Abstract of EMF RAPID Program Engineering Project #1: Development of Recommendations for Guidelines for Field Source Measurement

This study was designed primarily to better define the complexity of magnetic and electric fields to which humans are exposed, and to develop guidelines for measuring electric- and magnetic-field distributions near specific field sources.

These guidelines were to provide the basis for rigorous field-exposure analysis and risk assessment if a relationship between field exposure and human health effects were to be identified. The guidelines would provide researchers with a methodology to characterize EMF sources in a consistent manner and with sufficient spatial and temporal detail to guide electric and magnetic-field management, if necessary.

The study was divided into three tasks:

> Task A: Construct a set of characteristics for guiding and interpreting biological studies and for focusing any future effort at field management.
>
> Task B: Develop a systematic method of identifying sources during surveys so that they can be correlated with measurements made in other surveys or in laboratory tests.
>
> Task C: Develop guidelines for measurement of field sources.

The investigators discuss ways to reduce data to a manageable size. They develop a coding system to identify characteristic sources of magnetic fields, as well as guidelines for measuring magnetic fields *in situ* and for appliances in a testing laboratory situation. The report details equipment needed for measurement (waveform-capture instrumentation is recommended), as well as the series of steps required for adequate documentation in measuring. They stress the importance of identifying lost data, of recording physical characteristics that may affect measurements, and of documenting steps carefully. In all cases, a pilot study and systematic documentation are cited as being of critical importance.

Study Limitations

Comprehensive measurements of the electromagnetic characteristic of specific field sources are somewhat limited by available instrumentation. While any specific measure required to characterize and interpret biological studies can be achieved with a collection of instruments, no single instrument can collect all specific measures of electric and magnetic fields.

Areas for Future Research

Future research should concentrate on the rapid location of field sources from specific measurements. The types of measurements needed and the use of measurements needed and the use

of multi-pole location programs should be studied. This process is essential in general settings encountered in typical commercial, residential, and industrial settings.

EMF RAPID Program Engineering Project #1: Development of Recommendations for Guidelines for Field Source Measurement

Purpose and Focus

This study was designed primarily to: (1) better define the complexity of magnetic and electric fields to which humans are exposed, and (2) develop guidelines for measuring electric- and magnetic-field distributions near specific field sources.

These guidelines were to provide the basis for rigorous field-exposure analysis and risk assessment if a relationship between field exposure and human health effects were to be identified. The guidelines would provide researchers with a methodology to characterize EMF sources in a consistent manner and with sufficient spatial and temporal detail to guide electric and magnetic-field management, if necessary.

Tasks: Goals and Findings

The project was divided into three tasks:

Task A - Selection of Field Parameters,
Task B - Identification of Field Sources, and
Task C - Development of Protocol.

Task A: Construct a set of magnetic-field characteristics for guiding and interpreting biological studies and for focusing any future effort at field management.

Magnetic-field characteristics are quantified and reduced according to the availability (or possible development) of instrumentation to measure the desired characteristics. One focus of the research was on how to acceptably reduce the seemingly infinite number of samples required to describe electric and magnetic fields to a tractable number of specific measures. Specific measures are defined by methods that perform spatial and temporal reductions of measurements consistently. The investigators explored existing measurement techniques and suggested specific measures that will characterize electric and magnetic fields for use by health assessment studies.

Specific measures characterize one or more of six field attributes:

- intensity,
- frequency,
- intermittency,
- transients,
- spatial attenuation, and
- polarization.

Table 1, below, shows the field attributes characterized by specific measures and a citation to the location of discussion in the text. Numerous examples of specific measures are discussed in the text, from the common to the less common. The most common specific measures of intensity are the resultant and ac rms fields, which can also characterize spatial attenuation. A common specific measure for frequency is harmonic magnitude.

