SURVEYS

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WHY DO YOU NEED TO PERFORM SURVEYS ?

Surveys are performed for various reasons, such as: new or modified installations, changes in the previously surveyed environment, changes in the levels of emitted power or limits, and at the request of personnel or management.

A survey is required to have a real understanding of the RF environment. Calculations are necessary to ensure you choose the correct equipment to perform the task, minimize the potential hazard to the surveyor, and protect the equipment that you choose to employ. Calculations can provide an estimate of the field strengths involved, but this is only a starting point.

Two basic types of surveys are performed. The first one is near a known, or intentional, emitter such as an antenna. The second type of survey is near an unintentional emitter to detect a suspected leak (e.g., from waveguide that transfers the RF from an amplifier to an antenna). Both types of surveys are covered in this document.

I. SURVEYING INTENTIONAL EMITTERS

A. EMITTER CHARACTERISTICS

Before beginning a survey, it is important to obtain information about the system you are going to test. This includes the following information:

1. Frequency

2. Power Level

3. Modulation Characteristics

4. Number of Sources

5. Spurious Frequencies or Harmonics

6. Intermittence of Output

7. Antenna Information (e.g., size, beamwidth, gain, orientation)

8. Previous Survey Results (if available)

B. SITE CHARACTERISTICS

A drawing of the site characteristics is important to determine a plan of action that will minimize your potential exposure, allow you to perform the best survey with a minimum of site interruption, and will be used in your final report. Visiting the site before the date of the survey is very important and preferable to viewing a picture or drawing. However, pictures and/or drawings are helpful in explaining your reasons for choosing particular measurement positions and results. Items to consider in your site drawing should include:

1. Structures (such as buildings, fences, towers, etc.).

2. Areas Normally Occupied by People (work areas, walkways, etc.)

3. Barriers, Interlocks, Signs, and Visual or Audible Alarms

4. External Areas (such as parking lots, residential areas or any other “uncontrolled areas” that may receive lower, but measurable emissions)

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5.Topographical Information
(such as contour height from surveys)
For directional emitters like parabolic antennas, it is necessary to obtain beam elevation angles. This information is used to plot worst-case results if there are no mechanical means to stop the beam from illuminating people in the area.

C. PRE-SURVEY CALCULATIONS

Antennas come in various shapes and sizes but they all operate in the same way. They receive electromagnetic energy from a transmitter through coaxial or waveguide transmission line. Antenna design is dependent on the application and frequency range of operation. The table below gives some of the characteristics of the two major types of antennas – *wire* and *aperture.*

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Wire Types	Aperture Types
Radiation from currents induced in conductors	Radiation from fields reflected off a surface
Static	Rotating
Low Directivity	High Directivity
Broad Beamwidth	Narrow Beamwidth
Dimensions on the order of one wavelength or less	Dimensions on the order of many wavelengths

Aperture antennas come in several forms. Examples include: arrays of low directivity elements, aperture horns, and a shaped reflector or lens illuminated by a broad beam radiator.

There are three distinct areas in front of an antenna that you need to be familiar with. These areas are the reactive near field, the radiating near field, and the far field. All antennas operate as a point source once you are beyond the "Raleigh distance." The "Raleigh distance" is that point where the field strength decreases inversely with the distance and the equivalent power density decreases with the square of the distance.

1. Lower Frequency, Omni-Directional Antennas

For lower frequency (<1GHz) antennas, i.e., non-directional "whip" or "rod" type antennas, the following sample calculations may be used:

GAIN: Typically 8 dB; 20 dB or more for antenna arrays

NEAR FIELD: The reactive near field will be approximately 10% of the radiating near field at a distance of $\lambda/2\pi$. Most measurements will take place within this area, where simple calculations are not accurate. Arbitrary phases and amplitudes of both fields are present in the near field. Measurements should be made with isotropic probes.

