TECHNICAL REPORT

ISO TR 10305

First edition
1992-11-01

Road vehicles — Generation of standard EM fields for calibration of power density meters from 20 kHz to 1 000 MHz

Véhicules routiers — Génération de champs électromagnétiques pour l'étalonnage des champmètres entre 20 kHz *et* 1 000 MHz

Reference number
ISO/TR 10305:1992(E)

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 10305, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Sub-Committee SC 3, *Electrical and electronic equipment*.

This Technical Report is solely of an informative nature, setting out the state of the art for calibration of power density meters.

International Organization for Standardization
Case Postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

Road vehicles — Generation of standard EM fields for calibration of power density meters from 20 kHz to 1 000 MHz

1 Scope

This Technical Report describes techniques of calibrating power density meters in measuring high intensity (hazard level) RF fields in the frequency range 20 kHz to 1 000 MHz. It applies to road vehicles.

2 Techniques

The recommended techniques are those given in the document NBSIR 75-804, *Generation of standard EM fields for calibration of power density meters* 20 kHz *to* 1 000 MHz (Edition January 1975 amended), which is reproduced as an annex.

NOTE 1 For the purposes of international standardization, the author of this document has made corrections to figures 5, 8 and 12.

3 Revision of Technical Report

It has been agreed with the National Institute of Standards and Technology that Technical Committee ISO/TC 22 will be consulted in the event of any revision or amendment of document of NBSIR 75-804.

This page intentionally left blank

NBSIR 75-804

GENERATION OF STANDARD EM FIELDS FOR CALIBRATION OF POWER DENSITY METERS 20 kHz to 1000 MHz

M.L. Crawford

Electromagnetic Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Co. 80302

January 1975

Final Report

Prepared for
Calibration Coordination Group
Army/Navy/Air Force

U.S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

This page intentionally left blank

CONTENTS

LIST OF FIGURES

GENERATION OF STANDARD EM FIELDS FOR
CALIBRATION OF POWER DENSITY METERS
20 kHz to 1000 MHz

This report describes techniques for calibrating power density meters used by the Department of Defense in measuring high intensity (hazard level) RF fields in the frequency range 20 kHz to 1000 MHz. It reports on part of the work sponsored by the Calibration Coordination Group (CCG), of the Department of Defense covering the frequency range 20 kHz to 20 GHz.

Several techniques were considered for producing a standard field including parallel plate and parallel wire transmission lines, transverse electromagnetic mode (TEM) transmission cells, various directive antennas and open ended waveguide (OEG). The major emphasis in this report is on the TEM cells, which are recommended for the frequency range 20 kHz to 500 MHz. Design and evaluation details and an error analysis associated with the TEM cell measurement system are given. Power density levels can be established in the cells from a few $\mu W/cm^2$ to 100 mW/cm^2 with uncertainties less than ± 1 dB.

Limited information is also given describing the use of OEG, the recommended technique for the frequency range 500 MHz to 2.6 GHz, and giving the results of intercomparisions among parallel plate lines, TEM cells, OEG, and standard gain horns.

Key words: Hazard level fields; power density meter calibration; TEM transmission cells.

1. Introduction

There is increasing concern among military and civilian agencies about the effects of non-ionizing (RF) radiation on equipment and personnel. For example, potentially hazardous electromagnetic (EM) radiation may occur near radar or radio antennas, or may be produced by electric appliances such as microwave ovens. There are several types of commercial meters now being used to survey the strength of EM radiation. This report describes work performed under the sponsorship of DoD/CCG to develop and evaluate instrumentation and standard techniques for generating known RF fields in order to calibrate these radiation meters.

The objective was to develop optimum procedures for calibrating power density meters used by the DoD for measuring high-intensity (hazard level), free space RF fields over the frequency range 20 kHz to 20 GHz. The required power density levels are approximately 1 to 100 mW/cm^2 or E field strengths of 60 to 600 V/m. The desired calibration accuracy is ± 1 dB. This report describes techniques for use below 1000 MHz, with emphasis on the TEM (Transverse Electromagnetic Mode) cell which is recommended for use over the 20 kHz to 500 MHz range. The companion report will describe in more detail the techniques which are recommended in the frequency range 500 MHz to 20 GHz.

