Catalogue of Electromagnetic Environment Measurements, 30–300 Hz

J. Randa, *Senior Member, IEEE,* D. Gilliland, *Member, IEEE,* W. Gjertson, *Senior Member, IEEE,*
W. Lauber, *Member, IEEE,* and M. McInerney, *Member, IEEE*

***Abstract*—The IEEE Electromagnetic Compatibility Society's Technical Committee on Electromagnetic Environments (TC-3) has undertaken a long-term project to compile an inventory or catalogue of published measurements of electromagnetic environments. The frequency spectrum has been divided into tractable bands which will be considered one at a time. We have now completed the 30–300 Hz band. This paper presents the resulting bibliography, along with a brief overview of what has been measured.**

I. Introduction

THE IEEE Electromagnetic Compatibility Society's Technical Committee on Electromagnetic Environments (TC-3) has undertaken a long-term project to compile an inventory or catalogue of published measurements of electromagnetic (EM) environments. The first frequency band (30–300 Hz) has now been completed, and this paper contains the resulting bibliography. An abbreviated version of the bibliography has already been published [1]. The focus of the project is on published measurements of electric and magnetic fields. It includes measurements of average fields or the time integral of the field, often referred to as the "exposure." We do not, however, include measures of energy deposition or absorption, such as the specific absorption rate (SAR). Our principal aim in the project is to collect information on what has been measured on EM environments and to make available a bibliography for anyone interested in pursuing the matter further. We are interested primarily in what has been measured in what environments, rather than in the actual results. In general we do not include calculations, effects, or unpublished results. There are some exceptions, but we have not attempted to be complete in our coverage of anything except original published measurements. The restriction to *publish* results was made in order to insure some quality control by requiring that the papers had undergone peer review and also because we wanted a bibliography of papers which are available to the reader. A few review articles have been included because we thought that they provide good overviews or useful sets of references. Also some papers prescribing standard measurement methods have been included.

The search method employed was not entirely systematic, and the resulting bibliography is not likely to be entirely complete. Committee members listed papers with which they were familiar and searched databases which were easily accessible. We performed an issue-by-issue search of the following journals and series of conference proceedings up to mid-1993: IEEE Transactions on EMC, from 1982; IEEE Transactions on Power Delivery, from 1986; Radio Science, from 1987; Bioelectromagnetics, from 1982; IEEE International (and National) Symposia on EMC, from 1981; and International Zurich Symposia on EMC, from 1985. The reference lists of the papers which were found were searched for additional relevant papers. Announcements of the project were placed in the Newsletter of the EMC Society, the Power Engineering Review, and the Newsletter of the Bioelectromagnetics Society, along with invitations for authors to call their papers to our attention. Finally, preliminary versions of the bibliography were sent to several experts in the field, who had agreed to point out any omissions.

We have divided the papers into the following categories: natural noise, power-line fields, residential fields (including those from appliances), and workplace and other environments (including VDT's). Each is accorded a section in the remainder of the paper. The categories are not completely distinct, and papers whose results overlap several categories will generally be mentioned in each relevant section. In discussing the results, we will use the term "magnetic field" to refer generically to both the magnetic field (H) and the magnetic flux density (B); since all the measurements considered were performed in air, the distinction between H and B is largely semantic for this paper. Results of magnetic field measurements will be given in terms of B in teslas (T, μT, fT, etc.) rather than the other common units, B in gauss (1 G = 10^{-4} T) or H in amperes per meter (where H = 1 A/m corresponds to B = $4\pi \times 10^{-7}$ T).

II. Natural Noise

References [2]–[25] deal with natural ambient levels at extremely low frequency (ELF). Propagation studies, by which we mean measurement of a signal which was transmitted for the purpose of that measurement, are generally not included in our inventory unless they include measurement of the background noise. For frequencies between 30 and 300 Hz, the natural ambient noise arises primarily from lighting, the major part of which occurs in storms in the tropics. In

---

Manuscript received November 19, 1993; revised July 16, 1994.

J. Randa is with the Electromagnetic Fields Division, NIST, Boulder, CO 80303 USA.
D. Gilliland is with IBM Corporation, Rochester, MN 55901 USA.
W. Gjertson is with Boeing Helicopters, Philadelphia, PA 19142-0858 USA.
W. Lauber is with Communications Research Centre, Ottawa, ON, K2H 8S2 Canada.
M. McInerney is with U.S. Army Construction Engineering Research Laboratories, Champaign, IL 61826-9005 USA.

IEEE Log Number 9407406.

general, the magnitude of the natural noise will exhibit diurnal, seasonal, and geographic variations, but below about 100 Hz the variations are relatively small. The naturally occurring noise fields are broadband, and they have been studied almost exclusively in connection with communications applications. The results are typically given in terms of the noise factor f_a or quantities derived from it. To define f_a, one introduces the concept of the noise power p_n available at the terminals of an antenna which is lossless but equivalent in other respects to the antenna of the system used in the measurements [2], [3]. The noise factor is then defined by

$$f_a = \frac{p_n}{k_B t_0 b}, \qquad (1)$$

where k_B is Boltzmann's constant, t_0 is the reference temperature (288 K), and b is the bandwidth of the system in hertz. The noise figure is simply the noise factor expressed in decibels, $F_a = 10\log_{10} f_a$. While the noise factor is useful for communications applications, it is important to note that the noise factor by itself is not sufficient to determine the actual EM fields or power density. Information about the antenna and the system bandwidth is needed in order to relate the noise factor to the field strength.

An early review of measurements of atmospheric noise was that of Fischer [4], who compiled several sets of measurement results to span the spectrum from 5 Hz to 1 GHz, converting all the results into a common base (μV/(m$\sqrt{\text{Hz}}$). His principal source of 30-300 Hz data was Large and Wormell [5], who measured one component of the electric field at a single site. The first really extensive surveys covering the ELF range were those conducted by Maxwell and Stone [6], [7], who measured both vertical and horizontal components of the magnetic field, as well as the ratio of the vertical electric field to the horizontal magnetic field, at several locations worldwide. [7] gives data on the vertical electric field, including average and rms values and amplitude probability distributions. These results were included in the data fit in the model of Field and Lewinstein [8]. Other early measurements are cited in [9], which contains an exhaustive bibliography of surveys of ELF noise up to 1981. Other good reviews with extensive references are [10], [11].

Results of measurements made before 1978 were summarized by Spaulding and Hagn [2], who produced a plot of the worldwide maximum and minimum levels of natural noise as functions of frequency. The report was subsequently adopted by CCIR [3]. The ELF portion of the spectrum is reproduced in Fig. 1. The two curves C and D represent the maximum and minimum of all measurements worldwide. The spread between them indicates the magnitude of geographic and temporal (diurnal, seasonal) variations. As noted above, the temporal and geographic variations are not very great (<10 dB) below 100 Hz, though by 300 Hz they exceed 20 dB.

