14. BROADBAND FIELD STRENGTH MEASURING SYSTEM UP TO 18 GHZ

EXTENDED FREQUENCY RANGE AND MODERN INSTRUMENT CONCEPT OPENS UP NEW SEGMENTS OF RF FIELD MEASUREMENT

Article for Compliance Engineering 1997

Dr. Rainer Bitzer

Foreword

Wandel & Goltermann's EMR range of modern measuring instruments has yielded significant improvements in the measurement of field strength of up to 3 GHz. These instruments are an ideal combination of high precision, ease of use, advanced functionality and cost-effective design. Exact determination of electromagnetic fields in the EMC laboratory is, however, a big challenge, particularly if measurements in the frequency range above that of traditional EMC applications are called for. Human safety in the vicinity of high-powered microwave transmitters such as radar and flight control equipment also has to be determined by measurement. The near-field presents a particularly complex conditions: All the electric (E-field) and magnetic (H-field) components of the electromagnetic field have to be determined separately.

Introduction

The first instruments in the EMR series were born from the demand for innovative electromagnetic field measurement equipment and have been available since mid-1995. The function and major features of the EMR-20, the basic instrument for measuring isotropic field strength in the frequency range from 100 kHz to 3 GHz, were described separately [1].

A measurement system based on the design concept of the EMR-20/30 range, comprising a mainframe instrument and a range of interchangeable probes, was developed for isotropic measurement of magnetic fields of up to 1 GHz and electric fields of up to 18 GHz. This article describes the isotropic E-field probe up to 18 GHz and its application-specific characteristics.
In the EMR-200/300 series isotropic field detection probes are used, that ideally determine the r.m.s. field strength independently of direction and polarization of the radiation source. Due to the physical distance between the probes and the instrument the effects of the instrument casing on the measurement are reduced to an insignificant level. Since users generally know the main characteristics of the source, such as frequency and modulation, predetermined measurement deviations for practical usage conditions can be applied to correct the measurement values.

The principle of field detection probes

The EMR probes make use of dipoles to detect the E components of the electromagnetic field by measuring the received voltages. As sensors for the H-field they use coils and here measuring the induced current. Schottky diodes convert the r.m.s. value of the detected field components to a d.c. voltage. By using diodes instead of thermocouples, it is possible to handle a much wider field strength dynamic range of typically 60 dB. Thermocouples can also be damaged more easily than diodes at high power levels.

The resultant d.c. voltage is fed inside a tube to the display / evaluation unit. The isotropic probes have separate detectors and d.c. transmission lines for each of the three spatial dimensions. The equivalent field strength is computed inside the mainframe instrument by the square root of the sum of the squares of the three components. Conventional probes often only make use of the square-law of the detector characteristic and sum the analog d.c. voltages in the probe head. Contrary to this analog addition method, it is possible to achieve a very high linearity right up to the upper limit of the measurement range because any deviations from the square-law characteristic are corrected by the instrument controller. This dynamic correction here is for the first time based on characterization of the circuit components in the probes and guarantees a very small linearity error over the entire 60 dB dynamic range. At the same time, users make a profit from the fact that individual measurement and calibration of instrument dynamics is no longer needed, which significantly reduces the cost of final production testing. The individual field strength components are also available via the remote control interface.

Innovative mainframes

In the evaluation unit the signal processing of the detector voltages is performed over a range of about 100 dB in a single measurement range. This eliminates the hysteresis effects associated with automatic gain circuitry. It also guarantees the measurment of the signals at precise points in time, since signal blanking during range switching does not occur.

In normal operation, the instrument performs a zero adjustment every 6 minutes. This automatic zeroing also operates reliably even if the instrument is exposed to high-strength fields. The high precision of the zero adjustment resulted in high probe sensitivity.

All EMR instruments are equipped with an optical remote control interface, making them also ideal for automated measurements in EMC laboratories. All that is required for remote control is a computer with a serial interface along with the PC Transfer Set which includes a 20 m fiber optical cable and an opto/electric converter. The command syntax, similar to SCPI, is clearly structured and allows easy programming the instrument.

The version EMR-300 has got additional features compared ti the EMR-200. These include a real-time clock and memory of up to 1500 measurement values. This allows long-term monitoring without needing to connect the instrument to a computer. The measurement values are timestamped and can subsequently be displayed later or read out via the PC Transfer Set. The EMR-300 also offers spatial averaging in addition to the standard 6-min averaging interval.

