solid curves represent measured data, and the dotted curves represent predicted data. Since the assessment of agreement is quite subjective, the reader is encouraged to make his own. Our overall assessment is that, over the range for which valid comparisons can be made, agreement is good to excellent for major responses, good for all moderate responses, and is generally fair to good for minor responses, although, as in the case of the Q measurement at test point R1, it is poor.

CONCLUSIONS

We conclude from the comparisons that the three-dimensional finite-difference code provides an effective method of obtaining pretest predictions for axial and circumferential currents and charge densities on an aircraft shape, over a real earth. The computer program employed for this study yields the surface current and charges at as many points as one may wish to consider, at the cost of just under one second of CDC 7600 computer time for each ns of predicted data. The principal limitation on the accuracy appears to be our knowledge of the applied fields and the soil parameters [1].

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Field-Strength Measurements of Microwave-Oven Leakage at 915 MHz

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Abstract—Measurements of electric field strength of microwave emissions from microwave ovens in the 915-MHz industrial-scientific-medical (ISM) band are reported. Field strengths were determined at 10 and 1000 ft under laboratory conditions and in the vicinity of two large condominium buildings, containing 385 ovens, in Ft. Lauderdale, Florida. Monitoring equipment consisted of dipole and log-periodic antennas feeding the input of a spectrum analyzer which was interfaced to a minicomputer system for automatic data acquisition and analysis. Under controlled conditions, the tested oven produced maximum field strengths of 123.5 dBμV/m and 81.0 dBμV/m at distances of 10 and 1000 ft, respectively. Fields as high as 79.0 dBμV/m were observed at the Florida location, approximately 500 ft from the buildings. Additional measurements were made of band occupancy and the effects of load placement in the oven, orientation of the oven, and polarization of the emerging fields.

Key Words: Microwave oven, leakage, 915 MHz, measurements.

I. INTRODUCTION

THIS paper describes a series of measurements of the field strength of emissions from microwave ovens operating in the 915-MHz industrial-scientific-medical (ISM) band. Microwave-oven radiation leakage is controlled by a product performance standard promulgated by the Food and Drug Administration [1] and limits the level of exposure at the surface of new ovens to prevent a microwave hazard. The measurements reported here were accomplished using a sophisticated radiofrequency measurement system developed for the purposes of determining population exposure to ambient intensities of the electromagnetic background [2]. The measurements were initiated from a desire of the Federal Communications Commission (FCC) to investigate the potential for interference to future land-mobile radiocommunication activities in the 915-MHz region from unusual concentrations of microwave ovens already operating in this ISM band [3].

In January of 1975, measurements were conducted of emissions from a General Electric (G.E.) Versatronix model JB45004 microwave oven at the FCC laboratory in Laurel, MD, to attempt characterizing the emission spectra under free-field conditions, i.e., with no intervening obstacle. In February of 1976, environmental measurements were made of oven field intensities near a condominium complex in Ft. Lauderdale, FL, containing 385 similar G.E. microwave ovens which were installed in the buildings by the builder. This report details the instrumentation system used for the measurements and the observations obtained from both sets of measurements.

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II. MEASUREMENT APPARATUS

The measurement system used has been previously described in detail [2]. Only salient features of the system will be summarized. Fig. 1 depicts the system showing a spectrum analyzer interfaced to a minicomputer data-acquisition system for collection and appropriate analysis of the acquired data. Various antennas are used, depending on the specific band of frequencies being monitored; in this case, a tuned dipole and a small log-periodic were used. The log-periodic was carefully calibrated using the two-identical-antennas method [4], and subsequent comparison with National Bureau of Standards (NBS) calibrated dipoles over the frequency range of 400–1000 MHz. The dipole was referenced directly to the NBS dipoles. Antenna and other system correction factors are resident in the computer for automatic correction of the measured data and subsequent plotting of the processed results. For the measurements reported here, the total overall system error was less than ±2 dB. A spectrum analyzer resolution bandwidth of 30 kHz was used throughout the course of these measurements. Fig. 2 is a photograph of the measurement system as it appears in a 27-foot mobile laboratory van. On-board ac electric power is supplied with two 6-kW generators. A self-contained pneumatically operated telescoping antenna mast is used for antenna support up to a height of about 35 ft above ground. The rack to the left in Fig. 2 contains all of the basic detection gear, while the computer system is seen in the background.

