TRACEABLE CALIBRATION OF MAGNETIC FIELD TRANSFER SENSORS UP TO 1 GHZ IN A RADIATED STANDING WAVE PATTERN

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Abstract: A method is described to generate a traceable rf magnetic field by using a standing-wave pattern and to calibrate a special transfer sensor inside the magnetic field maxima. Preliminary experimental and numerical results are presented and discussed.

1. Introduction

Field strength meters (“radiation monitors”) for electromagnetic compatibility (EMC) tests and for occupational safety measurements must produce data the user can rely on. While the European standards for EMC susceptibility tests [1] only set limits for the electric field strength, the German regulations for human rf field exposure below 1 GHz [2] specify separate limits for the electric (*E*) and magnetic (*H*) field components as well as for the power flux density (*S*). This seems reasonable, because the free-space impedance is not defined in the proximity of a radiating antenna or in a standing wave pattern around scattering objects. As a consequence, in such areas all field quantities must be measured separately, because from only one measured the others are not directly calculable. Additionally, the field structure and energy flow in these “near field” areas may be quite complicated, because the orientations of the *E*- and *H*-vector polarization ellipses are usually unknown. But even under such unfavorable circumstances a field strength meter is expected to give meaningful results.

Radiation monitors measuring the electric field are conveniently calibrated [3,4] e.g. inside a sufficiently large “GTEM” cell, where the field strength is traceable, because it is adjusted using a “transfer sensor” previously calibrated in a very small precision TEM cell [5]. But this simple and straightforward procedure is not directly applicable for radiation monitors measuring the magnetic field strength, because in this case a calibrated “H field transfer sensor” would be required to establish a traceable magnetic field inside the “GTEM” cell. Even with a reasonably small magnetic field transfer sensor available (see section 3.), unfortunately it is too large to directly fit into the precision TEM cell.

2. RF Magnetic Field for Calibrations

2.1 Calculable Field Generators

With emphasis on traceability, here we can only consider methods and field generators which produce a *calculable* rf electromagnetic *field strength* at a certain *frequency* – both must be derived from suitable standards of the international SI system of physical units. The basic principle must be obvious from physics and the model for the calculation (including its limitations) should be clearly described.

TEM cells which are mode-free up to 1 GHz are too small to accomodate a magnetic field sensor of reasonable sensitivity and size. In contrast to an E-field sensor, the loop must be oriented for maximum output in a position where it significantly distorts the surrounding electric field. Below approx. 300 MHz precision TEM cells may be made sufficiently large and can be used for calibrations, so the most critical frequency range considered here is above 300 MHz to 1 GHz.

In this range it is still very difficult to use calculable radiated antenna fields for calibrations, because the antenna gain must be determined with low uncertainty. Additionally, the reflections from the environment (absorbers, obstacles etc.) must be kept very low. Above 1 GHz the absorber performance of anechoic rooms is better, and there are standard gain horns available with low uncertainty antenna factors, so we restrict the upper frequency limit of the method discussed here to 1 GHz.

2.2 Standing Wave Pattern as Calibration Field

Because of the problems encountered with calculable unidirectional “far-field” waves inside coaxial lines or from well-known radiating antennas it seemed attractive to try a completely different approach. For this purpose an arrangement with a rather simple radiating (log. periodic) EMC antenna illuminating a plane metallic reflector was considered, which was expected to produce a well-characterized standing wave pattern between the antenna and the reflector. To analyze the field structure in detail, a numerical calculation based on the “Method of Moments” (MoM) [6] was performed, using the “Concept” computer code [7].

To avoid modeling the log.-periodic antenna in detail, a dipole was assumed as the transmitter. This simplification seems justified, because in such an antenna at a certain frequency only two or three subsequent elements give dominant contributions to the total radiated power. The field structure in some distance from these elements is a spherical wave and very much like a dipole field. Especially at lower frequencies the wavelength is of the order of the reflector dimensions, so its finite size seemed more important for the fields near the sensor and was considered in the model.
With a flat metal reflector of 2 m x 2 m size (already available from previous experiments) it was assumed that a frequency range between 300 MHz and 1 GHz could be covered. For the initial calculations and measurements three frequencies (300 MHz, 500 MHz and 700 MHz) were chosen.