Interchangeable probes

Interchangeable probe types are offered to allow adaptation to different applications in various frequency ranges. The plug-in probes have got a probe head in a distance of about 30 cm from the display / evaluation unit. Three different isotropic probes are available so far: E-field probe (type 8) for the frequency range from 100 kHz to 3 GHz, E-field probe (type 9) from 3 MHz to 18 GHz and H-field probe (type 10) from 27 MHz to 1 GHz.

The mainframe EMR-200/300 handles one set of parameters for each probe type. These probe parameters comprise the correction of the detector characteristic and the calibration data for absolute field strength. Probe sensitivity is determined individually during factory calibration. All probe-specific data for each probe ordered is factory configured. When a probe is changed, the instrument automatically detects the probe coding, applies the relevant calibration data and activates the measurement mode for electric (V/m) respectively magnetic (A/m) field strength appropriate to the plugged in probe type.

If further probes are subsequently ordered to extend the range of instrument applications, the existing instrument configuration can be updated via the remote control interface using the Transfer Set, a PC and the probe data supplied on floppy disk.

E-field probe 100 kHz to 3 GHz

This isotropic E field probe is part of the basic version EMR-20 and is also optionally available for the EMR-200/300 measuring system. This probe covers practically the entire spectrum of telecom applications and industrial RF usage (ISM frequencies). As the probe has an extremely linear response over a broadband frequency range and high sensitivity from approximately 1 V/m, it can also be used as a field strength reference for EMI measurements. The frequency response and other characteristics have already been described elsewhere [1]. The technical data sheet and a further pamphlet available from Wandel & Goltermann also provide detailed information about the behavior in respect of modulated signals [9, 10].

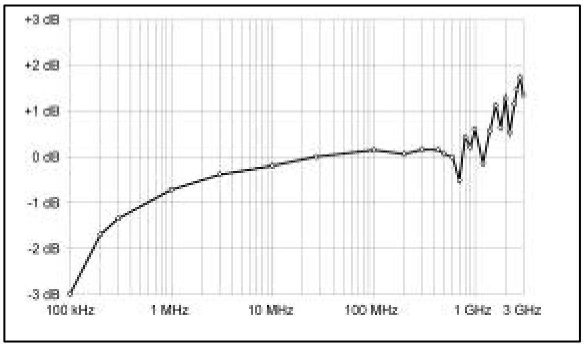

Fig. 1: Typical response of the EMR-measuring system with E-field probe (type 8) at 27,5 V/m in position PH

H-field probe 27 MHz to 1 GHz

Relatively simple relationships are found in the electromagnetic far-field regions. The E- and H-field vectors are perpendicular to each other and are transverse to the direction of wave propagation. The field vectors are in phase and their magnitudes are strictly related through the characteristic impedance of free-space, i.e. ZF0=377Ω. Here, for example, the H-field strength magnitude as well as the power density can be calculated from measuring the E-field strength. Much more complex relationships are found in the near-field region, i.e. in the immediate vicinity of the radiating source or a scattering object. Both field components generally show a difference in phase and the E/H ratio can deviate strongly above or below the free-space impedance ZF0. For this reason, both the electric and the magnetic field strength must be examined, for example, during maintenance work on broadcasting equipment close to the antennae. The new isotropic H-field probe (type 10) should additionally be used dB suppression for E-fields. This probe covers practically all ma here. It is resonance-free, with a flat frequency response between 35MHz and 1GHz (Fig. 2) and shows 20dB suppression for E-fields. This probe covers practically all major radio services, from

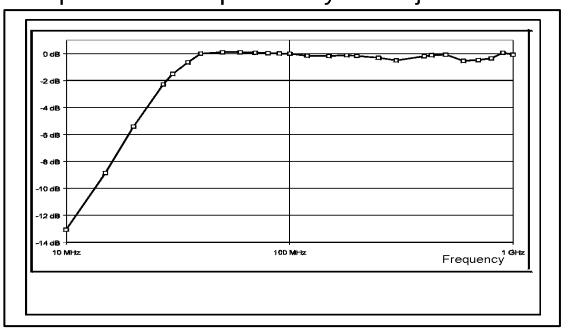

Fig. 2: Typical frequency response of the H-field probe (type 10) at 0,23 A/m in position PH