The system software provides for many different functions. Table I shows the various features of the data-acquisition-and-analysis system. Many of these features are implemented by calls to assembly-level subroutines which excute at extremely high speed, thereby greatly reducing the overall execution time for a particular repetitive function. Most importantly, the system produces graphical outputs which show absolute calibrated field-strength data in units of decibels with respect to a microvolt per meter (dBμV/m) versus frequency. In many cases the system was run using a peak-retention feature, wherein the system continuously examines corresponding frequency elements from successive scans of the analyzer and retains the peak value of field strength which has occurred during the observation period. Thus the system can monitor for a given period of time, for example 20 min and then produce afterwards a graph showing the maximum or peak value of field strength which occurred during the 20 min even if it occurred only for a fraction of a second. In this manner, one can look for peak values of field strength over long periods of time.

Using another software routine, a signal threshold level is entered by the operator, and then the system keeps track of the number of times that the measured signal amplitude exceeds this threshold. After any desired period, the system provides a graphical representation of the percent of time that received signals exceeded the threshold; this is interpreted as frequency occupancy. Such an analysis was performed at the FCC laboratory to determine if there was a particular center frequency about which the mocrowave oven shifted.

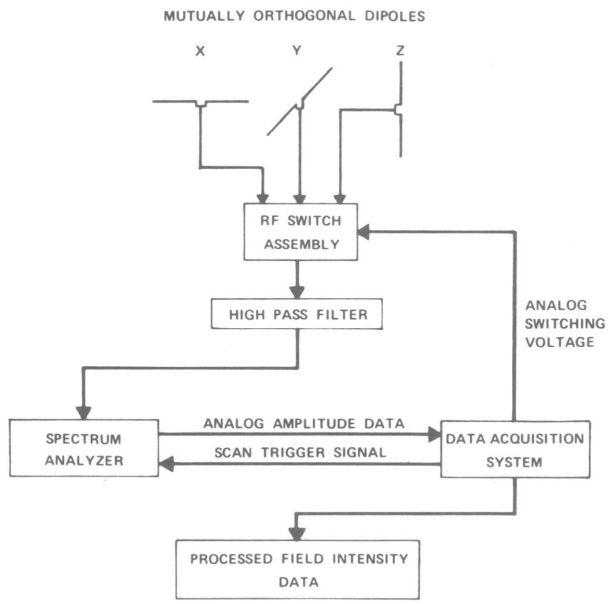

Fig. 1. Block diagram of RF measurement system.

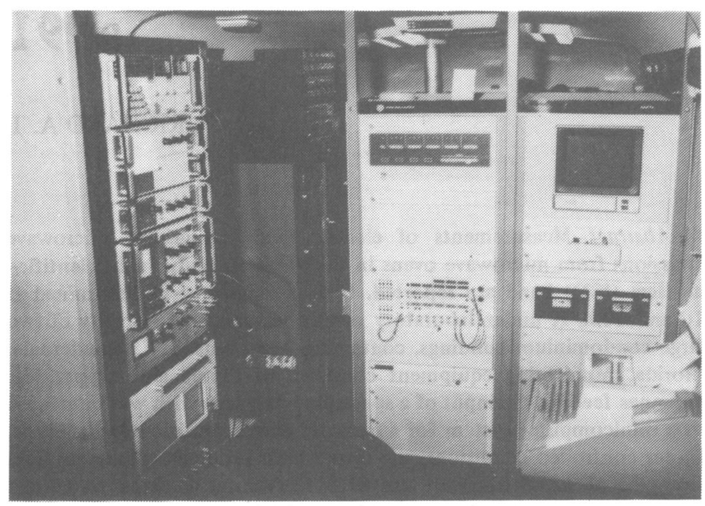

Fig. 2. Measurement system in van: instrumentation rack on left and minicomputer system on right.