FAR FIELD: Power density can be calculated using the following calculation:

$S\ (W/m^2) = PG/4\pi d^2$ where
P= Average Power at antenna
G= Numerical Gain = (Gain dB/10) antilog
d = Distance from antenna (meters)

2. Higher Frequency, Directional Antennas

GAIN: Usually expressed in dB (typically 25dB to 45dB) which can be converted from logarithmic to numerical gain by using the conversion shown above or, by using Table 1, below. Gain can be estimated from the formula:

$G = 4\pi A_n/\lambda^2$ where
A= Area of antenna
n= Efficiency Factor (Typ. 0.5 to 0.8)
λ= Wavelength

TABLE 1. LOGARITHMIC vs. NUMERICAL GAIN

dB	Numerical	dB	Numerical	dB	Numerical	dB	Numerical
1.0	1.26	11.0	12.59	21.0	125.89	31.0	1258.93
2.0	1.58	12.0	15.85	22.0	158.49	32.0	1584.89
3.0	2.00	13.0	19.96	23.0	199.53	33.0	1996.26
4.0	2.51	14.0	25.12	24.0	251.19	34.0	2511.89
5.0	3.16	15.0	31.62	25.0	316.23	35.0	3162.28
6.0	3.98	16.0	39.81	26.0	398.11	36.0	3981.07
7.0	5.01	17.0	50.12	27.0	501.19	37.0	5011.87
8.0	6.31	18.0	63.10	28.0	630.96	38.0	6309.57
9.0	7.94	19.0	79.43	29.0	794.33	39.0	7943.28
10.0	10.00	20.0	100.00	30.0	1000.00	40.0	10000.00

The near field can extend to a distance of $D^2/4\lambda$ where D is the antenna diameter.

The power density in the radiating near field can be estimated to be 4P/A. In other words, the maximum power in the near field could be four times the average power over the nominal antenna area. This relationship is shown in the figure below.

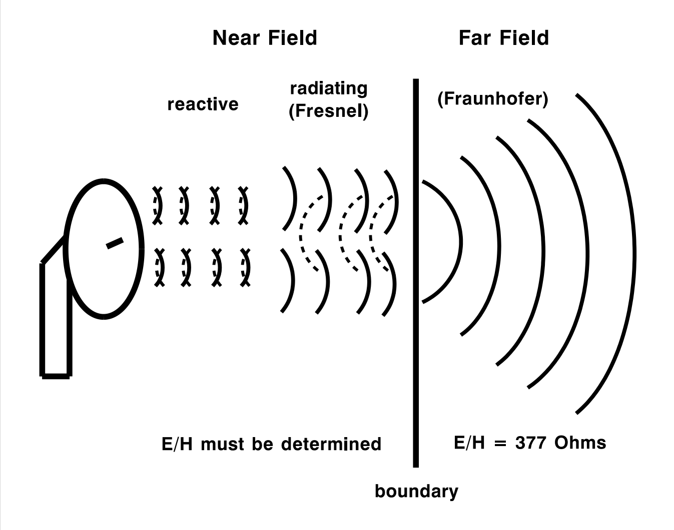

Figure 1

D. INSTRUMENTATION

Instruments are available to cover from 3 kHz to over 100 GHz. ELF and VLF frequency bands are measured by other types of instruments which are not covered in this document. Different types of detectors are covered in Narda's *RF Electromagnetic Monitors and Measurements,* which is recommended reading when choosing an instrument. Highlights of this document are as follows:

1. General A survey instrument usually contains three distinct parts: Meter, Probe and Cable (or leads). The meter displays the detected levels on an analog or digital display. Meters may include features such as storage of detected levels, audible alarms and built-in test sources. With few exceptions, meters do not form part of the measurement circuit, that is, they do not determine what frequencies or levels are detected. Probes, however, *are* part of the system that determines what may be measured. Probes are available in designs that detect from one direction (anisotropic) or from all directions (isotropic). Frequencies detected may be very few (narrow bandwidth) or very many (ultra-broadband, e.g., 300 kHz to 50 GHz). Dynamic ranges average 30 dB or more and usually only one field component (electric or magnetic) is measured at a time. Cables transmit information from the probe to the meter assemblies. Theses cables are either shielded copper wires, or (at lower frequency ranges) fiber optic cables. Some low frequency designs exclude cables to maintain accurate readings. Before performing a survey, certain characteristics need consideration, including:

2. Field Detection All probes available measure either the electric (E) or magnetic (H) fields. At higher frequencies (300 MHz) some standards require that only one field component be measured (usually E) while at lower frequencies both field components might need to be measured. Additionally, you need to determine if surveys are to be performed with *isotopic* or *anisotropic* probes. Isotropic probes are usually preferred because mistakes can be made when detecting fields from only one direction. Reflections are not as readily found and can result in considerable measurement errors. When measuring in the near field areas, an isotropic probe may be the only accurate solution because the phase relationship varies rapidly near the antenna.