The most recent major survey is the Standford University ELF/VLF Radiometer Project [12]–[17]. The measurement system and the general program are described in [12]. There are eight sites worldwide, each of which monitors the two horizontal components of the magnetic field. The systems can record temporal variations of the field and can determine both rms and average values, as well as amplitude probability distributions. [13]–[16] contain results for the average magnetic field at the various sites. There are also results for the voltage deviation V_d, the ratio of rms to average signal, which is a measure of the impulsive content of the noise. [17] concentrates on the average magnetic field noise amplitude at the two common power frequencies, 50 and 60 Hz, and their harmonics. It also contains the information needed to convert between the average field and the noise factor. In general the Stanford project finds that the average field amplitude decreases with frequency roughly as $1/f(1/f^2$ for the noise factor). The value at 60 Hz typically lies between 150 and 600 fT/$\sqrt{\text{Hz}}$, depending on location and season. A recent model and program for detailed prediction of natural noise over a range of frequencies including ELF is described in [18]–[20].

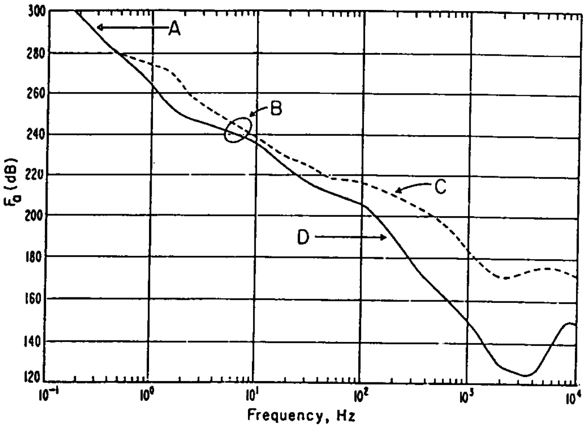

Fig. 1. Minimum (D) and maximum (C) natural noise levels, from [2], [3]. A refers to micropulsations, B to lightning.

There have also been other measurement results reported at various specific locations over the past 12 years (since [9]). Bannister [21] and Bruno [22] measured noise levels in Connecticut and at locations in the Atlantic near the New York and Connecticut coasts. Smuszkiewicz, Kiszkowski, and Szydlowski [23] measured noise levels at 50 Hz (and harmonics) in a rural area of Poland. Bashkuev, Haptanov, and Buyanova [24] measured electric and magnetic fields, their relative phase, and diurnal variations in central Asia, with instrumentation which was able to track the location of heavy thunderstorm activity as it progressed through the tropics. In [25] Chisholm *et al.* reported a detailed study of fields radiated by lightning strikes in northern Ontario. They studied peak radiated field and were particularly interested in the shape of the tails of the statistical distribution, which reflect the occurrence of very high-field lightning strikes.

III. Power-Line Fields

Fields from power lines are treated extensively in the Electric Power Research Institute (EPRI) handbook [26], but its availability is rather limited. There are a number of papers which are devoted to measurements of power-line fields. Measurements of the electric field, obtained with three different meters under and near high-voltage transmission lines, were reported and compared to calculated results by Bracken

[27]. (Regarding the title of [27], in the power engineering community the term "electrostatic" has, or at least had, a broader interpretation than in some other segments of society.) Tell *et al.* [28] also reported measurements of electric field, while Deno [29] presented results of measurements of both electric and magnetic fields under transmission lines. All three [27]–[29] compared measured and calculated results and found good agreement. Frazier and Dabkowski [30], [31] measured the longitudinal component of the electric field, which is of interest because it can induce sizable currents and voltages in long horizontal structures such as rail lines or water pipes.

Reviews of power-line fields, including some otherwise unpublished results, can be found in [32]–[38]. ([33] and [34] are the same paper.) A good, accessible, relatively recent review of power-line magnetic fields is that of Olsen *et al.* [36]. Besides a prescription for calculating the magnetic fields, [36] also discusses various factors affecting the amplitude of the fields around transmission and distribution lines and compares calculated results to measurements. It also contains information on harmonics and notes the usefulness of a statistical treatment of magnetic fields from power lines. A statistical treatment is appropriate because the magnetic field is determined by the currents on the lines, and (unlike the voltage) the currents on power lines are not constant and well controlled. Generally power-line electric and magnetic fields are understood quite well, provided that the currents in the lines are known [26]–[30], [36]. Agreement between measurement and prediction is typically within 10% or less in the absence of nearby structures or irregular terrain. Effects of nearby structures and trees have been measured and compared to calculations in [39]. The amplitudes of the fields depend on the voltage, the currents, the geometrical configuration of the wires, and the location at which the measurement is made. For the particular transmission lines measured in [27]–[29], the maximum amplitudes for the fields under the transmission lines were in the range 2–10 kV/m for electric fields and 1–40 μT for magnetic fields for lines in normal use. Magnetic fields near distribution lines can be comparable to those of transmission lines, due to the greater (locally) unbalanced currents in distribution lines.

A recent study by Gledhill [40] in New Zealand measured electric and magnetic fields from transmission lines as well as magnetic fields from low-voltage distribution lines, from 11-kV underground lines, and in areas of substations accessible to the public. Other measurements in and around substations were made by Feero, Yontz, and Dunlap for magnetic fields [41] and Vinh, Yi, and Shih for electric fields [42]. Magnetic fields from distribution lines were also measured by Vinh and coworkers [43]. A statistical study of electric and magnetic fields from a distribution network was performed in Quebec Province and was reported by Héroux [44]. A mobile unit was driven through various representative human environments. Typical values of electric and magnetic fields encountered were 32 V/m and 0.16 μT. A statistical study of magnetic fields in a neighborhood in Buffalo was conducted by Dlugosz *et al.* [45].

Both ANSI/IEEE [46] and IEC [47] have standards for measurements of power-frequency fields. The ANSI/IEEE standard covers both electric and magnetic fields, whereas the IEC standard is restricted to electric fields. Instrumentation for measurement of power system magnetic fields was evaluated by the Magnetic Fields Task Force of the IEEE Power Engineering Society's Transmission and Distribution Committee in [48], which also contains measurement results. The effect of the observer on the readings of hand-held meters was measured by Lambdin [49], who also reported measurement results for electric and magnetic fields as functions of distance from power lines. A recent review of ELF measurement methods can be found in [50]. There are also recommendations for measurement of power-frequency magnetic fields away from power lines [51]. There are several reasons for using different measurement methods away from power lines than those used in their proximity. Away from power lines, the fields have a much greater dynamic range, and the harmonic content is more important. Also, power lines provide a well defined, relatively simple geometry, which is not the case in other environments. Other papers relevant to ELF measurement and calibration methods are those of Greene [52] and Fulcomer [53].