TABLE 1
FEATURES OF DATA ACQUISITION AND ANALYSIS

Absolute Power Calibration
Signal Averaging—Determination of Mean Power Spectra
Peak Power Retention
Elapsed Monitoring-Time Measurement
Spectral Power Integration
Percent-Occupancy Measurement
Antenna Calibration
CRT Data Display
Digital Cassette Data Storage

Such a phenomonen would be shown by a peak in the occupancy curve at some frequency.

III. LABORATORY MEASUREMENTS

During the series of measurements conducted at the FCC laboratory, data were obtained on the field strengths of the microwave-oven emissions and the effects of polarization, load placement, oven orientation, and distance from the oven were investigated.

The effect of load placement within the oven cavity was studied by moving a 1000 ml volume of tap water to five different positions and making a measurement of peak field strength. During these measurements, the oven was oriented directly toward a dipole antenna (i.e., 0-degree azimuth) which was placed 10 ft in front of the oven and oriented for vertical polarization at 4 ft above ground. The oven was placed on a turntable mechanism in an open field free of immediate clutter with no intervening obstacle between the oven and antenna. A wooden tripod supported the dipole. Fig. 3 illustrates the different load positions used with the oven. Maximum field strength, as seen in Fig. 4, with vertical polarization was 123.5 dBμV/m or about 1.5 V/m. The total frequency excursion of the oven is readily apparent and was between 913 and 927 MHz.

Fig. 5 is the result of a measurement at 0-degree azimuth, but using horizontal polarization. The maximum field strength obtained was 113.0 dBμV/m, or about 450 mV/m, 10.5 dB weaker than the vertically polarized component.

Though individual emission spectra are not shown, field-strength measurements for load positions 1-5 revealed that the extent of frequency shift by the oven was essentially the same; however, the lower frequency components appeared to have higher amplitudes with load positions 4 and 5, while position 2 (center of oven) seemed to produce the narrowest frequency excursion. More data would be required to confirm this observation.

The effect of oven orientation was observed by rotating the oven 45 degrees either side of the 0-degree position. A positive 45 degrees was obtained by turning the oven in a clockwise direction as viewed from the top. A negative 45 degrees was obtained by rotating the oven counter-clockwise. Fig. 6 shows the results for vertical polarization at 10 ft distance and +45-degrees azimuth. Maximum field strengths obtained were 111.5 dBμV/m with vertical polarization and 110.0 dBμV/m with horizontal polarization (not shown). Similar measurements were obtained at –45 degrees with maximum field strength being 114.5 dBμV/m with vertical polarization and 111.0 dBμV/m with horizontal polarization.

In order to determine the effects of increasing the monitoring range from the oven, the van was moved to allow measurements at 1000 ft. In this instance, the dipole antenna was situated on the roof of the van, at a height above ground of about 14 ft. The line-of-sight path between the oven and the van was approximately level with a low spot of ground in between. Fig. 7 gives the results at 1000 ft with a maximum

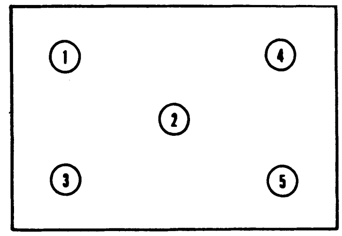

Fig. 3. Load placement diagram for GE microwave oven.

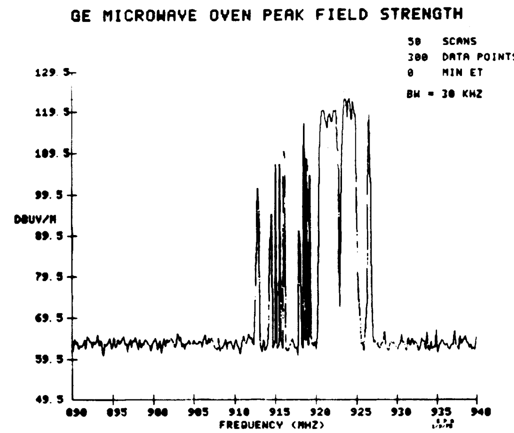

Fig. 4. Microwave-oven peak field strength at 10 feet and 0-degree azimuth; vertical polarization.