3. Frequency Range: The instrument you choose must cover the frequency or frequencies of the emission. Some emissions may have large harmonics (or multiples) of the main signal, which a narrowband detector may not respond to.

4. Measurement Range: Calculations give you an estimate of the field strengths to expect. Most likely, you will want a probe that measures levels both above and below the calculated levels.

5. Detection: Probes usually employ either *diode-based* or *thermocouple-based* detection. A diode is a non-linear device, which means that over its measurement range it may change from an average detector to a peak detector. As long as the emission is not modulated and it is a single-frequency emission there will not be a large error. If there is a compensating circuit that varies the detector's operation to maintain it in "square law," it will allow the diode to remain accurate in almost any environment. Thermocouple detection is also used at lower (<300 MHz) frequencies. Antenna arrays made up entirely of thermocouple junctions are available for use at higher (1 GHz) frequencies. Thermocouples are linear devices. This means that they will always give true RMS average results, even when used in multiple-emitter applications. Thermocouple array probes operate on energy deposition across their numerous junctions. In this way, they always generate an output that is proportional to the average energy, no matter how narrow the pulse's width is. This is why thermocouple detectors are usually used for measurements on pulse modulated emissions. The major drawback of thermocouples has been an inefficiency when compared to diode detectors, meaning that the diode provides a larger output voltage for an equivalent field strength. A thermocouple detector therefore exhibits "zero drift" which may be a significant part of a low level reading. Another consideration is that the diode can usually withstand a higher overload level than the thermocouple. This

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amplifies the need for performing pre-survey calculations, which helps guard against overloading either type of detector.

If, after reviewing literature, you have any questions about how equipment will operate in a specific environment, consult the manufacturer. It is imperative that your questions be answered before any equipment is purchased to ensure that such equipment will meet present and future needs.

E. MEASUREMENT METHODS AND SURVEY HINTS

1. Basic Survey Methods

Before beginning the survey, allow time to warm up and check out the equipment. When using thermocouple-based probes, it is advisable to allow the probe to stabilize to the ambient temperature. Allowing the probe to raise or lower its temperature to the ambient temperature helps minimize "zero drift." If this cannot be accomplished in an area of low field levels, it is recommended that a device equivalent to the Narda Model 8713B Electric Field Attenuator be used to guard against probe overload.

CAUTION

Thermocouple probes can be overloaded even when they are not in use!

Ensure that the meter's batteries are charged enough to complete the survey and, if check sources are available, use them to verify operation of the entire system.

Sites with multiple emitters are considerably more complex than single-emitter sites. Mobile emitters can be moved further complicating site measurements and future survey validity. Additionally, time may be a major factor, both in the survey time required and coordination with people who will be required to operate the equipment. Such surveys require careful planning to insure minimal site disruption.

Begin the survey from a distance well beyond the calculated hazard distance. Always begin a survey with the meter set on its highest measurement range. While surveys are usually conducted to seek out the highest field levels, more meaningful results will be obtained if field readings are compared to calculated values at certain distances.

The probe should be held at the maximum distance from your body. If the direction to the emitter is not known, or if there are multiple emitters, the probe should be held at a 45 degree angle. If there is a single emitter, the probe should be pointed directly at the source to minimize isotropic errors. Accuracy can be further improved by taking the mean reading while rotating the probe about its main axis. Results should be conservatively rated. If the system error is 2 to 3 dB, then results should assume worst cases. In other words, multiply your readings by (in this case) 1.6 to 2.0. An antenna reflection can increase the field strength by a factor of 4 and you may wish to include this factor in your result.

Field levels are normally averaged over the whole body. The IEEE/ANSI C95.1 standard allows time averaging, but not whole body averaging, for exposures to the eyes and male testes' body areas. Again, you may want to use a worst case example in your final data.

