**European intercomparison of antenna factors in the frequency range 30 MHz to 1 GHz**

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## Introduction

In January 1993 an intercomparison exercise began in which 15 laboratories from 9 European countries participated in the measurement of six antennas. The pilot laboratory, NPL, was sponsored by the European Commission under its BCR programme[1]. Antenna factor and reflection coefficient were measured at a selection of frequencies in the range 30 MHz to 1 GHz. Based on its wide experience of calibrating EMC antennas[2], NPL selected antennas which would give repeatable performances, being mechanically robust and with electrically well behaved baluns. The measurements began in June 1993 and were completed by March 1995.

The rationale for the exercise was that EMC testing was having a wider impact on society under the EC EMC Directive[3] and that a reduction in the uncertainty of EMC measurements would lead to a saving of resources to industry. Historically, radiated emission measurements have poor repeatability resulting in uncertainties of several decibels. The largest sources of error are the measuring site, the layout of the equipment under test and antenna factors of the receiving antenna. In the past the CISPR documents have failed to give due weight to the importance of uncertainties of measurement, but recently a statement has been proposed for all relevant standards. This states that limits have been set taking into account typical uncertainties and that measurement uncertainty must be evaluated and made available on request. This BCR intercomparison addressed the contribution that the receiving antenna makes to the uncertainty budget.

## Background to radiated emission measurements

Until recently the majority of EMC test houses used antenna factors provided by the antenna manufacturers, often with uncertainties greater than ± 2 dB. Using modern methods and equipment it is possible to reduce this uncertainty to less than ± 0.5 dB. This will enable emission conformance testing to be performed more accurately, which includes the accurate assessment of open area test sites (OATS). The largest source of uncertainty in radiated emission testing is radiation from the interconnecting leads and power cables of the equipment under test (EUT). Ideally the radiation should be measured on the surface of a sphere around the EUT but this would be too costly to implement. Instead the equipment is rotated through 360° about the vertical axis only, with the receiving antenna elevated over the limited angular range of 15°. This method combined with possible variations in the layout of the EUT leads to large variations in the results.

It is hoped that as the contributions to the uncertainty of emission measurements become better understood and quantified, more laboratories will be encouraged to include all known contributions in their uncertainty budgets. This will put the calculation of uncertainties on a more scientific footing. It will ensure that European trading partners are offering their services on equal terms. The organisations targeted to take part in the intercomparison were those with facilities to calibrate antennas, either for themselves or for others.

## Objectives

The objectives of the intercomparison were to (i) achieve an agreement within ± 1 dB in the measurement of antenna factors between calibration sites in different European countries and (ii) improve the level of metrology in calibration to a common standard within Europe.

The antennas included two biconicals (30 MHz to 300 MHz), two log-periodics (200 MHz to 1 GHz), one tuneable dipole set (30 MHz to 1 GHz) and one fixed length dipole (30 MHz to 100 MHz). These represented typical antennas used by EMC test houses and were made in Europe. There was a set of mandatory measurements of antenna factor at an average of 5 frequencies per antenna. The reflection coefficients of each antenna were also measured. Some laboratories were able to complete some optional measurements which gave valuable information on their calibration capabilities and information on the quality of their measurement sites. It is desirable to express antenna factor as a fixed property of the antenna, i.e. in the absence of mutual coupling. This can be done by measuring the free-space antenna factor, which in turn enables the uncertainties of emission testing to be reduced.

Participants were required to estimate the uncertainties of their measurements. The most widely used methods of calibrating EMC antennas[4] ignore the effect of mutual coupling between the antenna and ground plane: the antenna factors obtained by these methods specifically relate to the height at which the antenna was calibrated. It was mandatory to measure antenna factor at one frequency at three heights above the ground plane to explore the variation of antenna factor caused by mutual coupling to a metal ground plane.

The task of the pilot laboratory was to collate these results and establish the spread of measurements. This was to form the basis of discussions on how to improve the accuracy of the measurements and how the findings were to be applied to EMC emission testing. Two meetings were held. At the first meeting each laboratory described their test sites and proposed procedures. This was followed by a discussion on the best ways to optimise those procedures and avoid the pitfalls that can occur in antenna calibration. The details of the parameters to be measured and the number of frequencies were agreed. At the final meeting the methods for achieving the most accurate calibrations were agreed and maximum uncertainty limits were recommended. There was a discussion on ways of disseminating the recommended procedures to accredited laboratories throughout Europe.