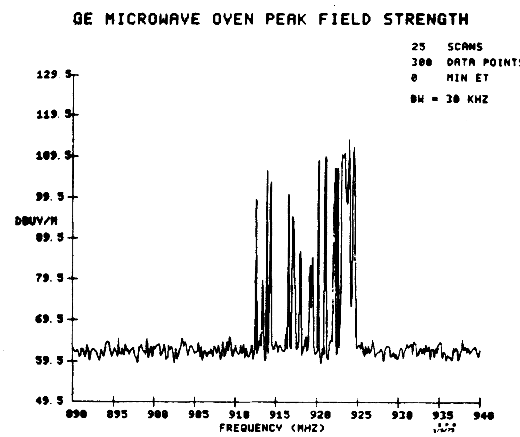

Fig. 5. Microwave-oven peak Fig. 4 strength at 10 feet and 0-degree azimuth: horizontal polarization.

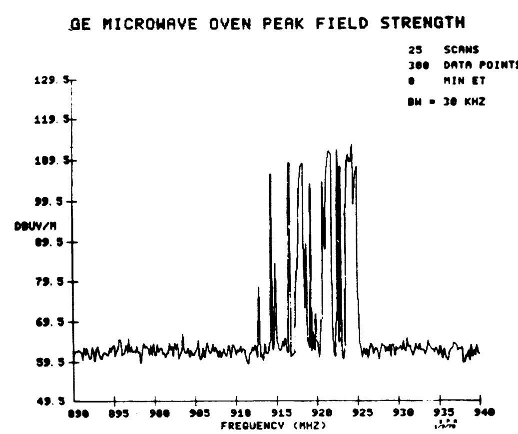

Fig. 6. Microwave-oven peak field strength at 10 feet and +45-degrees azimuth; vertical polarization.

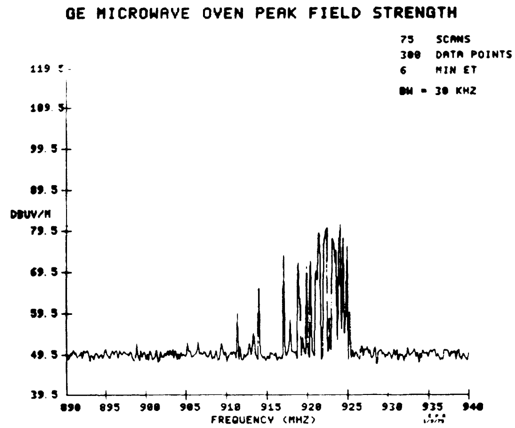

Fig. 7. Microwave-oven peak field strength at 1000 feet; vertical polarization.

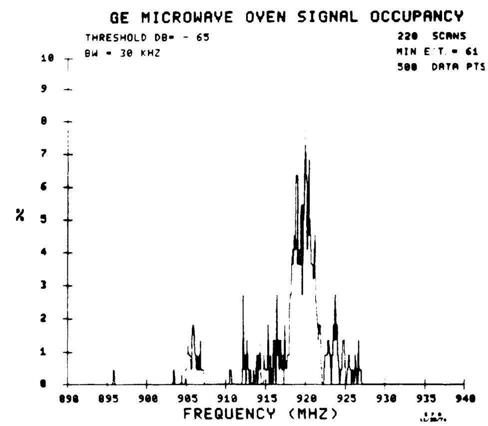

Fig. 8. Microwave-oven signal occupancy.

of 81.0 dBμV/m, or about 11 mV/m. The microwave oven was facing directly toward the van. Though no data are shown for horizontal polarization, it was found that the vertical component was again about 10-dB greater in amplitude than the horizontal.