A number of alternative techniques were evaluated and compared for ease, accuracy, and cost of duplicating the measurement procedures. These techniques are described briefly in section 2 of this report and include: (a) producing a uniform field between two parallel plate conductors or between two parallel wire lines, (b) generating a uniform field inside TEM transmission cells or waveguide, (c) producing a calculable field in front of directive antennas such as a standard gain horn or open-ended waveguide (OEG). The advantages and limitations of the various approaches are given to justify the choice of the recommended techniques (i.e., TEM cells and OEG). Sections 3, 4, and 5 describe the TEM cell method in considerable detail, since it is recommended over a large portion of the frequency range (20 kHz - 500 MHz). Details for using OEG over the frequency range (500 MHz - 2.6 GHz) will be given by Bowman in a companion report and are not repeated here. However, some of the background leading to the selection of OEG is included, along with results of some intercomparisions among parallel plate lines, TEM cells, OEG, and standard gain horns. These measurements were made at overlapping frequencies to strengthen the credibility of the particular approach and provide verification for the accuracy statements included in the error analysis portion of this report. These results are contained in section 4 and indicate excellent agreement, well within the prescribed accuracy limits (± 1 dB) attributable to these particular measurement techniques.

2. Techniques for Generating Standard Test Fields

2.1 Parallel Plate Transmission Lines

This technique has been in use for some time for EM pulse studies and for susceptibility testing of electronic equipment. Various authors have presented the technique in detail [1,2], hence only a brief description will be given here. Essentially, the test field is established between the conducting planes of a parallel-strip transmission line (figure 1) which is terminated with its characteristic impedance and driven by a high power RF source through an impedance matching network. Static field analysis given in reference [1] shows the TEM mode of a parallel plate line can simulate a free-space plane electromagnetic wave over a substantial portion of its interior region.

The impedance of the line, neglecting fringing, is given approximately by

$$Z_o \simeq 377 \frac{h}{w} \text{ ohms.} \tag{1}$$

where h and w are as shown in figure 1. The electric field is given as

$$E_v = \frac{V}{h} \text{ volts/meter.} \qquad (2)$$

For the line shown, field strengths in excess of 200 V/m can be obtained using 100 watt generators.

This system can be used at frequencies up to a few hundred MHz with a fair degree of accuracy if the test item, or hazard probe, is small (< h/5xw/5). However, as the frequency increases and h approaches $\lambda/4$, the line radiates strongly from the open sides. This creates interference which may interact with the measurement itself, be hazardous to an operator, or interfere with other experiments being conducted within transmission range. Also higher order modes will exist whenever the plate separation exceeds $\lambda/4$. These modes distort the test field configuration and limit the accuracy in determining the known field. The main disadvantages are then the size limitations imposed by the upper useful test frequency and the lack of shielding to prevent radiation. The system must also be carefully impedance matched and the dimensions of the device being tested should not exceed (h/5xw/5). Otherwise large standing waves can exist within the test region and the electric field will be significantly different between the test item and the plates than indicated by field calculations based upon the RF voltage measured between the plates. Construction costs are minimal for building a line capable of testing probes up to approximately 10 cm size, at frequencies up to 100 MHz. Parts plus labor should not exceed $2,000-$3,000.

A parallel plate line was constructed at NBS and used at 15 MHz to calibrate a dipole transfer standard probe for intercomparing with similar calibrations using a TEM transmission cell. The results of this comparison are contained in section 6. Errors associated with the parallel plate transmission line technique are similar to those described in evaluating the TEM transmission cell and are believed to be within the desired calibration accuracy of ± 1 dB.

