LPDA antennas it is possible to calculate (A), the result of an ARP958 1 m measurement rather than actually perform the measurement. We can do this because the LPDAs are in the far-field of each other. This calculated value does not take account of the small amount of coupling between the antennas which would occur during an actual ARP958 measurement, but this effect is included in the stated uncertainty.

We can also calculate (B), an adjustment to the antenna factor, which extrapolates the field measured at the phase centre of the antenna to a defined reference point. The separation to the EUT has to be specified and the reference point on the LPDA is often at the tip. This type of adjustment is not quite the same as the first type, but roughly similar results are generated (using a 1 m EUT to LPDA separation, and setting the reference point at the tip). However, for large LPDA antennas the difference between the two adjustments can be in the region of 1 dB.

The adjusted antenna factor is commonly given for 3 m and 10 m separation, measured from the marked reference position or the mechanical centre of the antenna. If these 3 m and 10 m antenna factors are used for measurements other than at 3 m and 10 m respectively, the uncertainty will be larger than if the free space antenna factors are used, with correction for phase centre. The latter can be used for any distance exceeding two wavelengths without the need to increase uncertainty.

A ARP958 calculation

$$AF_{1m} = AF_{FS} + 10 * Log_{10}\left[\frac{R + (2 * X_F)}{R}\right]$$

B Reference point adjustment

$$AF_{REF} = AF_{FS} + 20 * Log_{10}\left[\frac{R + X_F - X_{REF}}{R}\right]$$

Where :-
AF_{1m} = ARP958 antenna factor, usually with R = 1 m.
AF_{FS} = Measured free space antenna factor.
AF_{REF} = Antenna factor referenced to defined point on LPDA.
R = Separation either from tip to tip (A) or from EUT to reference point on LPDA (B).
X_F = Position of phase centre from LPDA tip.
X_{REF} = Position of defined reference point from LPDA tip.

Note
For R = 1 m and X_{REF} = 0 m, both expressions give similar answers for small values of X_F.

Use of ARP958 Antenna Factor

Measurement at 1 m distance from an emitter is called for in MIL-STD-461D[1], which stipulates that procedure ARP958[2] is to be used for 1 m calibrations. It is necessary to distinguish between AF_{1m} and conventional AF which enables absolute E-field strength to be obtained from the voltage output of the antenna. ARP958 describes AF_{1m} as "apparent" antenna factor because it is derived from equations which do not take phase centre into account. When AF_{1m} is used to measure absolute field strength (at position of the active element at the frequency of measurement, ie the phase centre) an additional uncertainty term of ± 4 dB must be included at 200 MHz, and this diminishes to ± 0.5 dB at 1 GHz. This is because AF_{1m} extrapolates the field strength from the position it is measured by the active element, to a distance of 1 m from the emitter. The extrapolation assumes a fall off in field inversely proportional to distance and does not take into account an imperfect measurement environment, such as a partially lined screened room, in which the field may not fall off linearly with distance.

ANSI Height Scan Method

The ANSI C63.5[3] procedure describes how the antenna factor may be measured over a ground plane by a height scanning three antenna method. For each measurement pair, one antenna is at a fixed height and polarisation, and the other is height scanned. The receiver is set to record the maximum measured signal during the scan. In the three pairings each antenna is measured twice, and if the customer supplies two antennas then one of the antennas is always allocated to the height scanning mount, and the other to the fixed mount. An NPL antenna is used for the third antenna which height scans for one pair and is fixed for the other pair. If the customer supplies one antenna it will be placed at the fixed height.

Where standards call for an ANSI calibration (e.g. for NSA measurements), NPL recommends the use of free-space antenna factors for measurements at 10 m separation because they agree well with 10 m ANSI antenna factors. However, at 3 m separation the ANSI antenna factors differ significantly from the free-space values, so for an emission measurement made by height scanning the uncertainties may be less using the ANSI 3 m AFs. Where the NSA of a 3 m site is being measured by the NSA method described in ANSI C63.4:1992 and CISPR 16-1:1999, [4], the ANSI 3 m AFs should be used for best results (the ANSI method ignores near-field terms, but this cancels out if the AFs and NSA are both calculated using the formulas given in the ANSI standards).

References

[1] MIL-STD-461D, Requirements for the control of electromagnetic interference emissions and susceptibility, 1993, Department of Defence, USA.

[2] SAE ARP958:1992, Electromagnetic interference measurement antennas; standard calibration method. Society of Automotive Engineers.

[3] ANSI C63.5-1998, American National Standard: Calibration of antennas used for radiation emission measurements in Electromagnetic Interference (EMI) control.