## Results

Most of the antenna factor results across the 14 laboratories were within ± 1 dB of each other. The results were averaged, excluding results which differed by more than 1.5 dB from those of the pilot laboratory. Two of the participants had more than 50% of results which lay outside the ± 1 dB limits, so all their results were excluded from the average. Of a total of 38 measurements of antenna factor 32 of NPL's results were within ± 0.2 dB of the average[5], 3 were within ± 0.3 dB and 3 were down by 0.4 dB on the average at 30 MHz. 4 participants had all their results within ± 1 dB of the average. 11 participants had more than 83% of all results within ± 1 dB. The log antennas were more difficult to measure because the array extended in the direction of measurement. Excluding the two log antennas, 6 laboratories had 100% of their results within ± 1 dB of the average, and 10 laboratories had 90%. The spreadsheet results for the tuneable dipole antenna E are shown in Fig. 1. and for biconical antenna A in Fig. 2.

One bicone and the short dipole were measured at 4 different heights. Unfortunately the antenna factor variation with height for the antennas and frequencies chosen was too small to be significant within a spread of results of ± 1 dB. The return loss results were satisfactory, half of the laboratories giving it in terms of complex reflection coefficient.

## Conclusions

This intercomparison showed that an agreement of ± 1 dB was a reasonable target. This was achieved by most of the participants for most of the results. All of the results of 4 laboratories, including the pilot laboratory were within ± 1 dB of the average. Of the remainder of the laboratories 8 were mostly within ± 1.5 dB and 2 were outside this limit sometimes by a large margin. The next steps to further reduce the uncertainties of EMC testing are 1) to use antennas with well behaved baluns, 2) to examine the methods of measurement and 3) to make more reproducible the layout of the EUT and its associated cables.

## Acknowledgements

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## References

1 Third Framework Programme 1991- 94, Measurement and Testing (formerly BCR), Commission of the European Communities, Directorate-General XII for Science, Research and Development.

2 ALEXANDER, M J., SALTER, M J., GENTLE, D G. and HOLLAND, K P. Advances in measurement methods and reduction of measurement uncertainties associated with antenna calibration, IEE Proc. Sci. Meas. Technol. Vol 141, No 4 July 1994.

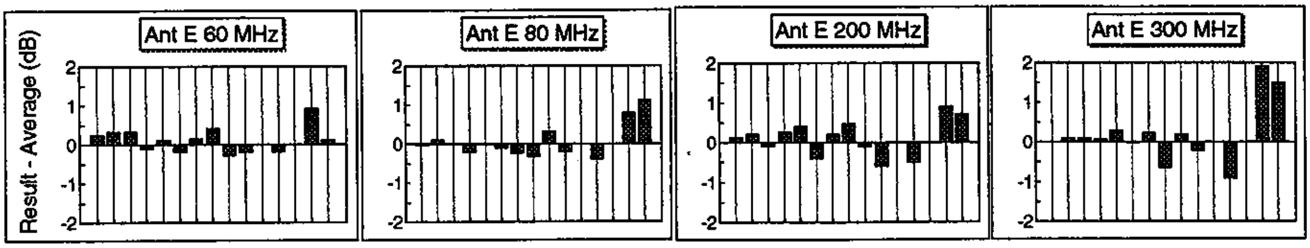
3 European Community EMC (ElectroMagnetic Compatibility) Directive 89/336/EEC of 3 May 1989, Official Journal of the European Communities, 23 May 1989, no. L139, pp 19-26.

4 American National Standards Institute, ANSI C63.5:1988. *Calibration of antennas used for radiated emissions measurements in electromagnetic interference (EMI) control*

5 ALEXANDER, M.J. and SALTER, M.J., The NPL calculable standard dipole antenna and 60 m ground plane, *British Electromagnetic Measurements Conference*, November 1995.

**Figure 1** **Antenna E** Result - average (dB)

| MHz | A | B | C | D | E | F | G | H | J | K |
|---|---|---|---|---|---|---|---|---|---|---|
| 60 | 0.2 | 0.3 | 0.3 | -0.1 | 0.1 | -0.2 | 0.2 | 0.4 | -0.3 | -0.2 |
| 80 | -0.0 | 0.1 | 0.0 | -0.2 | 0.0 | -0.1 | -0.2 | -0.3 | 0.3 | -0.2 |
| 200 | 0.1 | 0.2 | -0.1 | 0.3 | 0.4 | -0.4 | 0.2 | 0.5 | -0.1 | -0.6 |
| 300 | 0.0 | 0.1 | 0.1 | 0.1 | 0.3 | -0.0 | 0.2 | -0.6 | 0.2 | -0.2 |
| 500 | 0.0 | -0.1 | 0.8 | 0.1 | -0.2 | -0.0 | 0.3 | 0.1 | -0.2 | -0.2 |
| 700 | 0.2 | -0.7 | ~ | 0.1 | 0.5 | 0.2 | 0.0 | 1.1 | -1.0 | -0.3 |
| 1000 | 0.1 | 0.2 | -0.7 | -0.5 | 0.3 | -0.4 | -0.3 | 1.3 | -1.7 | 0.2 |