2. Microwave Frequency Surveys

Rotating radars and other scanning sources present additional monitoring requirements. You may wish to make time-averaged measurements of scanning sources. Some surveyors choose not to time-average these sources if there are no provisions to disable the emissions should the motor or scanning software fail. In this instance, the scanning should be disabled when performing the measurements.

Also, consider the diagram *Field Strengths in Front of an Antenna* in Figure 2. Being closer to the antenna may not result in higher readings due to the radiation pattern. Make sure you are in the beamwidth for measurable levels.

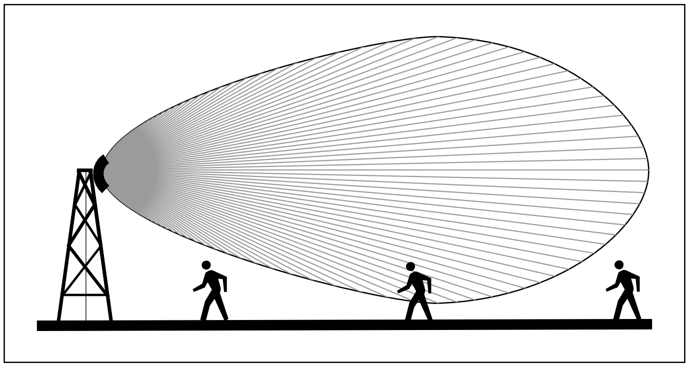

Figure 2

3. Radio Frequency Surveys (50 to 300 MHz)

When surveying in this frequency range, readings may be affected by the distance between your body and the survey equipment. Specifically, your body becomes a large reflector increasingly affecting the probe as you move into the lower part of this frequency range. For the most accurate measurements in this frequency range, we recommend that you maintain a distance of a few feet between your body and the probe. A simple way to do this is to place the probe on a non-metallic stand near the emitter, keeping the separation between the probe and you.

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For most standards, both E-field and H-field readings will be made separately and compared with standard, or guidance, limits. Antennas are normally omni-directional in their radiation patterns, so measurements will be made around the entire area in question. Metallic structures may re-radiate and/or reflect the energy present thereby complicating the survey. In the United States the IEEE/ANSI standard also includes limits for induced and contact currents, at frequencies below 100 MHz.

Once you are within a distance of $\lambda/2\pi$ to the antenna, the reactive field components may be greater than 10% of the radiating components, leading to errors of greater than 1 dB. Although the reactive components do not form part of the radiating field strength, they are real and can generate heating effects and/or induced currents.

4. Radio Frequency Surveys (3 kHz to 50 MHz)

The problems with reflections off the body that begin to appear at 300 MHz (see *Radio Frequency Surveys – 50 to 300 MHz* above) become increasingly significant as you move into even lower frequencies. Below 10 MHz, the equipment is affected also. For accurate readings, you must do one of two things: (1) *place the probe next to the meter,* coiling up the probe's cable so that all components of the system are in the same strength field and put the entire assembly on a non-metallic stand, or (2) *totally isolate the meter from the probe* using a Narda Fiber Optic Link (Model 8747) which allows you to remote the meter away from the probe without conducting the emission through the cable to the meter. For best results, you will still need to minimize field perturbance caused by the surveyor by using a stand to support the probe.

For low frequency antennas that employ guy wires, there will normally be a field radiated from them that should be measured. The level of the reading will be greatly affected by the measurement distance you use. The new IEEE/ANSI C95.1 standard recommends a minimum measurement distance of 20 cm from any passive re-radiator and 5 cm from an active radiator. Most other standards and guidances list distances of 5 centimeters.

Contact current hazards may be present when there are low (<100 MHz) frequency transmitters and conductive objects that may be touched by personnel. Ungrounded objects may store energy that will be discharged through a person's body when that object is touched. When in doubt, you should check the metallic objects near the antenna. The Narda Model 8870 Contact Current Meter provides the means to test contact currents at frequencies below 30 MHz for all major standards or guidances.

F. POST-SURVEY REPORTING

Your post-survey report is going to contain more than field readings. Valuable knowledge can be obtained from a complete listing of steps taken before, during and after the survey.