2.3 Numerical Results

The reflector plate was modeled with 40 x 40 equally sized patches. As expected, the calculated fields show spherical waves near the dipole source and some fringing effects around the reflector (indicated as the horizontal line at the bottom of Fig. 1 for 300 MHz). The mechanical distance between the reflector and the tip of the log.-periodic antenna was 3 m, the estimated distances to the active dipole(s) were 3,4 m at 300 MHz (3,25 m at 500 MHz and 3,10 m for 700 MHz, respectively).

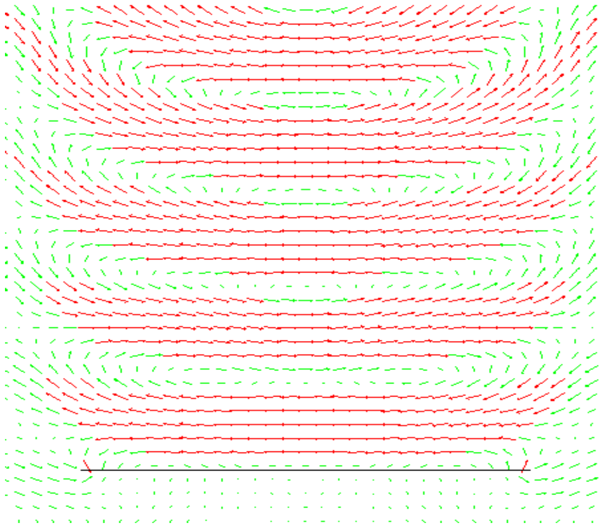

Fig. 1: Calculated E field structure (see text for details, straight black line = reflector plate)

As expected, the field structure near the reflector is dominated by the boundary conditions, requiring (linear) E- and H-field polarization parallel to the reflector, approximating a plane wave, with a H-field maximum and no tangential E-field at the metal surface. It was therefore expected that for the structure near the reflector the transmitting antenna should be quite arbitrary.

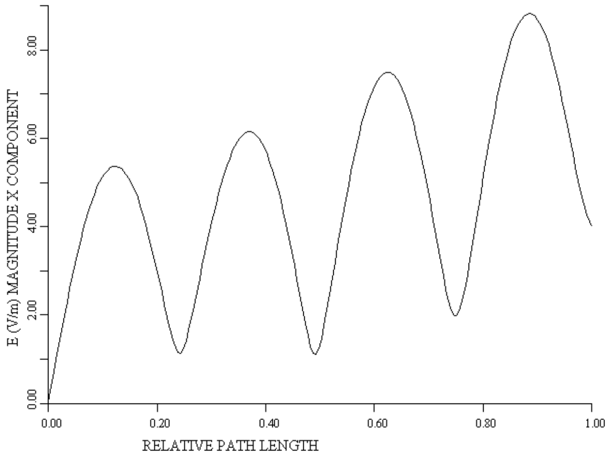

Fig. 2: Calculated “on-axis” E field at 300 MHz, (see text)

Figs. 2 and 3 show the calculated “on-axis” field amplitudes from the reflector (at zero, left) to 2 m towards the antenna (normalized, right), assuming a total radiated power of 1 W.

Also as expected, the electric and magnetic field maxima are found at alternating positions. The increasing amplitudes approaching the antenna indicate the spherical waves seen in Fig. 1.

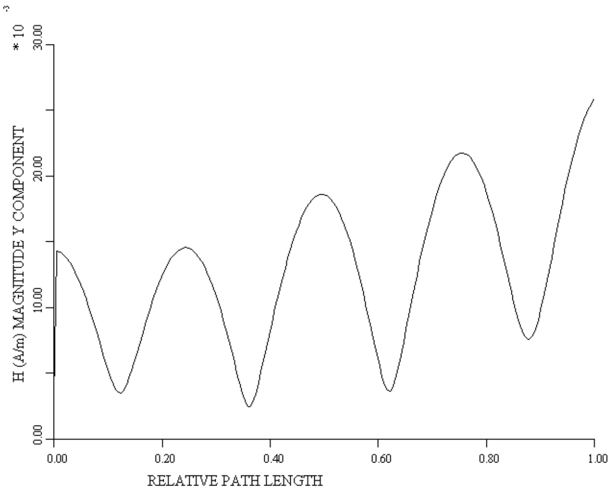

Fig. 3: Calculated “on-axis” H field at 300 MHz (see text)

2.4 Experimental Results

For the measurements a (traceably) calibrated transfer sensor for the electric field [5] and an uncalibrated balanced loop sensor (please see technical description in section 3) for the magnetic field were assembled in some distance on a styrofoam carrier (Fig. 4 shows the sensor pair).