There are a number of papers not devoted specifically to measurements of power-line fields which nevertheless contain relevant measurement results. Besides [48] and [49], mentioned above, there are papers by Valentino [54], D. Miller [55], Tell [56], and Skomal [57]. Additional papers which bear on power-line fields can be found in the sections below. In particular, fields in homes near power lines are treated with residential fields in Section IV, and offices near power lines and exposure of electric utility workers are included in workplace environments in Section V. Finally, we note that measurements in space of power-line fields have been reported by Yoshino and Tomizawa [58].

IV. RESIDENTIAL FIELDS

There has been a great deal of recent activity in measuring residential EM environments. Results of several substantial surveys of residential fields and exposure [59]–[62] have been published, and other surveys are in progress. References [59]–[61] all measured all components of the magnetic field at several locations in each of numerous residences. Kaune *et al.* [59] and Silva *et al.* [61] performed periodic measurements over continuous 24-hour periods as well as single-time (spot) measurements, whereas Barnes *et al.* [60] did only spot measurements. Barnes and Kaune both also measured the vertical component of the electric field, though the location chosen in the Kaune study was not representative of human occupation. All three studies investigated the correlation between field strength and wiring configuration. Other factors considered were harmonic content and temporal variation in [59], [60] and power use in [61]. Reference [60] also investigated correlations of the field strength with power-line proximity, population density, grounding, age of the home, and location in the room. The mean values of the magnetic fields found in these studies fall in the range 0.05–0.3 μT, with significant (a factor of 2) temporal variation. For the electric field, [61] found that the mean ranged from about 8 V/m to 12 V/m for the different classes of wiring configurations. An exposure study by Kavet *et al.* [62] measured the average magnetic field to which participants were exposed during the day, both at home and away from home. Participants were grouped according to whether they lived near overhead transmission lines. Average magnetic fields fell in the range 0.01–0.3 μT at home and 0.18–0.6 μT away. (For a caveat regarding exposure measurements, see section 5.)

A extensive study of residential magnetic fields conducted by EPRI is now in the data analysis stage, and results are becoming available [63]–[65]. The EPRI study focused on determining and characterizing the sources of residential magnetic fields, as well as measuring the field strength. They measured at regular intervals and on grids of points in the residences, and were thus able to obtain lateral profiles of the field through the property, peripheral profiles around it, and surface plots of fields in the home. They were also able to measure spatial distributions around appliances and temporal variations of fields.

Results of more limited residential studies are reported in [45], [66], [67]. Caola, Deno, and Dynek [66] measured primarily electric fields in houses at three different distances from a 500 kV transmission line. Dlugosz *et al.* [45] measured magnetic fields at locations in a residential neighborhood, including front sidewalks and doorsteps. Gillette and Hill [67] conducted a small-scale magnetic-field exposure study.

The studies mentioned above [59]–[67] were all performed on residences in the U.S. Surveys of residential magnetic fields have also been performed in several other countries. Gledhill [40] measured magnetic fields in living areas of homes and along city streets in Christchurch, New Zealand. Boal and Joyner [68] made measurements in homes and offices in Australia, including around appliances and office equipment. Magnetic field measurements were made in Braunschweig, Germany, by Kärner and Stamm [69], who reported results for suburban, urban, and business-quarter areas. Kärner and Stamm also compared spot measurements to 24-hour averages. Rauch and coworkers compared magnetic fields associated with different grounding practices in different countries [70], including Australia, Germany, Japan, the United Kingdom, and the U.S.

Several epidemiological studies have included measurements of residential magnetic fields. Wertheimer and Leeper [71] made measurements outside homes in the Denver area, grouping the homes according to wiring configurations. Tomenius [72] measured the magnetic fields outside the front doors of dwellings in Stockholm County, Sweden, and presented the results according to distance from power lines and presence or absence of visible electrical structures. Juutilainen *et al.* [73] also presented results of some residential magnetic field measurements. The field measurement results of Savitz *et al.* [74] are presented in more detail in [60]. Repeatability of spot measurements over 24-hour and 5-year periods was studied by Dovan, Kaune, and Savitz [75].

There are other papers besides the epidemiological studies which did not focus on residential field measurement but which reported residential field measurement results in addition to their principal results. Bowman *et al.* [76] and Deadman *et al.* [77] did occupational exposure studies for both electric and magnetic fields and included residential or nonwork exposure results for comparison. Tell's review [56] includes measurements of both electric and magnetic fields in homes in Las Vegas, Nevada. Valentino [54] measured the electric field in a "typical" home. A 1985 EPRI report [78] contains domestic electric-field exposure results, but they are quoted in terms of an "equivalent" uniform electric field from a transmission line which would induce the same current, and there seems to be insufficient information given to convert to more conventional quantities. Mader *et al.* [79] measured household magnetic fields to check their model.

Magnetic fields from many household appliances have been measured, with the most extensive studies being those by Gauger [80] and Silva *et al.* [61]. Gauger measured the maximum magnetic field as a function of distance from the appliance, using at least three different models for each type of appliance. Silva *et al.* measured the magnetic field in typical-use configurations for a number of appliances, using from 1 to 59 different examples of each appliance. Delpizzo [81] measured and averaged the magnetic field over a grid corresponding to the human body in order to estimate the exposure from various appliances. The measured fields from appliances fall off rapidly with distance. For distances corresponding to typical use the field is usually a few microteslas for most appliances, but several have fields exceeding 20 μT, and fields above 100 μT were found. Appliances with the largest fields tended to be relatively small devices—such as shavers, can openers, or hair dryers—which lack the shielding of large devices like dishwashers, refrigerators, or clothes dryers. Other measurement results for appliances can be found in Hartell, Miller, and Abromavage [82], for electric field; Valentino [54], electric field; D. Miller [55], electric and magnetic fields; Wertheimer and Leeper [71], magnetic field; Caola, Deno, and Dynek [66], electric field; Stuchly, Lecuyer, and Mann [83], magnetic field and harmonic content; Boal and Joyner [68], magnetic field; Hayashi, Isaka, and Yokoi [84], magnetic field; and Johnson [65], magnetic field.

Good, general reviews of residential fields are given by D. Miller [55], Deno [85], and Tenforde and Kaune [86].

V. WORKPLACE AND OTHER ENVIRONMENTS

The ELF EM fields have been measured for a variety of work environments. As might be expected, electric-utility workers have been the subject of several studies, including [77], [87], [88]. The Bonneville Power Administration (BPA) study [87] reported average daily accumulated electric-field exposure, whereas the Canadian study [77], [88] reported the geometric mean of both electric and magnetic fields to which the workers were exposed. Both studies used exposure of office workers for comparison, which provides data on the office environment also. The office exposures indicated field strengths comparable to residential levels, of order 1-10 V/m for electric fields and 0.1–0.2 μT for magnetic fields. In the BPA study electric-field exposures of "exposed" occupations (lineman, electrician, splicer, etc.) were all much (100–1000 times) higher than those of the office workers. In the Canadian study, some of the exposed occupations experienced elevated electric-field exposure (a few hundred volts per meter), and all experienced higher magnetic-field exposure (1–4 μT) than office workers. An interesting extension of the Canadian study was to compare a number of the different statistical indices which can be used to characterize exposure. Armstrong *et al.* [89] presented a comparison and correlations between indices such as mean, median, peak, 90th percentile level, etc. Direct measurements of electric fields encountered by utility workers in live-line work have been reported by Barnes, McElroy, and Charkow [90], Miller [91], Kouwenhoven *et al.* [92], and Yan *et al.* [93]. The measurements were made for both grounded and ungrounded workers and for various configurations of buckets or cages containing the workers.