[4] CISPR 16-1:1999, CISPR publication 16. Specification for radio disturbance and immunity measuring apparatus and methods, Part 1:1999 Apparatus, Central office of the IEC, 3 rue de Varembé, Geneva, Switzerland.

ANNEX TO NPL CERTIFICATE FOR SMALL BICONICAL ANTENNAS

This annex applies to small biconical antennas of dipole tip-tip length in the range 0.3 m to 0.45 m that are specified to cover the frequency range 30 MHz to 1000 MHz.

Antenna Factor

Where the antenna factor has been given for a specific configuration above a ground plane (including free-space), the associated uncertainties only apply when the antenna support structure, including the input cable, does not cause significant reflections which would affect the received signal. If there are any significant sources of reflection the user should asses the resulting uncertainty and treat it as an additional uncertainty term. For calibration purposes the free-space condition is achieved by mounting the antenna vertically polarised at a height above the ground plane at which mutual coupling is negligible.

Where there is a sharp resonance in the antenna factor the uncertainty given in the certificate does not apply. At the frequency where the resonance causes a deviation of greater than 1 dB from the overall trend of the data, the magnitude of the increased uncertainty can be estimated from the height of the spike on the antenna factor graph. The affected range can be taken as ± 1.5 % of the centre frequency. Because the data is sampled at discrete points the maximum error may be much larger than that shown in the antenna factor graph.

If the antenna is used in an unlined screened room the use of these antenna factors may not give the absolute value of field strengths, but a calibration provides an essential check that the antenna is working properly. The antenna factors can be used to compare measurements made in an identical setup using a different antenna of the same type.

During height scans, with the antenna vertically polarised, there will be an additional uncertainty caused by the directivity of the vertical radiation pattern. In normal use, signal maxima on a 10 m range occur for antenna heights below 2.5 m and the error here will be negligible. However, for a 3 m range the received signal could decrease by more than 1 dB.

Balance Test

The balance of the antenna balun may be tested by mounting the vertically polarised antenna in a uniform vertically polarised electric field, and observing the difference in received signal when the antenna is inverted. Any change greater than 0.5 dB is caused by common mode current on the cable which is caused by an unbalance of the balun. It is important for this test that the cable hangs vertically behind the antenna in the usual manner. For this test there should be a horizontal distance of between 0.5 m and 2 m from the antenna element to the point at which the cable drops vertically. The cable should not move during the course of the measurements. An antenna is considered to have a good balun balance when the observed difference is less than ± 0.5 dB.

The inversion test is a qualitative measurement which reveals imbalance of the balun which, for some models of biconical antenna, can cause a large uncertainty in the measured field when the output cable is aligned parallel to the antenna elements. It is recommended that the user conducts tests of their own to quantify this effect in each particular measurement configuration. For antenna models with significant balun imbalance it is recommended that ferrite clamps are placed on the cable near the antenna input when the antenna is used for emission testing. Ferrite clamps on the output cable only provide a partial reduction of the braid current; a better solution is to use a perfectly balanced balun. The uncertainty of Antenna Factors is increased by the magnitude of balun imbalance.

Return Loss

The quoted antenna factors apply when the mismatch between the antenna and the receiver is attenuated. A well matched 10 dB attenuator is recommended. If no attenuator is used (and the receiver front-end attenuation is set to zero), the antenna factor can change by ± 1.4 dB at 30 MHz, assuming a receiver return loss of greater than 14 dB, an antenna return loss of 1 dB and a cable loss of 1 dB.

ARP958 Antenna Factor

Measurements at 1 m distance from an emitter is called for in MIL-STD-461D[1], which stipulates that procedure ARP958[2] is to be used for 1 m calibrations. It is necessary to distinguish between AF_{1m} and conventional AF which enables absolute E-field strength to be obtained from the voltage output of the antenna. ARP958 describes AF_{1m} as "apparent" antenna factor because it is derived from equations which do not take near-field terms into account.

ANSI Height Scan Method

The ANSI C63.5[3] procedure describes how the antenna factor may be measured over a ground plane by a height scanning three antenna method. For each measurement pair, one antenna is at a fixed height and polarisation, and the other is height scanned. The receiver is set to record the maximum measured signal during the scan. In the three pairings each antenna is measured twice, and if the customer supplies two antennas then one of the antennas is always allocated to the height scanning mount, and the other to the fixed mount. An NPL antenna is used for the third antenna which height scans for one pair and is fixed for the other pair. If the customer supplies one antenna it will be placed at the fixed height.