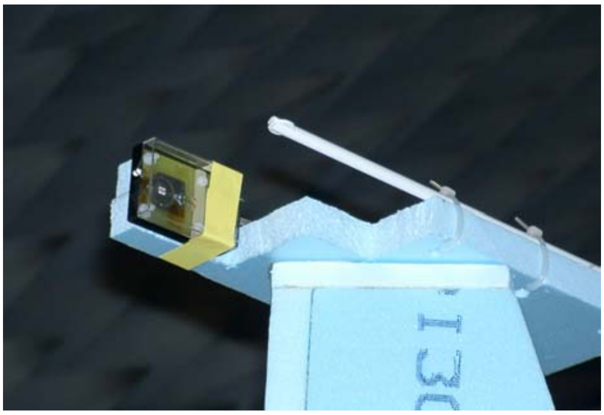

Fig. 4: Electric and Magnetic Sensors (left: magnetic sensor in protective box, right: electric field sensor; see text)

This carrier again was fixed on top of a pyramidal styrofoam support, which was moveable between the radiating antenna and the reflector – Fig. 5 shows the complete arrangement inside the laboratory’s semi-anechoic EMC facility.

Fig. 5: Measurement setup (see text for description)

With this arrangement the standing-wave pattern was scanned along the center axis, with a range between 0.1 m and 1 m from the reflector mechanically accessible. The results are shown in Fig. 6 for 300 MHz, they may be compared directly with the numerical results of Fig. 2 up to a relative path length of 0.5. In the measured results only the electric field values can be scaled – because the magnetic field sensor is uncalibrated at this stage, the values for the magnetic field are the square roots of the detected dc voltages, normalized to a suitable level clearly visible in the diagram.

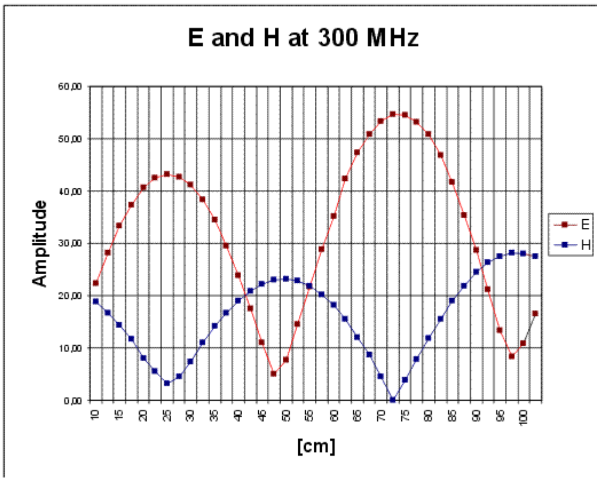

Fig. 6: Electric field strength and (unscaled) magnetic field sensor signal at 300 MHz

With the measured data the magnetic field strength at the maximum locations can be determined as follows:

- The *ratios of the electric and magnetic field amplitudes* at subsequent maxima of the standing wave pattern are calculated using the numerical MoM simulation with the „Concept“ program, where the transmitted power may be quite arbitrary – because in this model the calculated E and H ratio is independent of any absolute value.
- a magnetic field maximum in the homogeneous field area, but in sufficient distance from the reflector is chosen as the location most suitable for a sensor calibration,
- The field amplitudes at the adjacent electric field maxima are measured using a (traceably) calibrated sensor,
- the *magnetic field amplitude at the maximum* location of interest is *calculated from the measured E field maxima*, either based on the *ratios from the numerical model* or on the assumption of constant time-averaged energy density.