An important consideration in exposure measurements is the perturbing effect on the field caused by the person wearing the dosimeter or exposure vest. Some exposure studies, for example [77], [88], give results for the measured (perturbed) field, while others calculate an unperturbed field by using an "enhancement factor" [87] or "activity factor." An enhancement or activity factor is just the ratio of the perturbed field strength with the person present to the unperturbed field strength without the person. The activity factor is typically measured in a separate, controlled experiment. It depends on the position of the meter, grounding, body configuration (standing, sitting), etc. Extensive measurements of (electric-field) activity factors were reported by Silva, Zaffanella, and Hummon [94]. The effect of different positions of the dosimeter was considered by Delpizzo [95] as well as by some of the exposure studies, e.g. [87]. Instrumentation for measuring and displaying the electric field intensity around a person has been developed by Shimizu, Endo, and Matsumoto [96].

Other electric utility environments which have been measured are a French nuclear power plant, where Champiot and Agostini [97] measured magnetic fields, and power substations. In substations, Vinh, Yi, and Shih [42] measured the electric field, and Hayashi and coworkers [98], [99] measured the magnetic field. Hasselgren and Hamnerius [100] measured magnetic fields in an office located directly above a substation, both before and after installation of shielding between the substation and office.

A number of measurements of office EM environments have been made. Results for electric-field exposure of office workers were obtained in the electric utility studies mentioned above [77], [87], [88]. Laflin [101] made magnetic field measurements in four office buildings in Denver and New York, measuring spectral densities, amplitude probability distributions, and diurnal variations for both business days and weekends. Measurements of both electric and magnetic fields in an office building near a transmission line have been reported by Nielsen [102]. The building provided some shielding for the electric fields, although fields inside were somewhat high. The building provided little or no shielding of magnetic fields. Spot measurements in particular offices were reported in [53] and [83]. Boal and Joyner [68] measured magnetic fields in several offices in Australia, including near typical office equipment. The specific case of VDT emission at ELF has been addressed in several papers [83], [103]–[107]. Harvey [103] measured the electric field in the presence of a model person. Stuchley, Lecuyer, and Mann [83], Juutilainen and Saali [104], and Tofani and D'Amore [105] measured magnetic field; and Jokela, Aaltonen, and Lukkarinen [106] and Takemoto-Hambleton, Dunseath, and Jones [107] measured both electric and magnetic fields. Typical values measured 30 cm from the screen were 0.2–0.6 μT. Note, however, that these measurements may not reflect the behavior of newer model VDT's.

A variety of other EM environments have been measured. Bensema, Kanda, and Adams measured magnetic fields in coal mines to determine background for a communications system [108], [109]. Electric-field exposure during farming operations, particularly near power lines, was the subject of an EPRI report [78] and a paper by Deno and Silva [110]. Magnetic fields in hospitals were measured by Frank and Londner in the early 1970's [111]. Magnetic fields in the electrosteel industry, in particular near welders and electric furnaces, were measured by Lovsund, Oberg, and Nilsson [112]. Mauriello and Clark [113] measured magnetic emissions from rail and transit vehicles. Haradem, Gauger, and Zapotosky [114] conducted a long term ecological monitoring program at 50 sites to assess the environmental effects of an ELF communications system. [114] contains results of electric and magnetic field measurements and references for measurements at other sites. Hartell, Miller, and Abromavage [82] measured electric fields at a small number of specific sites to assess the environmental impact of Project Sanguine. Other measurements at specific locations can be found in [51], [55], [76].

VI. SUMMARY

We have presented an overview of measurements of electromagnetic environments in the 30-300 Hz frequency range. In discussing measurement results and characteristics of specific environments, we have indicated only general, approximate features to provide some perspective in comparing different environments. Results we quote should be regarded as representative, not definitive. Anyone needing a quantitative characterization of particular electromagnetic environments should consult the original papers for exact, detailed results and for discussion of measurement methods and limitations. In doing so, the reader should also consider the date of the paper and bear in mind that many electromagnetic environments have changed significantly over the past decade or two.

ACKNOWLEDGMENT

The authors would like to thank the many authors and authorities who aided in compiling this bibliography by reviewing the preliminary bibliography, suggesting additions, and/or sending copies of their papers. This project was initiated during the tenure of A. A. Smith, Jr., as TC-3 chairman.

REFERENCES

[1] J. Randa *et al.*, "Condensed catalogue of electromagnetic environment measurements, 30-300 Hz," in *Proc. IEEE 1993 Int. Symp. Electromagn. Compat.* (Dallas, TX), 1993, pp. 126–131.

[2] A. D. Spaulding and G. H. Hagn, "Worldwide minimum environmental radio noise levels (0.1 Hz to 100 GHz)," in *Proc.: Effects of the Iono-*

sphere on Space and Terrestrial Syst., J. M. Goodwin, Ed. Arlington, VA: ONR/NRL, 1978, pp. 177–182.

[3] CCIR Study Group 1 on Spectrum Utilization and Monitoring, "Worldwide minimum external noise levels, 0.1 Hz to 100 GHz," vol. 1, CCIR Rep. 670, ITU Geneva, 1986.

[4] W. Fischer, "The radio noise spectrum from ELF to EHF," *J. Atmospheric & Terrestrial Phys .*, vol. 27, pp. 475–480, 1965.

[5] M. Large and T. Wormell, "Fluctuations in the vertical electric field in the frequency range from 1 cycle per second to 500 cycles per second," in *Recent Advances in Atmospheric Chemistry*, L. G. Smith, Ed. New York: Pergamon Press, 1958, pp. 603–607.

[6] E. Maxwell and D. Stone, "Natural noise fields from 1 cps to 100 kc," *IEEE Trans. Antennas Propagat.*, vol. AP-11, pp. 339–343, May 1963.

[7] E. Maxwell, "Atmospheric noise from 20 Hz to 30 kHz," *Radio Science*, vol. 2, pp. 637–644, June 1967.

[8] E. Field, Jr., and M. Lewinstein, "Amplitude-probability distribution model for VLF/ELF atmospheric noise," *IEEE Trans. Commun.*, vol. COM-26, pp. 83–87, Jan. 1978.

[9] E. Soderberg, "ELF noise surveys—a review," in *AGARD Conf. Proc. No. 305: Medium, Long and Very Long Wave Propagation (At Frequencies Less than 3000 kHz)* (Brussels, Belgium), J. S. Belrose, Ed. 1981.