Where standards call for an ANSI calibration (e.g. for NSA measurements), NPL recommends the use of free-space antenna factors for the scanned antenna for measurements at 10 m separation because they agree well with 10 m ANSI antenna factors. However, at 3 m separation the ANSI antenna factors differ significantly from the free-space values, and therefore only the ANSI antenna factors should be used in order to comply fully with the NSA method described in ANSI C63.4:1992 and CISPR 16-1:1998.

References

[1] MIL-STD-461D, Requirements for the control of electromagnetic interference emissions and susceptibility, 1993, Department of Defence, USA.

[2] SAE ARP958:1992, Electromagnetic interference measurement antennas; standard calibration method. Society of Automotive Engineers.

[3] ANSI C63.5-1998, American National Standard: Calibration of antennas used for radiation emission measurements in Electromagnetic Interference (EMI) control.

ANNEX TO NPL CERTIFICATE FOR BICONICAL AND SHORT DIPOLE ANTENNAS

Antenna Factor

Where the antenna factor has been given for a specific configuration above a ground plane (including free-space), the associated uncertainties only apply when the antenna support structure, including the input cable, does not cause significant reflections which would affect the received signal. If there are any significant sources of reflection then the user should asses the resulting uncertainty and treat it as an additional uncertainty term. For calibration purposes the free-space condition is achieved by mounting the antenna vertically polarised at a height above the ground plane at which mutual coupling is negligible.

Where there is a sharp resonance in the antenna factor the uncertainty given in the certificate does not apply. At the frequency where the resonance causes a deviation of greater than 1 dB from the overall trend of the data, the magnitude of the increased uncertainty can be estimated from the height of the spike on the antenna factor graph. The affected range can be taken as ± 1.5 % of the centre frequency. because the data is sampled at discrete points the maximum error may be much larger than that shown in the antenna factor graph.

The antenna factors are valid at the measurement height for any separation distance from the source exceeding one wavelength. For shorter distances the change in antenna factor with distance becomes significant and additional uncertainty would therefore be introduced. When the antenna is used for emission testing at a distance of 3 m from an equipment under test, whose size does not exceed that of the biconical antenna, there is an estimated increase in uncertainty of ± 0.3 dB in the range 50 MHz to 100 MHz, which is caused by mutual coupling of the antenna to the EUT. Below 100 MHz the antenna is in the near-field of the EUT and though the field magnitude will be correctly measured there will be additional uncertainty if the field strength were extrapolated to a greater distance. For extrapolation to a distance of 10 m, which is effectively in the far-field, this uncertainty is estimated to be ± 0.2 dB at 100 MHz and ± 1 dB at 30 MHz.

In order to measure the absolute E-field at different heights and polarisations above the ground plane it is necessary to know the antenna factor at each height and polarisation. However, a viable alternative is to use the free-space antenna factor for every configuration which minimises the additional uncertainty incurred. The additional uncertainty is caused by coupling of the antenna with its image in the ground plane which results in a change in the input impedance. For vertical polarisation there is no additional uncertainty for heights above 1.5 m, but between 1 m and 1.5 m the additional uncertainty is ± 0.7 dB in the range 50 MHz to 100 MHz. For horizontal polarisation, at heights above 1 m, the antenna factor may differ from the quoted values by up to ± 0.5 dB in the range 20 MHz to 50 MHz, and by ± 1.5 dB in the range 50 MHz to 100 MHz, and by ± 1 dB in the range 100 MHz to 300 MHz. The values for horizontal polarisation can be reduced by 0.5 dB for antenna heights above 2 m. The above variations are representative; the exact variation will vary slightly according to each antenna design.

If the antenna is used in an unlined screened room the use of these antenna factors may not give the absolute value of field strengths, but a calibration provides an essential check that the antenna is working properly. The antenna factors can be used to compare measurements made in an identical setup using a different antenna of the same type.

During height scans there will be an additional uncertainty caused by the directivity of the vertical radiation pattern. In normal use, signal maxima on a 10 m range occur for antenna heights below 2.5 m and the error here will be negligible. However, for a 3 m range the received signal could decrease by more than 1 dB.

Balance Test
The balance of the antenna balun may be tested by mounting the vertically polarised antenna in a uniform vertically polarised electric field, and observing the difference in received signal when the antenna is inverted. The change is caused by common mode current on the cable which is caused by an unbalance of the balun. It is important for this test that the cable hangs vertically behind the antenna in the usual manner. Typically there should be a horizontal distance of between 0.5 m and 2 m from the antenna element to the point at which the cable drops vertically. The cable should not move during the course of the measurements. An antenna is considered to have a good balun balance when the observed difference is less than ± 0.5 dB.

