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The cover design depicts the microwave planar near-field scanner being developed at NPL.

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The measurement of free-space antenna factors of EMC antennas

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1. Introduction

One of the major contributors to the uncertainty of EMC emission measurements in the frequency range 30 MHz to 1 GHz is the antenna factor[1]. The minimum uncertainty attributable to the antenna in the measurement of electric field strength from an equipment under test (EUT) is that obtained in free-space conditions. This is true for a combination of reasons elaborated in section 2, but in practice measurements are made in the presence of a ground plane which is necessitated by the omni-directional nature of the antennas and the high cost of obtaining free-space conditions with RF absorbers at the lower end of this frequency range. Specifications, such as CISPR 16[2], describe emission measurements made over a ground plane by height scanning the receiving antenna to obtain a signal maximum.

Over the frequency range 30 MHz to 250 MHz the most commonly used broadband antenna is the biconical, whose antenna factor can vary by 2 dB when scanned in height over the recommended range of 1 m to 4 m. It is impracticable to calibrate the antenna at every height and also to identify the height at which the signal maximum was obtained and then to apply the correct antenna factor. In practice the antenna is calibrated at one height above a conducting ground plane with a given uncertainty and then an additional uncertainty of 2 dB is applied when the antenna is used at any other height. It is the reduction of this additional uncertainty contribution which is the main subject of this paper.

It is well known[3] that the antenna factor of a horizontally polarised resonant dipole oscillates in the manner of a damped sinusoid about its free-space value as the height of the antenna above the ground plane is increased. By characterising the antenna by its free-space antenna factor the height related uncertainty over a ground plane can be halved from ± 2 dB to ± 1 dB. A biconical antenna was calibrated at several heights in order to see whether the antenna factor oscillated about the free-space value; the differences from the free-space antenna factor were expressed as uncertainties since it was not intended to calibrate other antennas at more than one height. A different magnitude of uncertainty was allocated to three subdivisions of the frequency band, related to the resonant frequency of a typical biconical antenna of approximately 75 MHz: (i) below 50 MHz where the input impedance is highly reactive and the antenna factor varies little with height, (ii) between 50 MHz and 100 MHz where the antenna exhibits properties of a resonant antenna and (iii) above 100 MHz where again the input impedance is reactive, but the effective length of the antenna changes with height because of changes in the current distribution in the elements.

In section 2 the antenna related uncertainties of emission testing are reviewed and the reasons for choosing free-space antenna factor are given. In section 3 the measurement capability on the NPL open-field site is described, and in section 4 the techniques developed at NPL for measuring free-space antenna factor above a ground plane are described.

2. Reasons for using free-space antenna factor

The antenna factor relates to the gain of the antenna in its boresight direction only. When calibrating an antenna above a ground plane, knowledge of the antenna radiation pattern is required so that the contribution of the ground reflected signal can be accurately calculated. When performing emission tests the antenna is scanned in height and it is impracticable to properly account for the radiation pattern because this changes with frequency. Because the boresight antenna factor is the minimum, the corrected antenna factor off boresight is increased. Since the user does not use a corrected factor an uncertainty term must be associated with the effect of the radiation pattern. If the emission test could be performed in free-space conditions this uncertainty term would not apply; other factors that are not taken into account in conventional EMC testing are (i) the distance between the EUT and the antenna increases with antenna height and (ii) the measured field strength is nearly doubled by the ground reflection.

Another reason for using free-space antenna factor is that it is approximately the median value of the changing antenna factor when scanning in height above a ground plane. For vertical polarisation the mutual coupling of the antenna with its image in the ground plane is much smaller than for horizontal polarisation. For heights of greater than half a wavelength the difference of the antenna factor of a vertically polarised antenna from its free-space value is insignificant compared with other EMC uncertainty terms. Measuring the free-space antenna factor has the advantage of overcoming the incongruity that common calibration techniques employ horizontal polarisation (at one height) whereas most EMC emission problems involve measurements with vertically polarised antennas. Other antenna related contributions to the uncertainty of emission testing are the proximity of the antenna to the EUT, the phase centre of log-periodic antennas and the return loss of antennas[3]; further factors are balun imbalance of some biconical antennas and resonances caused by poor element contact on some log-periodic antennas.