[10] C. Polk, "Sources, propagation, amplitude and temporal variation of extremely low frequency (0–100 Hz) electromagnetic fields," in *Biological and Clinical Effects of Low-Frequency Magnetic and Electric Fields*; J. Llaudaro, A. Sancer, and J. Battocletti, Eds. Springfield, IL: Thomas, 1974, pp. 21–48.

[11] E. K. Smith, "The natural radio noise source environment," in *Proc. IEEE 1982 Int. Symp. Electromagn.Compat.* (Santa Clara, CA), 1982, pp. 266–277.

[12] A. Fraser-Smith and R. Helliwell, "The Stanford University ELF/VLF radiometer project: Measurement of the global distribution of ELF/VLF electromagnetic noise," in *Proc. IEEE 1985 Int. Symp. Electromagn.Compat.* (Wakefield, MA), 1985, pp. 305–311.

[13] A. Fraser-Smith *et al.*, "A new global survey of ELF/VLF radio noise," *AGARD Conf. Proc. No. 420; NATO/AGARD Conf. Military Radio Commun.* (Lisbon, Portugal), 1987, pp. 4A1–4A9.

[14] A. Fraser-Smith *et al.*, "Global measurements of low-frequency radio noise," in *Environmental, Space Electromagn.*, H. Kikuchi, Ed. Tokyo, Japan: Springer-Verlag, 1991, pp. 191–200.

[15] ——, "Measurements of ELF/VLF radio noise in Japan," in *Environmental and Space Electromagn.*, H. Kikuchi, Ed. Tokyo, Japan: Springer-Verlag, 1991, pp. 201–207.

[16] A. Meloni, P. Palangio, and A. Fraser-Smith, "Some characteristics of the ELF/VLF radio noise measured near L'Aquila, Italy," *IEEE Trans. Antenn. Propagat.*, vol. 40, pp. 233–236, Feb. 1992.

[17] A. Fraser-Smith and M. Bowen, "The natural background levels of 50/60 Hz radio noise," *IEEE Trans. Electromagn. Compat.*, vol. 34, pp. 330–337, Aug. 1992.

[18] C. Warber and E. Field, "Long wave noise prediction, vol. 1: Physical basis of the model," Pacific Sierra Research Corp., Rep. 2137, Apr. 1991.

[19] C. Warber, "Long wave noise prediction, vol. 2: User's guide to the computer code LNP version 1.1," Pacific Sierra Research Corp., Rep. 2137, Apr. 1991.

[20] C. Warber, E. Field, Jr., and M. Shearer, "Modeling ELF atmospheric noise," in *Proc. IEEE 1993 Int. Symp. Electromagn. Compat.* (Dallas, TX), 1993, pp. 144–149.

[21] P. Bannister, "Summary of ELF propagation validation system effective noise measurements, 1967–1978," *IEEE J. Oceanic Eng.*, vol. QE-9, pp. 196–201, July 1984.

[22] A. Bruno, "Electromagnetic field measurements at 60 Hz in the sea near Montauk Point, NY, and New London, CT," *IEEE J. Oceanic Eng.*, vol. QE-9, pp. 209–211, July 1984.

[23] R. Smuszkiewicz, P. Kiszkowski, and H. Szydlowski, "Measurements of electric and magnetic fields of very low frequencies in unurbanized environment," in*Proc. Int. Wroclaw Symp. Electromagn. Compat.* (Wroclaw, Poland), 1984, pp. 773–780.

[24] Yu Bashkuev, V. Haptanov, and D. Buyanova, "The natural electromagnetic field in central Asia," in *Proc. 8th Int. Zurich Symp. Electromagn.Compat.* (Zurich, Switzerland), 1989, pp. 13–18.

[25] W. Chisholm *et al.*, "Analytical and statistical tools for studies of lightning-radiated fields," in *Proc. IEEE 1985 Int. Symp. Electromagn.Compat.* (Wakefield, MA), 1985, pp. 333–337.

[26] EPRI, "Transmission Line Reference Book: 345 kV and Above," EPRI Rep. EL-2500, 2nd ed., revised 1987.

[27] T. D. Bracken, "Field measurements and calculations of electrostatic effects of overhead transmission lines," *IEEE Trans. Power App. Syst.*, vol. PAS-95, pp. 494–504, Mar./Apr. 1976.

[28] R. Tell *et al.*, "An examination of electric fields under EHV overhead power transmission lines," USEPA technical report EPA-520/2-76-008, 1977, NTIS accession no. PB 270 613.

[29] D. Deno, "Transmission line fields," *IEEE Trans. Power App. Syst.*, vol. PAS-95, pp. 1600–1611, Sept./Oct. 1976.

[30] M. Frazier and J. Dabkowski, "Powerline longitudinal electric fields—measurement and prediction," in *Proc. IEEE 1983 Int. Symp. Electromagn. Compat.* (Arlington, VA), 1983, pp. 467–471.

[31] M. Frazier and J. Dabkowski, "Magnetic coupled longitudinal electric field measurements on two transmission lines," *IEEE Trans. Power App. Syst.*, vol. PAS-104, pp. 933–970, Apr. 1985.

[32] J. Bridges and M. Preache, "Biological influences of power frequency electric fields—A tutorial review from a physical and experimental viewpoint," in *Proc. IEEE*, vol. 69, pp. 1092–1120, Sept. 1981.

[33] M. Frazier, "Evaluation of health and environmental effects of extra high voltage (EHV) transmission," IIT Res. Inst. (Chicago), Final Rep. on EPA Contract 68-01-4604, Feb. 1979, NTIS Order No. PB-292 391.

[34] D. Janes, "Evaluation of health and environmental effects of extra high voltage (EHV) transmission," U.S. EPA Technical Note ORP/SEPD 80-13, June 1980.

[35] R. G. Olsen, "The magnetic field environment of electric power lines," in the Panel Session on Biological Effects of Power Frequency Electric and Magnetic Fields, IEEE Special Publication 86TH0139-6-PWR, 1986.

[36] R. G. Olsen, *et al.* (Magnetic Fields Task Force), "Magnetic fields from electric power lines: theory and comparison to measurements," *IEEE Trans. Power Del.*, vol. PWRD-3, pp. 2127–2136, Oct. 1988.

[37] R. G. Olsen, "Electromagnetic fields from power lines," in *Proc. IEEE 1993 Int. Symp. Electromagn.Compat.* (Dallas, TX), 1993, pp. 138–143.

[38] H. Haubrich and Th. Seitz, "Electrical and magnetic fields around overhead transmission lines," in *Proc. 9th Int. Zurich Symp. Electromagn.Compat.* (Zurich, Switzerland), 1993, pp. 19–24.

[39] D. Deno, L. Zaffanella, and J. Silva, "Transmission line electric field shielding by objects," *IEEE Trans. Power Del.*, vol. PWRD-2, pp. 269–280, Jan. 1987.