The inversion test is a qualitative measurement which reveals imbalance of the balun which, for some models of biconical antenna, can cause a large uncertainty in the measured field when the output cable is aligned parallel to the antenna elements. It is recommended that the user conducts tests of their own to quantify this effect in each particular measurement configuration. Some reduction of braid current can be achieved by the use of ferrite clamps on the cable. For antenna models with significant balun imbalance it is recommended that ferrites are also placed on the cable near the antenna input when the antenna is used for emission testing. Ferrite clamps on the output cable only provide a partial reduction of the braid current; a better solution is to use a perfectly balanced balun.

Return Loss
The quoted antenna factors apply when the mismatch between the antenna and the receiver is attenuated. A well matched 10 dB attenuator is recommended. If no attenuator is used (and the receiver front-end attenuation is set to zero), then the antenna factor can change by ± 1.4 dB at 30 MHz, assuming a receiver return loss of greater than 14 dB, an antenna return loss of 1 dB and a cable loss of 1 dB.

ARP958 Antenna Factor
Measurements at 1 m distance from an emitter is called for in MIL-STD-461D[1], which stipulates that procedure ARP958[2] is to be used for 1 m calibrations. It is necessary to distinguish between AF_{1m} and conventional AF which enables absolute E-field strength to be obtained from the voltage output of the antenna. ARP958 describes AF_{1m} as "apparent" antenna factor because it is derived from equations which do not take near-field terms into account. When AF_{1m} is used to measure absolute field strength an additional uncertainty term of ± 2 dB must be included. This only applies to the frequencies above 30 MHz, below 30 MHz the additional uncertainty is ± 5 dB.

ANSI Height Scan Method
The ANSI C63.5[3] procedure describes how the antenna factor may be measured over a ground plane by a height scanning three antenna method. For each measurement pair, one antenna is at a fixed height and polarisation, and the other is height scanned. The receiver is set to record the maximum measured signal during the scan. In the three pairings each antenna is measured twice, and if the customer supplies two antennas then one of the antennas is always allocated to the height scanning mount, and the other to the fixed mount. An NPL antenna is used for the third antenna which height scans for one pair and is fixed for the other pair.

References
[1] MIL-STD-461D, Requirements for the control of electromagnetic interference emissions and susceptibility, 1993, Department of Defence, USA.
[2] SAE ARP958:1992, Electromagnetic interference measurement antennas; standard calibration method. Society of Automotive Engineers.

[3] ANSI C63.5-1998, American National Standard: Calibration of antennas used for radiation emission measurements in Electromagnetic Interference (EMI) control.

ANNEX TO NPL CERTIFICATE FOR CONICAL LOG SPIRAL ANTENNAS

Antenna Factor

Where there is a sharp resonance in the antenna factor, at the bottom end of the frequency range, the uncertainty given in the certificate does not apply. At the frequency where the resonance causes a deviation of greater than 1 dB from the overall trend of the data, the magnitude of the increased uncertainty can be estimated from the height of the resonance on the antenna factor graph.

If the antenna is used on an open field site in the height scan range from 1 m to 4 m above a ground plane, the antenna factors may differ from the values quoted by up to ± 0.5 dB. This is because the input impedance of the antenna changes due to coupling with its image in the ground plane. This coupling is greatest at the lower frequencies where the height above the ground plane is a larger fraction of one wavelength. The cable should extend horizontally behind the antenna for at least 2 m before dropping to ground in order to minimise parasitic reflections.

If the antenna is used in an unlined screened room the use of these antenna factors may not give the absolute value of field strengths, but a calibration provides an essential check that the antenna is working properly. The antenna factors can be used to compare measurements made in an identical setup using a different antenna of the same type.

The antenna factors are valid for any separation distance from the source exceeding one wavelength. For shorter distances the change in antenna factor with distance becomes significant and additional uncertainty would therefore be introduced.

Measurement of linearly polarised fields

Conical log spiral antennas are intended to measure circularly polarised fields with the same hand of polarisation as the spiral. If the field is known to be linearly polarised, the antenna factor must be increased by 3 dB in order to give the magnitude of the field. The uncertainty may need to be increased if the ellipticity of the spiral deviates from perfect circular.

Phase Centre

When a conical log spiral is receiving E-field radiation the phase centre is the active part of the antenna at any given frequency.