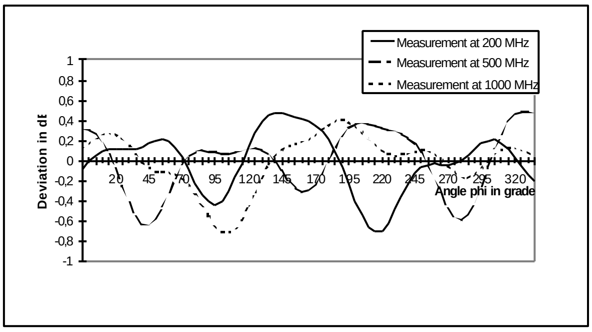

Fig. 3: Typical isotropy deviation at different frequencies (position PH)

short-wave, VHF and UHF bands up to mobile radio frequencies. The lower cut-off frequency of close to 27 MHz allows shaped measurements conform to the most important safety limits for magnetic fields [4, 5]. This allows control of human safety limits to RF electromagnetic fields even in the presence of several transmitter signals right down to the medium-wave range. The specified measurement range from 0.03 A/m to 16 A/m means that all relevant safety limits can be reliably provided.

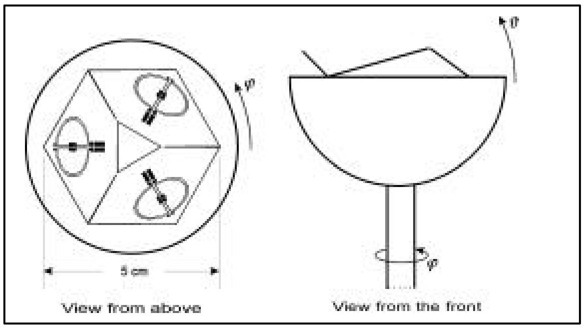

Fig. 4: Schematic representation of a 3-dimensional magnetic field probe

E-field probe 3 MHz to 18 GHz

Frequencies above 3 GHz are also used for radar applications, radio-link and satellite communications. The new type 9 isotropic E-field probe can be used here between 3 MHz and 18 GHz. Despite this wide frequency range (Fig. 5), the probe has a high sensitivity from 1.2 V/m on and a high dynamic range. The advantages of this high dynamic range of type. 60 dB become especially apparent when measuring radar signals, which have a high crest factor (i.e. high peak value in relation to the r.m.s. value). The high sensitivity is particularly useful when rotating radar arrays are measured, since the probe captures only a fraction of the radiated energy. Considerable display deviations are encountered whenever such extreme pulse modulation is detected. For defined signal shapes information about the expected measurement error can, however, be given.

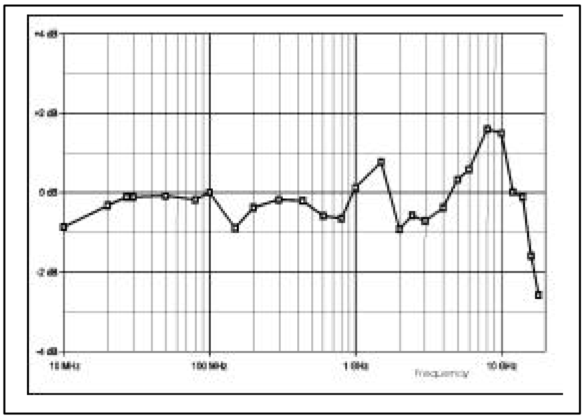

Fig. 5: Typical frequency response of the EMR-measuring system with E-field probe (type 9) at 27,5 V/m in position PH

Construction of isotropic E probe

In the isotropic E field probes a dipole triple is arranged as an orthogonal detector system. Three dipole elements at angles of 54.7º mounted on separate substrates are arranged as a prism. This geometry ensures that the three axes of the dipoles are close to each other, which is a basic requirement for a well isotropic behaviour (Fig. 6).

A cost-effective design in SMT on FR-4 printed circuit boards was possible for the E-field probe type 8 up to 3 GHz. This technology cannot be employed for field sensors operating above about 3 GHz because the component sizes are similar to the radiation wavelength and component resonances may therefore occur. For such probes thin-film sensors with high precision structures and dimensions of a few µm on amorphous quartz substrates are used. Schottky diodes are also used for detection, these having very low parasitics to make best use of the advantages of a high measurement dynamic range. The individual sensors make use of aperiodic damping to avoid dipole resonances [6, 7]. Complex procedures based on the method of moments are employed to optimize the frequency response. These simulations were confirmed by accompanying measurements.