3. Measurement uncertainties on the NPL antenna range

The NPL antenna range comprises a sheet steel ground plane of dimensions 60 m x 30 m with a flatness of ± 8 mm and an equipment cabin positioned 45 m from and perpendicular to the main site axis. Using standard antennas developed at NPL[3], the measured coupling (site insertion loss) between two horizontally polarised antennas was in agreement with theoretical prediction using NEC[4] to within ± 0.1 dB up to 300 MHz, increasing to ± 0.8 dB at 1 GHz. This proved that the antenna factors of the standard antennas were calculable to high precision, which applies to any polarisation and any height above a flat conducting ground plane and also in free-space. It enabled the antenna factors of horizontally polarised biconical antennas to be measured very accurately at any height above the ground plane by both the three-antenna and the standard antenna methods. This was the basis for the derivation of free-space antenna factor from horizontally polarised measurements of a biconical antenna at several heights referred to in the next section.

4. Measurement of free-space antenna factor

NPL has developed techniques to determine the free-space antenna factor above 200 MHz by using RF pyramidal absorbing material (RAM) on the ground underneath the antennas. There are two problems with this method below 200 MHz: (i) the absorber used was not effective and (ii) the area covered by the absorber would have to be increased in order to maintain a separation of two wavelengths between the antennas - this was not practicable. The three antenna method was used successfully with log-periodic antennas above RAM; their directivity reduces the signal directed into and reflected from the absorber, enabling the frequency to be extended downwards to 150 MHz.

An obvious way to obtain the free-space antenna factor is to measure a vertically polarised antenna at a height exceeding half a wavelength above ground. The problems with using vertical polarisation above a ground plane are (i) the field distribution over the length of the antenna is not uniform, (ii) the antenna support is usually a vertically polarised mast causing reflections - but the main problem is the parasitic action of the feed cable which drops vertically to ground behind the antenna, and (iii) site imperfections, including edge diffraction, which manifest themselves for vertical polarisation but which are negligible for horizontal polarisation.

Despite these problems, calibrations of vertically polarised biconical antennas were performed by both the three antenna method and the standard antenna method. The advantage of the latter was that the site effects were partially cancelled because they were similar for the biconical antenna and for the substituted standard antenna. The cable was extended 19 m behind the antenna before dropping to ground. In order to confirm the antenna factor thus obtained, the biconical antenna was also measured horizontally polarised from 100 MHz by the standard antenna method above RAM, ensuring a uniform aperture distribution and the absence of edge effects. The RAM was found to be effective down to 100 MHz - its action here was to damp mutual coupling to the ground plane rather than suppress reflections as for the three antenna method. The other method was to extrapolate the free-space antenna factor from values measured at a series of heights above the ground plane; the standard antenna method was used, for precision, in the frequency range 30 MHz to 100 MHz.

The three sets of values agreed to within ± 0.5 dB. It was concluded that the effective free-space antenna factor of a biconical antenna can be measured by the standard antenna method with the antenna vertically polarised at a height of 2 m above a ground plane to an uncertainty of ± 1 dB, with additional height related uncertainties reduced to ± 1.5 dB.

5. References

1 ALEXANDER, M.J. and SALTER, M.J., The calibration of RF antennas, *British Electromagnetic Measurements Conference*, November 1991, pp 32/1-4.

2 CISPR publication 16: CISPR specification for radio interference measuring apparatus and measurement methods. 2nd ed., 1987. Central office of the IEC, 3 rue de Varembé, Geneva, Switzerland. Refer also to the draft revisions of CISPR 16.

3 ALEXANDER, M.J. and SALTER, M.J., The calibration and use of EMC antennas, 30 MHz to 1000 MHz, *Eighth International Conference on Electromagnetic Compatibility*, 1992, IEE Conference publication 362, 189-195.

4 LOGAN, J.C. and BURKE, A.J., Numerical Electromagnetic Code, 1981, Naval Oceans Systems Centre, CA, USA.