The quoted uncertainty in antenna factor is only valid when the phase centre is placed at the point at which the field is required to be measured. If the antenna position is not adjusted with frequency to make this condition true, then a correction should be made to the measured field (at the phase centre position) in order to give the field at the required point. For distances of greater than one wavelength from the antenna a reduction of the field proportional to the inverse of the distance can be assumed, which means that in an anechoic environment a linear extrapolation may be used to adjust the field strength. The adjustment of antenna factor to a fixed reference point on the antenna is described later in the annex

The NPL certificate contains an expression which allows the approximate phase centre at any frequency to be calculated. The values for the constants, which are given in the NPL certificate are derived from the following equations :-

$$Z = \frac{Y \cdot L_H}{L_L - L_H} \qquad \mathrm{Cos}(\alpha) = \sqrt{1 - \left(\frac{L_L - L_H}{2 * Y}\right)^2}$$

$$X_F = \left\{\frac{(Y + Z) \cdot LF_{MHz}}{F_{MHz}} - Z\right\}\mathrm{Cos}(\alpha)$$

Where :- L_L and L_H = The diameters of the Low and High frequency (large and small respectively) ends of the spiral.
Y = The length of the spiral along the sloping edge.
LF_{MHz} = The specified low frequency limit of the antenna

Return Loss

The antenna factors quoted apply when the mismatch between the antenna and the receiver is attenuated. A well-matched 6 dB attenuator is recommended. For example, if no attenuator is used and the receiver front-end attenuation is set to zero, the antenna factor can change by typically ± 0.4 dB, assuming a receiver return loss of greater than 14 dB.

Adjusted Antenna Factor

For spiral antennas it is possible to calculate the result of an ARP958 1 m measurement rather than actually perform the measurement. We can do this because the conical log spiral antennas (CLSA) are in the far-field of each other. This calculated value does not take account of the small amount of coupling between the antennas, which would occur during an actual ARP958 measurement, but this effect is included in the stated uncertainty.

We can also calculate an adjustment to the antenna factor, which extrapolates the field measured at the phase centre of the antenna to a defined reference point. The separation to the EUT has to be specified and the reference point on the CLSA is often at the tip. This type of adjustment is not quite the same as the first type, but roughly similar results are generated (using a 1 m EUT to CLSA separation, and setting the reference point at the tip). However, for CLSA antennas operating down to 100 MHz, the difference between the two adjustments can be in the region of 1 dB.

A ARP958 calculation

$$AF_{1m} = AF_{FS} + 10 * Log_{10}\left[\frac{R + \left(2 * X_F\right)}{R}\right]$$

B Reference point adjustment

$$AF_{REF} = AF_{FS} + 20 * Log_{10}\left[\frac{R + X_F - X_{REF}}{R}\right]$$

Where :-
AF_{1m} = ARP958 antenna factor, usually with R = 1 m.
AF_{FS} = Measured free space antenna factor.
AF_{REF} = Antenna factor referenced to defined point on CLSA.
R = Separation either from tip to tip (A), or from EUT to reference point on antenna (B).
X_F = Position of phase centre from antenna tip.
X_{REF} = Position of defined reference point from antenna tip.

The adjusted antenna factor is commonly given for 3 m and 10 m separation, measured from the marked reference position or the mechanical centre of the antenna. If these 3 m and 10 m antenna factors are used for measurements other than at 3 m and 10 m respectively, the uncertainty will be larger than if the free space antenna factors are used, with correction for phase centre. The latter can be used for any distance exceeding two wavelengths without the need to increase uncertainty.

Use of ARP958 Antenna Factor

Measurement at 1 m distance from an emitter is called for in MIL-STD-461D[1], which stipulates that procedure ARP958[2] is to be used for 1 m calibrations. It is necessary to distinguish between AF1m and conventional AF which enables absolute E-field strength to be obtained from the voltage output of the antenna. ARP958 describes AF1m as "apparent" antenna factor because it is derived from equations which do not take phase centre into account. When AF1m is used to measure absolute field strength (at position of the active element at the frequency of measurement, ie the phase centre) an additional uncertainty term of ± 4 dB must be included at 200 MHz, and this diminishes to ± 0.5 dB at 1 GHz. This is because AF1m extrapolates the field strength from the position it is measured by the active element, to a distance of 1 m from the emitter. The extrapolation assumes a fall off in field inversely proportional to distance and does not take into account an imperfect measurement environment, such as a partially lined screened room, in which the field may not fall off linearly with distance.

References

[1] MIL-STD-461D, Requirements for the control of electromagnetic interference emissions and susceptibility, 1993, Department of Defence, USA.

[2] SAE ARP958:1992, Electromagnetic interference measurement antennas; standard calibration method. Society of Automotive Engineers.