Table 1: Alphabetical Listing of Specific Measures and Related Source Field Attributes

Specific Measure	**Applicable Concepts and/or Equations**		**Field Attributes**						
	Section	Equation	Intensity	Frequency	Intermittency	Transients	Spatial Attenuation	Spatial Polarization	Not Fully Defined
AC-DC Angle	3.5.1	3.14							X
AC-DC Parallel Magnitude	3.5.1	3.15	X						X
AC-DC Perpendicular Magnitude	3.5.1	3.17	X						X
AC RMS	3.3.3	3.8	X				X		
Analog AC RMS	3.3.4	3.11	X				X		
Coherency Index	3.5.2								X
DC	3.3.2	3.6	X	X			X		
Harmonic Magnitude	3.5.5	3.19	X	X			X		
Harmonic Phase	3.5.5	3.20		X			X		
Intermittency Index	3.5.2								X
Maximum Spatial Component	3.2.2	3.4	X					X	
Maximum Spatial Phase	3.2.2	3.4	X					X	
Minimum Spatial Component	3.2.2	3.4	X					X	

Specific Measure	Applicable Concepts and/or Equations		Field Attributes						
	Section	Equation	Intensity	Frequency	Intermittency	Transients	Spatial Attenuation	Spatial Polarization	Not Fully Defined
Minimum Spatial Phase	3.2.2	3.4	X					X	
Peak Magnitude	3.4.1		X						
Peak Rate-of-Change	3.5.4	3.18	X			X			
Peak Resultant	3.4.2		X						
Peak-to-Peak Magnitude	3.4.1		X						
Polarization	3.2.2	3.4						X	
Resultant	3.2.1	3.3	X				X		
Transient Indices of Rise Time, Overshoot, Settling Time, Natural Frequency	3.6					X			X
Transient Peak Rate-of-Change	3.6					X			X

Specific measures can also be categorized by whether they describe characteristics related to field orientation, steady-state temporal properties, forces exerted on magnetic materials, induction phenomena, transients, and relationships between the AC and DC fields.

Data collection should ensure that all specific measures can be associated with (1) spatial information relative to the source, (2) temporal information relative to the measurement, (3) information on the state of the source(s), and (4) the orientation of the transducer (if appropriate) relative to the source.

The report surveys all available instrumentation for required measurements (including ac and dc survey meters, broadband or narrowband three-axis recorders, single-axis and three-axis wave capture recorders, multi-sensor three-axis wave capture recorders, and special purpose transient capture recorders), and concludes that waveform capture is the most efficient means to capture all electric- and magnetic-field attributes. Currently available equipment provides most of the specific measure information that applies to the biological research efforts.

Finally, this section of the report notes the critical importance of understanding and documenting loss of data and other physical characteristics that can affect the measurement process (e.g., temperature, peak field level, minimum field level, motion of the transducer, frequency interactions, and high-frequency radio frequency fields).

Task B: Develop a systematic method of identifying sources during surveys so that they can be correlated with measurements made in other surveys or in laboratory tests.

In approaching this task, the investigators note that any attempt to codify sources should give some indication of the expected nature of the magnetic-field attributes associated with the source. Before this research, nothing had been reported that attempts to classify apparatus sources. The report looks at a variety of potential coding methods (e.g., arbitrary, Standard Industrial Classification, and so on) before detailing the recommended method (below).

The proposed classification system is restricted to a general quantification of the magnetic-field attributes of a source. The classification system is based on identifying the source by its common name, followed by alphanumeric descriptors for a total of 50 characters, followed by a four-digit code. An example would be:

UPS-brandxx50kVA208V 4238

Within the code (shown here in italics), the first digit grades the range of magnetic-field magnitudes that may be expected at a point 30 centimeters (1 foot) in front of the surface of the device. The second is a measure of the frequency of the most dominant magnitude; the third a measure of how intermittent the point source may be; and the fourth a measure of two different attributes— spatial attenuation and polarization. The ranges assigned to each code digit are shown in Table 2, below.

Task C: Develop guidelines for measurement of field sources.

Guidelines presented simply as a list of steps may not always work effectively unless they provide documentation of the reasoning process behind the steps. Task C develops guidelines—in the form of step-by-step procedures accompanied by the rationale behind each step—for two situations: *in-situ* measurements, and measurements at an appliance test center. Areas covered by guidelines include documented preparation, documentation of the environment, documentation of measurements locations, documentation of human activity, methods of measurement, checkpoints for data, and analysis methods, including processing material into a standard data base.

In-situ. *In-situ* testing is the most frequent measurement situation, and has its own special problems. These include (1) the inability to readily repeat measurements; (2) the inability to access areas of interest or operating information such as currents or voltages, and (3) the inability to measure all phases of machine operation.