| MHz | L | M | P | Q |
|---|---|---|---|---|
| 60 | -1.3 | -0.2 | 0.9 | 0.1 |
| 80 | 0.1 | -0.4 | 0.8 | 1.1 |
| 200 | 0.4 | -0.5 | 0.9 | 0.7 |
| 300 | 0.7 | -0.9 | 1.9 | 1.5 |
| 500 | 0.6 | -0.8 | 0.9 | 0.7 |
| 700 | -0.1 | ~ | 0.4 | 1.5 |
| 1000 | -0.3 | -3.7 | 2.8 | -0.8 |

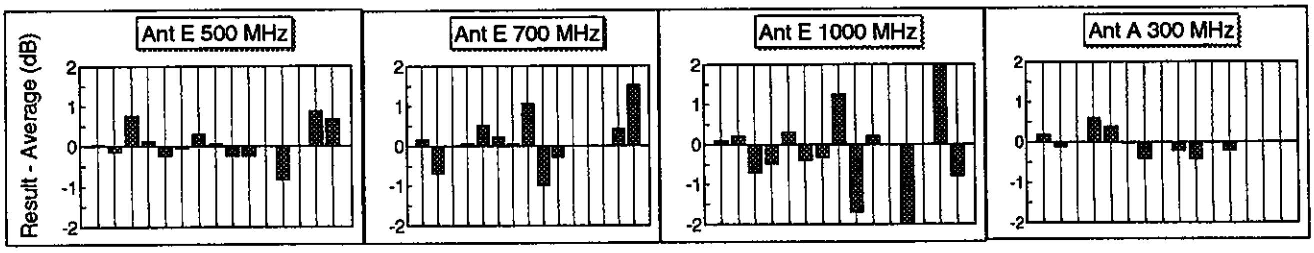
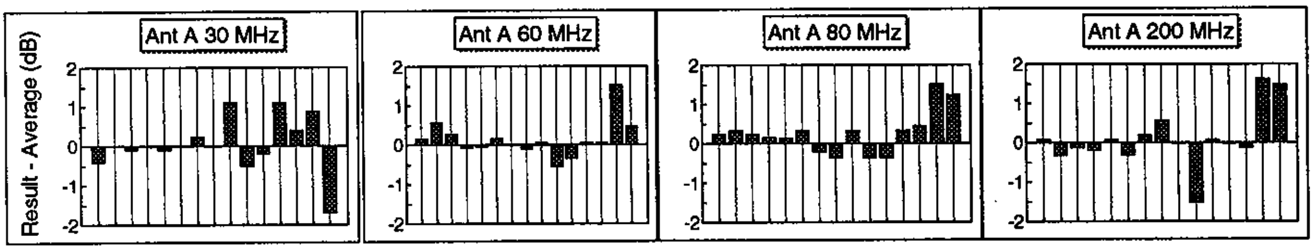



**Figure 2** **Antenna A**

| MHz | A | B | C | D | E | F | G | H | J | K |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | -0.4 | -0.0 | -0.1 | -0.0 | -0.1 | -0.0 | 0.2 | 0.0 | 1.1 | -0.5 |
| 60 | 0.2 | 0.6 | 0.3 | -0.0 | -0.0 | 0.2 | -0.0 | -0.1 | 0.1 | -0.5 |
| 80 | 0.2 | 0.3 | 0.2 | 0.2 | 0.1 | 0.3 | -0.2 | -0.4 | 0.3 | -0.4 |
| 200 | 0.1 | -0.3 | -0.1 | -0.2 | 0.1 | -0.3 | 0.2 | 0.6 | -0.0 | -1.5 |
| 300 | 0.2 | -0.1 | ~ | 0.6 | 0.4 | -0.0 | -0.4 | ~ | -0.2 | -0.4 |




| MHz | L | M | N | P | Q |
|---|---|---|---|---|---|
| 30 | -0.2 | 1.1 | 0.4 | 0.9 | -1.7 |
| 60 | -0.3 | 0.1 | 0.1 | 1.5 | 0.5 |
| 80 | -0.4 | 0.3 | 0.4 | 1.5 | 1.2 |
| 200 | 0.1 | -0.0 | -0.1 | 1.6 | 1.5 |
| 300 | -0.0 | -0.2 | ~ | ~ | ~ |