A measurement of the band occupancy of the oven was performed at a distance of 10 ft using vertical polarization. The results, shown in Fig. 8, indicate that the predominant frequency about which the oven shifted was 920 MHz. Most of the emissions are contained in a band of approximately 10 MHz, with less frequent excursions over a total frequency range of about 30 MHz. This result represents a sample of only one microwave oven, and other ovens, even though they may have a fairly tight frequency excursion, might overlap in their frequency shifts, thereby occuping a greater portion of the ISM band. Fig. 8 was result of 61 min of monitoring while the previous plots were for substantially shorter periods of time.

On the basis of these tests, it was found that, with a 30-kHz spectrum-analyzer bandwidth (the value used for all measurements reported in this paper), even at 1000 ft the detection system exhibited 30 dB of additional available dyamic range with the dipole antenna.

Using a higher gain antenna, the small log-periodic, it was thought that reliable signal detection would be possible under actual field conditions in Ft. Lauderdale.

IV. FIELD MEASUREMENTS IN FT. LAUDERDALE

In February 1976, in conjunction with a scheduled radiofrequency-intensity survey of the greater Miami metropolitan area, additional measurements were made of field strengths from the G.E. ovens installed in a large condominium complex at Point of Americas in Ft. Lauderdale.

All measurements conducted at the condominiums were made from a location approximately 500 ft from the two buildings which comprise the condominium complex, on the south side of the complex and at ground level. A log-periodic was used in each polarization plane, vertical and horizontal, elevated to approximately 20 ft above ground.

Monitoring was accomplished on three separate evenings during the usual dining hours of about 1700–1900 local time. The choice of the three particular evenings for monitoring were made on the basis of convenience with a prescheduled radiofrequency survey of the greater Miami area. Figs. 9–11 summarize the pertinent observations. It was not evident just which polarization produced the highest field strengths, but Fig. 9 shows one of the highest levels monitored and it was with horizontal polarization. The highest intensity was 79.0 dBμV/m or 8.9 mV/m at 920 MHz. Multiple ground and wall reflections are potentially the cause of the ill-defined polarization of the detected signals. The software used in the monitoring had evolved since the previous measurements, and it was possible to acquire many more scans from the spectrum analyzer in a given elapsed time.

Fig. 10 shows the presence of at least two separate ovens being on at the same time, each with its own individual character in terms of frequency dispersion. It was interesting to the author that more ovens were not observed operating at any given time. In fact, on the first evening of monitoring, after 10 min of looking at the spectrum analyzer, and not seeing any activity at all, it was assumed that there was something wrong with the hardware. All of a sudden, on popped an oven and, shortly thereafter, another. The use of the microwave ovens in these buildings is perhaps peculiar; some ovens would be on for very short periods of time, e.g., one to two min, while others would be on for relatively long times, upwards of 20 min. Also, certain ovens could be distinguished, it was thought, by their spectral characteristics over the three evenings of observation. Some occupied very discrete areas with little frequency shift. Others were extremely erratic in their excursions, shifting sometimes 30 MHz or so, back and forth. Presumably, this phenonomon has to do with the size of the load placed in the oven. Some ovens showed drastic turn-on frequency excursions, while others were quite stable from the moment of turn-on.

Fig. 11 presents the results of a 76-min continuous monitoring run begun at 1805 local time. Here, total excursion of about 14 MHz is evident and a single oven component at almost 915 MHz is in the center of the total spectral spread from all ovens involved in the measurement. Maximum field

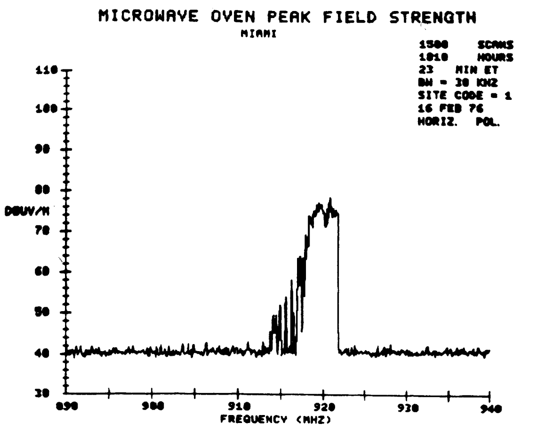

Fig. 9. Microwave-oven peak field strength as measured outside a condominium in the Miami area; horizontal polarization.