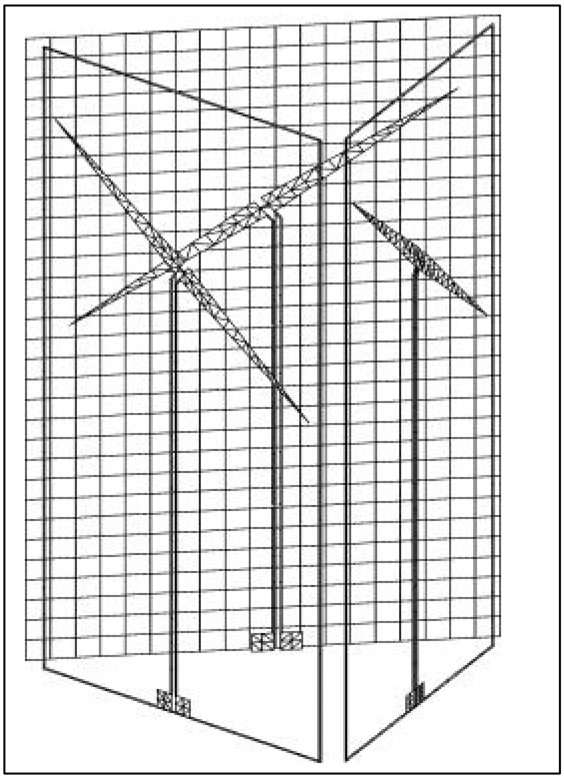

Fig. 6: FEKO-simulation model of the 3-dimensional arrangement of the probe

The d.c. leads from the sensor system to the display / evaluation unit conclusively effects the entire system and requires special know-how. To avoid field distortion caused by metallic conductors or coupling effects, high-impedance leads have to be employed (several MΩ/m). Known weaknesses of similar arrangements were taken into account and avoided here for the most part. In the E-field probe type 9 up to 18 GHz, the leads are partly realized using thin-film structures on the quartz substrates in the immediate vicinity of the dipole sensors, and partly using more economical thick-film structures.

Calibration

Individual calibration of field strength meters is meaningful in order to reduce measurement uncertainty. Field probe and mainframe instrument are calibrated separately and independently. The d.c. calibration uncertainty for the mainframe instrument is practically negligible. Basically all EMR probes are calibrated at a reference frequency and a medium field strength. The absolute value of the electric field strength is traceable to the national standards kept by the German Bureau of Standards (PTB) via a transfer probe. As no corresponding standard for the magnetic field strength currently exists, the H-field probes are calibrated in a TEM cell by calculating the field value from the geometry and RF power. In both cases, an absolute error of 1 dB can be specified after calibration and adjustment under reference conditions.

In addition, extended calibration including frequency response is optional for all EMR probes. This calibration procedure determines a correction factor versus frequency which displays the field strength of the undistorted field on the instrument. Users can set this calibration factor on the instrument and get the corrected measurement value displayed. Individual calibration of frequency response is useful if signals outside the flat frequency response are to be determined with high precision. The entire measuring system is exposed during calibration process to as homogeneous a far-field as possible. At high frequencies, the calibration field is often the plane-wave in front of an aperture antenna in an anechoic chamber. Calibration should take place with the same probe orientation as the future application. For example, the high-frequency E-field probes type 9 are calibrated with the probe axis parallel to the magnetic field vector (PH) to minimize the effects of the sensor leads at low frequencies and to reduce effects of the mainframe instrument at high frequencies. The typical frequency response at 27.5 V/m is shown in Fig. 5. The typical anisotropy of the probe including the mainframe instrument is around ±1.5 dB in most of the frequency ranges between 10 MHz and 8 GHz.

A comparison was made of the frequency response calibrations on a prototype which was performed by a recognized German calibration laboratory and by an international authority (the NPL in the UK). Fig. 7 shows the frequency responses determined by the two laboratories for an EMR system with E-field probe type 9. The deviations detected in the PH direction are over wide ranges within 2 to 3 dB and can be practically explained by the expected calibration uncertainties. However in certain frequency ranges, e.g. between 14 GHz and 18 GHz, additional systematic errors are obviously revealed. At the reference frequency of 100 MHz both calibrations differ by 0.82 dB absolutely.