[40] M. Gledhill, "Electric and magnetic field levels around Christchurch," National Radiation Laboratory (Christchurch, New Zealand) Rep. NRL 1992/1, 1992.

[41] W. Feero, J. Yontz, and J. Dunlap, "Magnetic fields remote from substations," *IEEE Trans. Power Del.*, vol. PWRD-4, pp. 1962–1868, Jul. 1989.

[42] T. Vinh, C. Yi, and C. Shih, "Measurements and analysis of electric fields in HV and EHV stations," *IEEE Trans. Power App.* & Syst., vol. PAS-101, pp. 4122-4130, Oct. 1982.

[43] T. Vinh, T. Jones, and C. Shih, "Magnetic fields near overhead distribution lines—measurements and estimating technique," *IEEE Trans. Power Del.*, vol. 6, pp. 912–921, Apr. 1991.

[44] P. Héroux, "60-Hz electric and magnetic fields by a distribution network," *Bioelectromagn.*, vol. 8, pp. 135–148, 1987.

[45] L. Dlugosz *et al.*, "Ambient 60-Hz magnetic flux density in an urban neighborhood," *Bioelectromagn.*, vol. 10, pp. 187–196, 1989.

[46] ANSI/IEEE, "IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines," ANSI/IEEE Std 644-1987 (Revision of ANSI/IEEE Standard 644-1979). New York: IEEE, Inc., 1987.

[47] IEC, "Measurement of power-frequency electric fields," *IEC Publication* 833, 1987.

[48] R. G. Olsen *et al.* (Magnetic Fields Task Force), "An evaluation of instrumentation used to measure AC power system magnetic fields," *IEEE Trans. Power Del.*, vol. 6, pp. 373–383, Jan. 1991.

[49] D. Lambdin, "A comparison of measurement techniques to determine electric fields and magnetic flux under EHV overhead power transmission lines," U.S. EPA Technical Note ORP/EAD 78-1, Mar. 1978.

[50] M. Misakian, "ELF electric and magnetic field measurement methods," in *Proc. IEEE 1993 Int. Symp. Electromagn.Compat.* (Dallas, TX), 1993, pp. 150–155.

[51] M. Misakian *et al.* (Magnetic Fields Task Force), "Measurement of power frequency magnetic fields away from power lines," *IEEE Trans. Power Del.*, vol. 6, pp. 901–911, Apr 1991.

[52] F. Greene, "NBS field strength standards and measurements," *Proc. IEEE*, vol. 55, pp. 970–981, 1967.

[53] P. Fulcomer, "NBS ambient magnetic field meter for measurement and analysis of low-level power frequency magnetic fields in air," NBS Internal Rep., NBSIR 86-3330, 1985.

[54] A. Valentino, "A small ELF electric field probe," *Proc. IEEE 1972 Int. Symp. EMC* (Arlington Heights, IL), 1972, pp. 265–270.

[55] D. A. Miller, "Electric and magnetic fields produced by commercial power systems," in *Biological and Clinical Effects of Low-frequency*

Magnetic and Electric Fields; . J. Llaudaro, A. Sancer, and J. Battocletti, Eds. Springfield, IL: Thomas, 1974, pp. 62–70.

[56] R. Tell, "Instrumentation for measurement of radiofrequency electromagnetic fields: equipment, calibrations and selected applications," in *Proc. of a NATO ASI on Advances in Biological Effects and Dosimetry of Low Energy Electromagnetic Fields*, M. Grandolfo, S. Michaelson, and A. Rindi, Eds. New York: Plenum, 1983, pp. 95–162.

[57] E. Skomal, "Comparative radio noise levels of transmission lines, automotive traffic and RF stabilized arc welders," *IEEE Trans. Electromagnetic Compat.*, vol. EMC-9, pp. 73–77, Sept. 1967.

[58] T. Yoshino and I. Tomizawa, "Measurement of power line radiation over eastern Asia and northern Europe by the EXOS-A 'OHZORA' satellite," in *Proc. 7th Int. Zurich Symp. EMC* (Zurich, Switzerland), 1987, pp. 455–460.

[59] W. Kaune *et al.*, "Residential magnetic and electric fields," *Bioelectromagn.*, vol. 8, pp. 315–335, 1987.

[60] F. Barnes *et al.*, "Use of wiring configuration and wiring codes for estimating externally generated electric and magnetic fields," *Bioelectromagn.*, vol. 10, pp. 13–21, 1989.

[61] M. Silva *et al.*, "Power frequency magnetic fields in the home," *IEEE Trans. Power Del.*, vol. 4, pp. 465–477, Jan. 1989.

[62] R. Kavet, J. M. Silva, and D. Thornton, "Magnetic field exposure assessment for adult residents of Maine who live near and far away from overhead transmission lines," *Bioelectromagn.*, vol. 13, pp. 35–55, 1992.

[63] EPRI, "Pilot study of residential power frequency magnetic fields," Rep. EL-6509, RP2942 Final Rep., Sept. 1989.

[64] EPRI, "Residential magnetic field sources: interim report," EPRI Rep. TR100194, Oct. 1992.

[65] G. B. Johnson, "Residential field sources at power frequencies," in*Proc. IEEE 1993 Int. Symp. Electromagn.Compat.* (Dallas, TX), 1993, pp. 132–137.

[66] R. Caola, D. Deno, and V. Dynek, "Measurement of electric and magnetic fields in and around homes near a 500 kV transmission line," *IEEE Trans. Power App. Syst.*, vol. PAS-102, pp. 3338–3347, Oct. 1983.

[67] L. Gillette and D. Hill, "Personal 24 hour magnetic field exposures," in *Proc. of the 85th Annual Meeting of the Air and Waste Management Association* (Kansas City, MO), 1992.

[68] T. Boal and K. Joyner, "Levels of 50 Hz magnetic fields in the home and office environment in Australia," in *Radiation Protection Practice*. Sydney, Australia: Pergamon Press, 1988, pp. 485–488.

[69] H. Kämer and A. Stamm, "Residential long-term magnetic field exposure," in *Proc. 7th Int. Symp. High Voltage Engin.* (Dresden, Germany), 1991, pp. 71–74.

[70] G. Rauch *et al.*, "A comparison of international residential grounding practices and associated magnetic fields," *IEEE Trans. Power Del.*, vol. 7, pp. 934–939, Apr. 1992.

[71] N. Wertheimer and E. Leeper, "Adult cancer related to electrical wires near home," *Int. J. Epidemiol.*, vol. 11, pp. 345–355, 1982.

[72] L. Tomenius, "50-Hz electromagnetic environment and the incidence of childhood tumors in Stockholm County," *Bioelectromagn.*, vol. 7, pp. 191–207, 1986.

[73] J. Juutilainen *et al.* "Early pregnancy loss and exposure to 50 Hz magnetic fields," *Bioelectromagn.*, vol. 14, pp. 229–236, 1993.