Table 2: Appliance Code Ranges

Code Digit	1	2	3	4
Characteristic / Value	Field Magnitude [1] (mG)	Frequency [2] (Hz)	Operational Changes [3] Less Than Once Every ...	Attenuation/ Polarization [4]
0	<0.1	<1	Year	Unknown/linear
1	<1	<10	1.2 months	(1/r)/linear
2	<10	$<10^2$	0.52 weeks	(l/r^2)/linear
3	$<10^2$	$<10^3$	8.76 hours	(l/r^3)/linear
4	$<10^3$	$<10^4$	0.876 hours	(>1/r^3)/linear
5	$<10^4$	$<10^5$	5.256 minutes	Unknown/elliptical
6	$<10^5$	$<10^6$	0.5256 minutes	(1/r)/elliptical
7	$<10^6$	$<10^7$	3.1526 seconds	(1/r^2))/elliptical
8	$<10^7$	$<10^8$	0.31536 seconds	(1/r^3)/elliptical
9	$<10^8$	$<10^9$	31.536 milliseconds	(>1/r^3)/elliptical

[1] Field magnitude at 30 cm (1 ft) in front of surface of device
[2] Dominant frequency
[3] Period between changes in steady-state operating conditions
[4] Spatial attenuation characteristic/nature of field polarization.

It is important to include a pilot study as an integral part of *in-situ* measurements. The pilot study often produces significant findings needed to perform the full characterization. The resulting data can also become part of the characterization record.

Ideally, three people should be present to conduct the protocol, in order to carry out the sequence in a timely fashion. The following equipment is required:

- a magnetic wave-capture system with four sensors,
- an electric field sensor with an ELF bandwidth if electric fields are to be characterized,
- a video camera and several cassettes of video tape,
- a rigid staff for mounting the sensors,
- measurement equipment, including a non-metallic measuring tape,
- a data log with a supply of pens or pencils,
- a clamp-on current meter that may be used to measure source current, and
- a portable computer if the magnetic-field recorder requires configuration or down-loading during or after the measurement process.

The three-person team takes the following steps, keeping records as an integral part of the protocol:

- inspect the site;
- discuss the measurement procedure with the facilities manager;
- draw a quick sketch showing the location of the sources;
- examine the method of powering the sources;
- draw the proposed coordinate grid on the sketches;
- take four measurements close to the appliance front center, sides, and back to ensure that the sensor range is acceptable;
- take four more measurements on a profile from the front center position along a grid line;
- use as long a "snapshot" duration as possible to detect low frequency activity or to separate out off-power frequencies;
- use a high frequency sensor to detect activity in the very low-frequency (VLF) and low-frequency (LF) bands;
- download and inspect the data for integrity;
- if measurements appear reasonable, continue the measurement process starting at a selected grid point (for simple estimates, magnetic fields should be sampled at at least 4 lateral points in at least 4 directions within 180 degrees and at 4 heights);
- monitor the location, sensor orientation, and the coordinate numbers with a video camera;
- request people to move from their workplace only when absolutely necessary;
- review the results of a few random measurements before leaving the site; and
- reduce the data.

Appliances at a Test Center. For these measurements, the researchers should first conduct a pilot study. That study would produce the following findings, to be used in developing the full characterization:

- type of sensors needed,
- expected maximum levels,
- transient trigger levels,
- location of dc sensors,
- minimum frequencies for recording,
- intervals between "snapshots," and
- LF-VLF recording requirements.