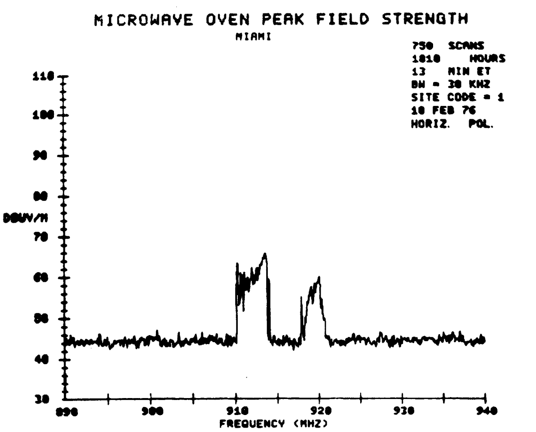

Fig. 10. Microwave-oven emission spectra showing presence of at least two different ovens.

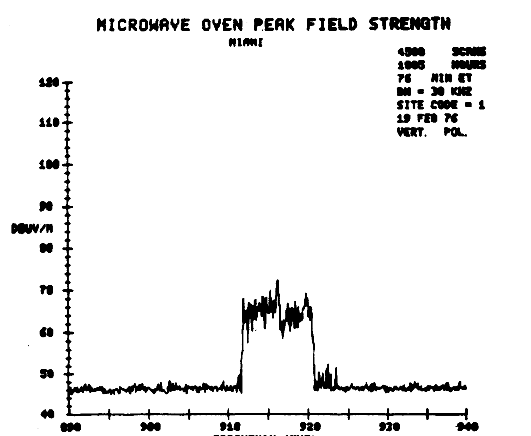

Fig. 11. Microwave-oven peak field strength over continuous period of 76 min of monitoring.

strength during this period was 72.5 dBμV/m (4.2 mV/m). During all of the monitoring at the condominium, it was never obviously evident that more than three ovens were on at any one time, though it is possible since it is difficult to distinguish among the various frequency components when all ovens are dancing in the frequency domain.

CONCLUSIONS

A summary of the salient findings is given below:

Frequency excursion by an individual oven is usually within a 10-MHz band, but instantaneous shifts over a 30-MHz band are common. Ovens appear not to be necessarily uniform in the extent of frequency dispersion during turn-on.

Maximum field strength at 10 ft was 123.5 dBμV/m or about 1.5 V/m.

Maximum field strength at 1000 ft was 81.0 dBμV/m or about 11 mV/m. This is 42.5 dB lower than at 10 ft. Simple free-space propagation would predict a 40-dB lower signal, and thus the measured values are in good agreement with theory over the distance range measured.

Load placement does have some effect on both frequency excursion and relative signal level, but could be considered insignificant.

Maximum field strength was observed directly in front of the oven, being typically 9-12 dB greater than at 45-degree angles from the front of the oven.

With the laboratory study, vertical-polarization field strength was significantly stronger, by typically 10.5 dB, than the horizontal-polarization component. This was presumed important for land-mobile antenna considerations, but field data from Ft. Lauderdale did not seem to confirm this polarization effect; in fact, horizontal polarization was strongest during the time monitored.

At angles of 45 degrees to the front of the oven, the difference between vertical and horizontal polarization components of the field are typically in the range of only 1.5-3.5 dB, as opposed to the difference directly in front of the oven of about 10 dB.