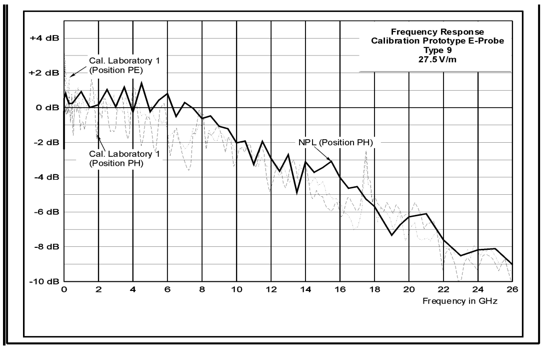

Fig. 7: Comparison of the frequency response calibration with E-field probe (type 9) in position PH respective PE at 27,5 V/m

The measurement uncertainties in the calibration fields lie between about 1.3 dB at low frequencies (200 MHz) and 1.8 dB above 12 GHz. The major causes are due to the method of field generation: The required field strength can only be generated at a relatively small distance from the transmitting antenna, i.e. within the radiating near-field where the antenna pattern is frequency-dependent. Moreover, often only far-field calibration data for the antennae themselves are available. As a result, the resulting uncertainty is also strongly dependent on the local position of the field probe during the calibration. Improvement of calibration at the weak points thus detected would be desirable.

Summary and conclusion

The innovative instruments in the EMR range with their interchangeable plug-in broadband probes provide an improved basis for measuring electromagnetic fields in the RF and microwave range. The mainframe instruments give users a range of useful features including automatic probe recognition and activation of valid calibration data. The isotropic broadband probes for measurement magnetic fields of up to 1 GHz and electric fields of up to 18 GHz are characterized by a very wide dynamic range. The instruments are ideal as field strength reference meters in EMC laboratories, as well as for human safety applications. Calibration has got several challenges, particularly with regard to measurement uncertainty. A comparison between two recognized laboratories on an international level yielded a result which can be considered all in all satisfactory but which indicates that improvements in the calibration method are desirable.

Bibliography

[1] Keller, H.; Bitzer, R.: Moderne hochfrequente Feldstärkemeßgeräte
(Modern high-frequency field strength meters).
EMC-Journal, EMV Kompendium 96, pp. 304 to 307, 1996 (in German).

[2] Keller, H.; Bitzer, R.:
Technische Problemlösungen bei der Entwicklung von Meßgeräten für nichtionisierende Strahlung
(Solving technical problems in the development of measuring instruments for non-ionizing radiation).
EMC Symposium, 04. to 06.10.1995 at BAKWT, Mannheim (in German).

[3] Bitzer, R.: Breitbandiges Feldstärkemeßsystem bis 18 GHz
(Broadband Field Strength Measuring System up to 18 GHz).
EMC-Journal, EMV Kompendium 97, pp. 264 to 267, 1997 (in German).

[4] Entwurf einer Verordnung zur Durchführung des Bundesimmissionsschutzgesetzes
(Draft regulation concerning electromagnetic fields, BImSchV).
Federal Ministry of the Environment, Nature Conservancy and Reactor Safety, 1995 (in German).

[5] IRPA Guidelines on Limits of Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 100 kHz to 300 GHz.
Health Physics, Vol. 54, No. 1, pp. 115 to 123, Jan. 1988.

[6] Rippl, K.: Feldstärkemeßgeräte: Anwendbarkeit und Kalibrierung.
(Field strength meters: Application and calibration)
EMC-Journal, EMV Kompendium 95, pp. 171 to 172, 1995 (in German).

[7] Wu, T.T.; King, R.W.P.: The Cylindrical Antenna with Nonreflecting Resistive Loading.
IEEE Transactions on Antennas and Propagation, Vol. AP-13, No. 6, pp. 369 to 373, May 1965.

[8] Kanda, M.: A Broadband Antenna with Tapered Resistive Loading for EMI Measurements.
IEEE International Symposium on EMC, Seattle, pp. 13 to 18, Aug. 2-4, 1977.

[9] EMR-200/300 and Field Probe Type 8, 9 and 10 Data Sheets.
Wandel & Goltermann, 1996.

[10] Keller, H.: Standardized Personal Safety Measurements in the RF and Microwave Range.
Wandel & Goltermann Application Note, 1996.

Picture captions:

Fig. 1: Typical frequency response of H probe type 10 in direction PH at 0.23A/m

Fig. 2: Typical frequency response of EMR measuring system with E probe type 9 in position PH at 27.5V/m

Fig. 3: Comparison of frequency response calibration with E probe type 9 in positions PH and PE at 27.5V/m

Key words:

Field strength meter, E probe, H probe, human safety, limit values, calibration