2.2 Parallel Wire Transmission Line

This technique is very similar to the parallel plate line except it utilizes electrically balanced wires in place of electrically balanced or unbalanced plates. Since typical power density meter probes are small, the spacing between conductors of a parallel wire transmission line can be kept small thus making this technique appear feasible for generating a standard test field [3]. The field midway between the conductors is approximately uniform if the wire diameter is significantly less than the spacing between conductors and is given by

$$E_v \cong \frac{377}{\pi d} |I_\ell| \tag{3}$$

where I_ℓ is the current in the conductors, and d is the half distance separating the two conductors of the transmission line. The characteristic impedance of open two-wire line in air is given as:

$$Z_o = 120 \cosh^{-1} \frac{2d}{a} \tag{4}$$

where d is a defined above and a is the conductor diameter. The line current I_ℓ is determined by terminating the line in its characteristic impedance (approximately 600 ohms), accurately measuring the resistance R of the termination, the power P dissipated in R, and using the relation

$$|I_\ell| \cong \sqrt{P/R}. \tag{5}$$

A block diagram of the line and associated equipment is shown in figure 2. The thermopile is used to compare the heating effect of the RF power in the terminating resistor to an equivalent dc power which is measured with the dc voltmeter.

This technique suffers from essentially the same disadvantages as the parallel plate line with the added disadvantage of less field uniformity; thus no effort was made to further develop it for calibrating power density meters.

2.3 TEM Transmission Cells

This technique utilizes a transverse electromagnetic (TEM) transmission cell that operates as a 50Ω impedance-matched system (figure 3). A calculable, uniform TEM field is established inside the cell at the test frequency of interest by coupling RF energy through the cell from a transmitter connected at the cell input port. A 50Ω (reflectionless) termination is connected at the cell's output port. This technique operates essentially the same as a parallel plate line except it has the major advantage of not radiating energy into the surrounding space, i.e., the EM field is contained inside the cell. It is extremely broadband in frequency, being limited only by the waveguide multimode frequency associated with the cell size. The cells are inexpensive to construct, approximately $3,000 per cell and the use of expensive anechoic chambers or shielded enclosures are unnecessary. The cells can be used to establish known field strength levels from below 1 V/meter to 600 V/meter with uncertainties less than ± 1.0 dB. This technique proved to be the optimum procedure for establishing standard fields for calibrating power density meters at frequencies below about 500 MHz. (Details of this technique are contained in sections 3 through 5.) At frequencies above about 500 MHz, the small physical size of the cells (required to prevent multimoding) provides too small a test region for use with typical commercially available units, and alternative techniques of producing known fields are required.

2.4 Directive Antennas

At frequencies above a few hundred megahertz, the most feasible technique for generating an accurately known cw calibrating field proved to be by radiation from a directive antenna. The probe is mounted on a positioner and aligned in front of the source antenna. Measurements are made by adjusting the input power to the source antenna until the desired power density meter reading is obtained. The standard test field level, P_d, is then calculated from the following equation:

$$\frac{E^2}{377} = P_d = \frac{P_n \cdot G_p \cdot NZC}{4\pi r^2} \text{ (watts/m}^2\text{)} \qquad (6)$$

where P_n = net power into the source antenna,

G_p = source antenna power gain,

NZC = near-zone correction factor, which is a function of r,

r = separation distance between the source antenna and the probe under test, and

E = standard test field in V/m.

Corrections can be made for the multipath within the chamber by recording the power density meter reading, P_{indic}, as a function of r while holding the input power of the source antenna constant. The correction factor ratio, P_d/P_{indic}(dB), is then computed as a function of r and averaged to give its corrected value.

Four alternative source antennas were considered: a) calibrated single or multifeed backfire antennas, b) a 4-element dipole array with calculable gain, c) pyramidal standard gain horns, and d) calibrated "short horns" or open-ended waveguides.

Short backfire antennas, shown in figure 5, were considered because of their relatively high gain [4], ($\geq$ 15 dB), thus requiring less source power. Two short backfire antennas patterned after figure 5 were constructed at NBS to operate