[74] D. Savitz *et al.*, "Case-control study of childhood cancer and exposure to 60-Hz magnetic fields," *Am. Journal of Epidemiology*, vol. 128, pp. 21–38, 1988.

[75] T. Dovan, W. Kaune, and D. Savitz, "Repeatability of measurements of residential magnetic fields and wire codes," *Bioelectromagn.*, vol. 14, pp. 145–159, 1993.

[76] J. Bowman *et al.*, "Exposure to ELF electromagnetic fields in occupations with elevated leukemia rates," *Appl. Ind. Hyg.*, vol. 3, pp. 189–194, 1988.

[77] J. Deadman *et al.*, "Occupational and residential 60-Hz electromagnetic fields and high-frequency electric transients: exposure assessment using a new dosimeter," *Am. Ind. Hyg. Assoc. J.*, vol. 49, pp. 409–419, 1988.

[78] EPRI, "AC field exposure study: Human exposure to 60-Hz electric fields," Rep. EA-3993, RP0799-16, 1985.

[79] D. Mader *et al.*, "A simple model for calculating residential 60-Hz fields," *Bioelectromagn.*, vol. 11, pp. 283–296, 1990.

[80] J. Gauger, "Household appliance magnetic field survey," *IEEE Trans. Power App. Syst.*, vol. PAS-104, pp. 2436-2444, Sept. 1985.

[81] V. Delpizzo, "A model to assess personal exposure to ELF magnetic fields from common household sources," *Bioelectromagn.*, vol. 11, pp. 139–147, 1990.

[82] W. Hartell, D. Miller, and M. Abromavage, "Project Sanguine's environmental compatibility assurance program," in *Proc. IEEE 1972 Int. Symp. Electromagn.Compat.* (Arlington Heights, IL), 1972, pp. 125–129.

[83] M. Stuchly, D. Lecuyer, and R. Mann, "Extremely low frequency electromagnetic emissions from video display terminals & other devices," *Health Physics*, vol. 45, pp. 713–722, Sept. 1983.

[84] N. Hayashi, K. Isaka, and Y. Yokoi, "Analysis of magnetic field profiles in electric blanket users," *IEEE Trans. Power Del.*, vol. 4, pp. 1897–1903, Jul. 1989.

[85] D. Deno, "Sources and structures of magnetic and electric fields in the home," in *Interactions of Biological Systems with Static Electric and Magnetic Fields*, L. Anderson, B. Kelman, and R. Weigel, Eds., 23rd Hanford Life Sci. Symp., 1984, pp. 207–224.

[86] T. Tenforde and W. Kaune, "Interaction of extremely low frequency electric and magnetic fields with humans," *Health Physics*, vol. 53, pp. 585–606, Dec. 1987.

[87] V. L. Chartier, T. D. Bracken, and A. S. Capon, "BPA study of occupational exposure to 60 Hz electric fields," *IEEE Trans. on Power App. Syst.*, vol. PAS-104, pp. 733–744, March 1985.

[88] P. Héroux, "A dosimeter for assessment of exposure to ELF fields," *Bioelectromagn.*, vol. 12, pp. 241–257, 1991.

[89] B. Armstrong, J. Deadman, and G. Theriault, "Comparison of indices of ambient exposure to 60-Hz electric and magnetic fields," *Bioelectromagnetics*, vol. 11, pp. 337–347, 1990.

[90] H. Barnes, A. McElroy, and J. Charkow, "Rational analysis of electric fields in live line working," *IEEE Trans. on Power App. Syst.*, vol. PAS-86, pp. 482–492, April 1967.

[91] C. Miller, Jr., "The measurement of electric fields in live line working," *IEEE Trans. Power App. Syst.*, vol. PAS-86, pp. 493–498, Apr. 1967.

[92] W. Kouwenhoven *et al.*, "Body currents in live line working," *IEEE Trans. Power App. Syst.*, vol. PAS-85, pp. 403–411, Apr. 1966.

[93] Z. Yan *et al.*, "Calculation and measurement of field parameters during live-line maintenance," *IEEE Trans. Power Del.*, vol. 6, pp. 1187–1191, Jul. 1991.

[94] M. Silva, L. Zaffanella, and N. Hummon, "An activity systems model for estimating human exposure to 60 Hz electric fields," *IEEE Trans. Power App. Syst.*, vol. PAS-104, pp. 1923–1929, Jul. 1985.

[95] V. Delpizzo, "Misclassification of ELF occupational exposure resulting from spatial variations of the magnetic field," *Bioelectromagn.*, vol. 14, pp. 117–130, 1993.

[96] K. Shimizu, H. Endo, and G. Matsumoto, "Visualization of electric field around a human model," in*Proc. 1984 Int. Symp. Electromagn. Compat.* (Tokyo), 1984, pp. 578–582.

[97] C. Champiot and J. Agostini, "Electromagnetic environment in a PWR power plant," in *Proc. IEEE 1982 Int. Symp. Electromagn.Compat.* (Santa Clara, CA), 1982, pp. 377–387.

[98] N. Hayashi, K. Isaka, and Y. Yokoi, "ELF Electromagnetic environment in power substations," *Bioelectromagn*, vol. 10, pp. 51–64, 1989.

[99] N. Hayashi *et al.*, "Power frequency magnetic field in a 187/66 kV electric power substation," in *Proc. 1989 Int. Symp. Electromagn.Compat.* (Nagoya, Japan), 1989, pp. 505–510.

[100] L. Hasselgren and Y. Hamnerius, "Calculation of low frequency magnetic shielding of a substation using a two-dimensional finite element method," *European Trans. Elect. Power Eng.*, 1993.

[101] M. Laflin, "ELF/VLF spectrum measurements," NATO/AGARD Conf. on ELF/VLF/LF Radio Propagation and System Aspects (Brussels), 1992.

[102] P. Nielsen, "Power line frequency field measurements in and about an office building located near a 240 kV transmission line," in*Proc. IEEE 1988 Int. Symp. Electromagn. Compat.* (Seattle, WA), 1988, pp. 401-405.

[103] S. Harvey, "Electric-field exposure of persons using video display units," *Bioelectromagn.*, vol. 5, pp. 1–12, 1984.

[104] J. Juutilainen and K. Saali, "Measurements of extremely low-frequency magnetic fields around video display terminals," *Scand. J. Work Environ. Health*, vol. 12, pp. 609–613, 1986.

[105] S. Tofani and G. D'Amore, "Extremely-low-frequency and very-low-frequency magnetic fields emitted by video display units," *Bioelectromagn.*, vol. 12, pp. 35–45, 1991.

[106] K. Jokela, J. Aaltonen, and A. Lukkarinen, "Measurements of electromagnetic emissions from video display terminals at the frequency range from 30 Hz to 1 MHz," *Health Physics*, vol. 56, pp. 79–88, July 1989.