Further study is necessary, using typical land-mobile receiving equipment to ascertain the actual degree of reception degradation from oven emissions. Also, additional measurements at greater distances would be desirable to determine the area over which such an interfering field might have an impact. Oven density and distribution are other factors to consider, of course; interference to roaming mobiles might turn out not to be a problem; however, a base-station antenna located near a collection of ovens might be subject to unacceptable RFI.

These data, though limited, illustrate a technique which might prove useful for determining typical usage patterns for microwave ovens. Future measurements of this type could incorporate two features not present during this study. It would be informative to know the correlation between the field-strength measurements performed and leakage values of microwave energy as obtained through product-performance tests required by the Bureau of Radiological Health, FDA [5]. Finally, field measurements could possibly be optimized by analyzing building plans and oven placement to determine preferential directions from the building where maximum field intensities would be expected.

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Short Papers

Statistical Correlation Between Conducted Voltages on the Powerline and Those Measured with a Line-Impedance Stabilization Network

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Abstract—In measurements of physical parameters, it is not always possible to obtain consistent results because of the dependence on and interaction of a significantly uncontrolled variable element in the measurement. For consistent results to be obtained, the variation in the element may be eliminated by replacing the element with a simulated representative constant.

Measurement of conducted powerline noise from electric/electronic equipment is subject to such variation. Conducted-noise measurement procedures used in the United States, and also internationally, typically employ line-impedance stabilization networks (LISN's) which, in theory, eliminate the effects of variations in the ac power-distribution-network impedance on the measurement. The LISN is designed to be representative of the actual power-distribution-network impedance presented to equipment connected to the network. The LISN and power-network impedances are both frequency variant. Power-network impedances can assume a wide range of values at a fixed frequency, whereas the LISN impedance, assuming that any line-impedance effects are small, is a single value.

This paper explores the correlation between conducted noise voltages measured in a LISN configuration and the actual noise voltages expected to be impressed on the power distribution system. The analysis is conducted at 1 MHz. The paper analytically relates the impedances of the LISN, power distribution system, and equipment. A LISN of the type used in the United States is used in the development; however, the concept and procedure presented is applicable to any LISN, frequency, and equipment.

Key Words: Conducted noise, statistical correlation, powerlines, line-Impedance stabilization network.

I. INTRODUCTION

Much electric and electronic equipment generates radio-frequency noise during normal operation. Such noise can be conducted from the equipment to the ac power-distribution system through the equipment power cord. The amount of noise coupled to the power-distribution system depends upon the impedance transfer function between the equipment and the power system.

The regulation and control of powerline conducted noise originating in commercial equipment is recognized by both industry and government in the United States [1]–[6] and by many other national government agencies, technical agencies, and international standards organizations [7]–[11]. Most measurements of commercial equipment require the use of an LISN (line-impedance stabilization network) that is designed to isolate the EUT (equipment under test) from unwanted electrical noise on the ac power source, and also to present a specified representative impedance to the EUT.

The level of conducted noise is generally measured by a calibrated RF voltmeter (receiver) appropriately connected to the LISN, and is dependent on the strength of the EUT noise source and the relationship between EUT and LISN impedances at the frequency of interest. Depending upon the EUT/LISN impedance transfer function, practically all or very little actual EUT source noise may be impressed across the LISN and measured via the receiver. The LISN impedance, provided the effect of the line impedance on the LISN is small, is single-valued at a given frequency. The level of EUT source noise measured with a LISN and a receiver can therefore be calculated uniquely, provided the EUT and LISN impedance and actual EUT source noise are known.

The level of EUT source noise actually impressed on the ac power-distribution system may be quite different from that determined in the LISN configuration because the impedance presented by the ac power system is variant, being dependent upon the instantaneous aggregate loading on the system at the time and the line design. The power-distribution-system impedance at a given frequency gives rise to a distribution of values describing this parameter and may, at times, be equal to the LISN impedance. As an immediate consequence, any EUT source noise that is impressed on the power distribution system assumes a distribution of values because it is dependent on the power-system impedance.

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