In the first E-field maxima effective values of 43,1 V/m and 54,7 V/m were measured with the calibrated electric field transfer sensor. The numerically calculated effective values at the same locations (for 1 W radiated power) were 3,85 V/m and 4,67 V/m, giving slightly different factors of 11,2 and 11,7 for the two maxima – so we have taken the average (11,45) as the best estimate for the normalization factor at the magnetic field maximum between them. There the numerically calculated magnetic field strength (0,0106 A/m) is converted to 0,12 A/m in the actual experiment, where the magnetic field sensor produced a dc voltage of 10,2 mV. Finally, the (effective value) calibration factor for this sensor was determined as 11,9 $\Omega^{-1}m^{-1}$ (at 300 MHz and 0,12 A/m).

3. Magnetic Field Transfer Sensor

In this text a “transfer sensor“ is a device which has been calibrated at a predefined field strength in a suitable field generator as described above, ensuring its “traceability“. With such a device we may reproduce the same field strength at a later time and at a different location with the lowest (additional) uncertainty. Of course, such a sensor and its associated electronics must be highly stable, and the sensor should be small to minimize field distortions (backscatter). The complete system should also be portable, mechanically rugged, and easy to operate – although initially calibrated in a well-defined laboratory environment, it is intended for measurements at more adverse “real world“ locations.

While small transfer sensors with low uncertainty are readily available for radiofrequency electric fields, magnetic field sensors with similar performance are much more difficult to design and to calibrate for the following reasons:

- the magnetic field sensor design requires a critical tradeoff between sensitivity, resonance-free operation bandwidth and size,
- the sensitivity against simultaneous electric fields must be suppressed,
- well-defined (traceable) magnetic fields with sufficient volume are not readily available.

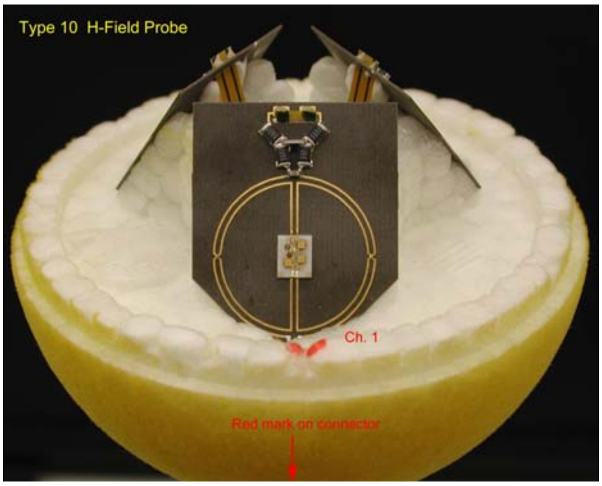

Fig. 7: Photo of Magnetic Field Sensor ([8], see text)

A manufacturer producing isotropic magnetic field probes made one single loop antenna element (Fig. 7, front]) available for these measurements. This balanced two-turn loop has approx. 15 mm diameter and offers resonance-free operation up to 1.2 GHz. A very compact detector circuitry located at the center employs Schottky chip diodes, small chip capacitors and integrated thin film resistors to minimize the direct field coupling mechanism. Previous measurements by the manufacturer have shown a flat frequency response bandwidth from 80 MHz to 1 GHz and a DC output voltage of approx. 6 mV in an external magnetic field of 0.1 A/m. The compensated design should give 20 dB E-field suppression under far field conditions.

4. Conclusion

Calibration of small magnetic field sensors is possible with a radiating antenna and a plane reflector. Traceability is based on a previously calibrated electric field sensor. The physical background is simple and obvious, but the procedure is rather time-consuming, because it requires accurate mechanical repositioning of the sensor after each frequency change, thus inhibiting fast automatic swept measurements. Future investigations should address more frequencies (experimental data for 500 MHz and 700 MHz already in progress), refinement of the numerical model, finding the optimum positions for the components, a complete uncertainty budget, additional uncertainty contributions (especially the influence of field distortions caused by reflections from the antenna, the environment and the ground) and a possible uncompensated electric field sensitivity of the sensor. A comparison with other methods and at least a semi-automatic procedure for more effective routine calibrations would also be desirable.

5. Acknowledgement

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6. References

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