[107] R. Takemoto-Hambleton; W. Dunseath, Jr.; and W. Joines; "Electromagnetic fields induced in a person due to devices radiating in the 10 Hz to 100 kHz range," *IEEE Trans. Electromagn.Compat.*, vol. EMC-30, pp. 529–537, Nov. 1988.

[108] W. Bensema, M. Kanda, and J. Adams, "Electromagnetic noise in Robena no. 4 coal mine," U.S. NBS Tech. Note 654, Apr. 1974.

[109] W. Bensema, "Measurement and display of amplitude, time, and frequency statistics of quasi-impulsive noise," in *Proc. 2nd Symp. Electromagn.Compat.* (Montreux, Switzerland), 1977, pp. 347–352.

[110] D. Deno and M. Silva, "Method for evaluating human exposure to 60 Hz E-fields," *IEEE Trans. Power App. Syst.*, vol. PAS-103, pp. 1699–1701,

Jul. 1984.

[111] U. Frank and R. Londner, "The hospital electromagnetic environment," *J. of the Association for the Advancement of Medical Inst.*, vol. 5, pp. 246–254, Jul/Aug. 1971.

[112] P. Lovsund, P. Oberg, and S. Nilsson, "ELF magnetic fields in electrosteel and welding industries," *Radio Science*, vol. 17, pp. 35S–38S, Sept./Aug. 1982.

[113] A. Mauriello and J. Clarke, "Measurement and analysis of radiated electromagnetic emissions from rail-transit vehicles," *IEEE Trans. Electromagn.Compat.*, vol. EMC-25, pp. 405–411, Nov. 1983.

[114] D. Haradem, J. Gauger, and J. Zapatosky, "ELF communications system ecological monitoring program: electromagnetic field measurements and engineering support—1990," IIT Research Institute Technical Rep. E06628-3, Jul. 1991.

James Randa received the Ph.D. degree in physics from the University of Illinois, Urbana, in 1974. He then successively held postodctoral or faculty positions at Texas A&M University, University of Manchester (England), and the University of Colorado at Boulder. During this time, he did research on the phenomenology of elementary particles and on theories of fundamental interactions.

Since 1983 he has been with the Electromagnetic Fields Division of the National Institute of Standards and Technology (NIST), in Boulder, CO. From 1983 until early 1994 he was in the Fields and Interference Metrology Group, where he worked on characterization of electromagnetic environments, probe development, and other topics in EMI metrology. He chaired the EMC Society's TC-3 from 1991 to 1994. He is now in the Microwave Metrology Group of NIST, working in the area of thermal noise standards for MMIC devices.

William G. Gjertson (M'85–SM'90) is Senior Principal Engineer with the Boeing Company, Military Airplanes Division at Lockheed Aeronautical Systems Company, Marietta, GA. In his current position Bill is responsible for Electromagnetic Environmental Effects Verification Engineering on the F-22 Program.

Mr. Gjertson has over 30 years experience in electromagnetic effects and electromagnetic systems engineering, design, analysis and test since completing his B.S. degree in physics and mathematics at Wisconsin State University in 1960. He also completed graduate courses in electrical engineering at Wisconsin State University, University of Hawaii, and the University of Alabama-Huntsville. Additional education consisted of off-hours courses in SMPS, Digital Signal Processing, Statistics, Magnetic materials, microwave propagation, Antennas, Fiber-Optics theory, and IEMCAP theory and operation.

Mr. Gjertson is currently responsible for F-22 MIL-STD-1818 Electromagnetic Environmental Effects Verification Engineering at the Lockheed Aeronautical Systems Company in Marietta, GA. Prior to his current position with Boeing at Lockheed, Bill was lead EMC engineer on Boeing Helicopters Division Osprey, Chinook and Comanche Programs in Philadelphia, PA and prior to the Boeing-Helicopters assigment, Bill was responsible for EMC on Boeing's Missile Systems Division projects including MX, Minuteman, AIWS, Peaceshield, SRAM II, Small ICBM, Rail Garrison Peacekeeper, and proposal activities. Earlier EMC experience was with LTV, UNISYS and Boeing.

Bill is a Senior Member of the IEEE, the 1994 Vice President of the IEEE EMC Society, a 1992–1994 member of the IEEE EMCS Board of Directors, and was 1993 Technical Director of Communications Services. He is a member of IEEE EMCS TC-3 Committee and a member of the AIAA, ADPA, AFCEA, and AHS. He served as 1988 IEEE EMCS Symposium Arrangements Chairman and was named as Symposium Chairman of the 1999 IEEE EMCS Symposium-Seattle, WA. He has authored numerous papers on EMC, EM and MW and is a NARTE certified EMC Engineer. (EMC-000468-NE.)

Wilfred R. Lauber (S'66–M'70) was born in Windsor, ON in 1944. He graduated from the University of Waterloo, Waterloo, ON Canada, in 1968 with a Ba.Sc. in electrical engineering, and in 1970 with an Ma.Sc. in electrical engineering, majoring in Statistical Communication Theory.

In 1970 he joined the Communications Research Centre (CRC) in Ottawa as a research engineer in the Radio Research Laboratory. He has published several papers on measurements and modeling of the electromagnetic environment from HF to UFH and has contributed to CCIR reports for both atmospheric and man-made noise. He is presently the Manager of the Electromagnetics and Compatibility Research Group of the Radio Sciences Division at CRC.

Mr. Lauber is a registered Professional Engineer in the Province of Ontario.

Michael K. McInerney (M'84) was born in Evanston, Illinois in 1955. He graduated with honors from Iowa State University, Ames, IA USA, in 1978. He received the B.Sc. degrees in electrical engineering, mathematics, and physics. He received the M.Sc. degree in electrical and computer engineering from the University of Illinois, Urbana, IL in 1984

Prior to joining the Construction Engineering Research Laboratories' (CERL) research staff, he was a graduate research assistant at Aeronomy Laboratory, Sounding Rocket Group, of the University of Illinois, studying the properties and composition of the ionoshpere. Since his employment at CERL in 1982, Mr. McInerney has worked in the field of electromagnetic compatibility. His research activities have been concerned with protecting electrical and electronic equipment from electromagnetic transients. The majority of his research has been in the area of electromagnetic shielding technologies focusing on shielding materials and construction techniques.

Mr. McInerney is a member of Tau Beta Pi, Eta Kappa Nu, and Pi Mu Epsilon. He is a Regeistered Professional Engineer in Illinois.

Don Gilliland received the B.S. and M.S. degrees in electrical engineering from Kansas State University (KSU), Manhattan , KS. Areas of interest included image processing, communications and instrumentation. After a research assistantship at Kansas University Medical Center, he joined KSU as a faculty member in engineering technology, attaining the rank of assistant professor.

Mr. Gilliland joined IBM in 1984 to design test systems for I/O processor cards and moved to the EMC Design and Verification department in 1986. At present, he is an advisory engineer responsible for EMC performance on low-end and portable models of AS/400. His interests include EMC, power quality, applied statistics, instrumentation, and metrology. He is a member of IEEE.