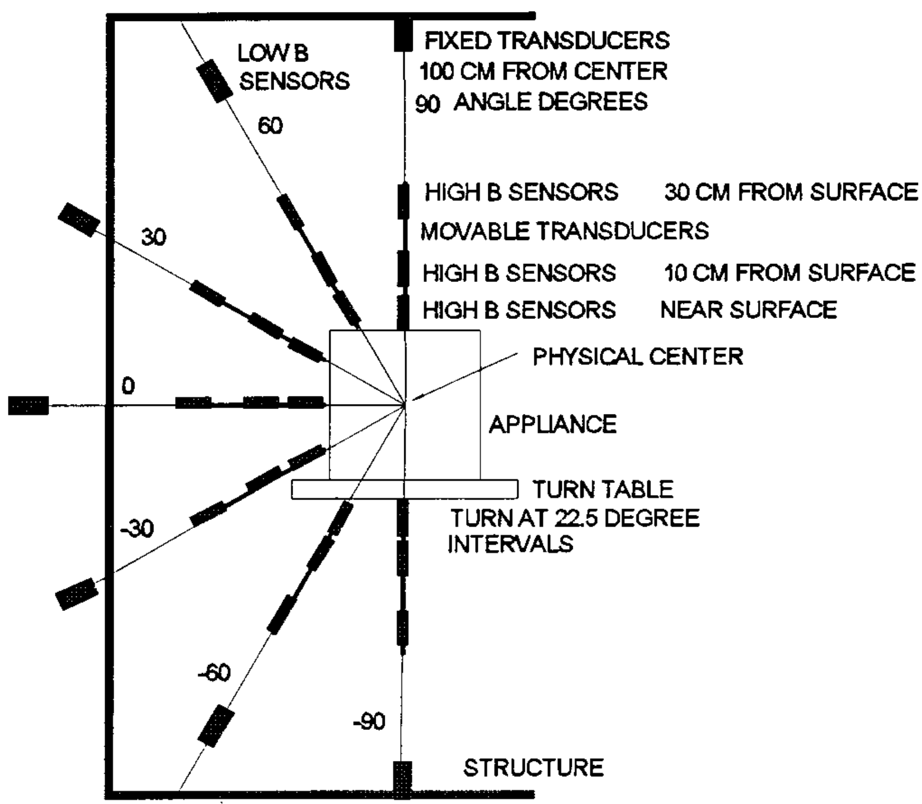
The test center protocol uses structures with mounted sensors to allow maximum characterization in the minimum amount of time.

The final protocol should include the following:

- creation of a sketch of the appliance;
- preparation of a set of photographs to document the details of the device;
- the size of the wiring, construction of the wiring, voltage rating, and current rating of the sources;
- collection of field data on spherical coordinates to completely surround the appliance;
- measurement of LF and VLF data;
- measurement of transient data; and
- analysis of data, including verification that no recording failures occurred.

A protocol should be developed to test the fixture with an array of probes. Some issues include choice of coordinate system, and the spacing of sensors at or near the appliance surface. Another issue is how to select the center of the location of an appliance for measurements. The recommended protocol is to use spherical coordinates and progressively larger spacing between probes. For example, for a source with a radius of approximately 30 cm, sensors should be placed at the surface of the appliance, and at distances of 10, 30, and 100 cm from the surface. (See Figure 1.) The center of the coordinate system may be selected as the physical center of the appliance or, for practical reasons in mounting the appliance, of the center of gravity.

Figure 1: A Simplified Diagram of the Appliance Test Set



The project collected detailed magnetic-field data for 20 appliances. See Table 3, below.

Table 3: Summary of Magnetic Field Measurements from Appliances

Description	Code*	RMS Resultant Field, mG		
		At 30 cm (front)	Highest at surface	
		60 Hz	60 Hz	180 Hz
Window air conditioner	2247	1.1	97	1.99
Kitchen blender	3263	18.6	7913	1825
Crock pot for kitchen use	1253	0.7	41.3	0.28
Drill–hand hammer	2263	7.0	6103	2547
Oscillating table fan	2248	0.28	606	100
Portable space heater	2258	2.2	156	39.7
Steam iron	1263	0.8	16	23.9
Hand jig saw	2262	3.2	1536	870
Kitchen hand mixer	2268	4.0	1458	75.7
Paint sprayer	3262	61.5	21659	2643
Pencil sharpener	2273	9.5	4900	2410
Hot air popcorn popper	1253	0.2	255	124.9
Laser printer	1261	0.2	82.7	7.61
Skil hand saw	3278	13.2	2560	1826
AC man's shaver	3263	23.9	11471	2637
Soldering iron station	2262	2.6	2865	363
Kitchen toaster	2262	1.1	191	3.35
Electric tooth brush	2263	4.2	939	33.1
Upright vacuum sweeper	3253	18.6	4711	2049
Video display terminal	1242	0.9	104	37.3

* See Table 2.

Summary

It is possible to develop an effective protocol for specific field-source measurements, using parameters that will quantify EMF attributes for use by health assessment studies. Waveform capture is the most efficient means to capture all EMF attributes. A method to code apparatus sources is described, as are the steps for *in-situ* and appliance test center testing. Magnetic-field data collected following these protocols are reported for 20 appliances. In all cases, a pilot study and systematic documentation are of critical importance.