1. **Emitter Information**
2. **Emitter Purpose**
3. **Site Map**
4. **Operational Procedures**
5. **Field Readings**
6. **Induced and/or Contact Current Hazards**
   (if emissions are 100 MHz)
7. **Outline of Hazardous Areas**
8. **Existence of Ionizing Radiation**
9. **Control Procedures**
   (Lockout-Tagout, Permit to Work, etc.)
10. **Existence of any other Hazards**
    (Fuel Storage,Ordinance,etc.)

After-the-survey steps may include:

1. **Calculations Performed Before the Survey**
   (If readings do not match calculations, this should be explained)
2. **Hazard Areas**
3. **Field Readings at Areas Normally Accessible by People**
4. **Hot Spots**
5. **Existence and Adequacy of Engineering Controls and Warning Signs**
6. **Use of and Operating Procedures to Control Exposures**
7. **Attitudes of Workers Related to RF Radiation**
8. **Drawings, Sketches or Photographs of Area**
9. **Conclusions and Recommendations**

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If your survey uncovers potentially hazardous areas, you may want to also provide information, such as:

1. Placement of Warning Signs

2. Engineering Controls

3. Antenna Restriction Devices

4. Use of Terminations or Dummy Loads when Testing

5. Use of Barriers, Interlocks and Visual/Audible Alarms

6. Area or Personal Monitors that Continually Monitor for Excessive Fields (should any of the above measures fail)

II. SURVEYING UNINTENTIONAL EMITTERS

Leakage surveys vary considerably from surveys involving known emitters such as antennas. In most cases there are no field calculations that can be performed before the survey.

This section concentrates on the most common types of leakage surveys. The three types of surveys are: (A), Microwave Ovens, (B), Industrial Equipment and, (C), Transmission Line leakage.

A. MICROWAVE OVENS

Microwave oven standards regulate the permissible leakage around the perimeter of an oven door, not human exposure. This leads to a difference in the basic design of the survey equipment. The instruments required to measure this leakage are one-directional or anisotropic. This design helps ensure that only the oven is being tested, rather than having measurements potentially disturbed by other sources in the immediate area.

The U.S. Code of Federal Regulation (CFR) 21 part 1030, specifies the maximum amount of leakage from the oven at distances of 5 cm – 1.0 mW/cm^2 before the oven is sold and 5.0 mW/cm^2 throughout its operating life. Similar standards are used in other countries.

1. Presurvey Inspections

Microwave ovens have built-in safety features that should be checked before surveying for leakage. Visual inspections of the door hinges, door seals and latch mechanism should be performed. The latch mechanism can be checked by insuring the oven stops operation when the door is opened. Excessive food around the door gasket can increase leakage, so ovens need to be kept clean.

2. Oven Surveys

Microwave ovens are normally tested when operating on their highest power level, and with a load of water (approximately 275 ml.). The test equipment is scanned about any surface of the oven, paying close attention to the area of the door seal while holding the probe horizontally. Most surveying equipment will have a 5 cm spacer to allow you to hold the probe against a surface. Response time for oven meters is usually around one second, but can be up to 3 seconds, so you need to scan the surface at an appropriate speed. The Narda Model 8217 can perform additional testing, allowing you to test the output power of the oven by monitoring the temperature rise of the water load.

B. INDUSTRIAL EQUIPMENT

Industrial equipment that is used for heating, drying, and sealing is very common in the workplace. These systems can operate from a few Hertz, as in the case of induction heating at foundries, up to hundreds of kilohertz. Sputtering and plasma equipment usually operate at 13.56 MHz and heat sealing or vinyl welding devices usually operate at 27.12 MHz. Before beginning your survey, the emission frequency should be checked with a frequency counter, spectrum analyzer, or manufacturer-supplied data. Spectrum analysis is also useful for determining if equipment is generating multiple emissions, or harmonics, when operated at its highest power level.

With industrial surveys it is important to consider both whole-body averaging and time averaging. Most processes use high power for a short period, which allows for considerably lower averaged exposure levels. When surveying, it is normally beneficial to use a “story pole” that will allow you to mark various survey heights and repeatably measure at the same point. The Narda Models 8511 and 8513 Industrial Compliance Meters are unique in their ability to measure electric and magnetic fields without changing probes, which can greatly reduce survey time. High power handling is also worth mentioning here. When surveying a device that operates at 27.12 MHz, you will most likely be in the near field. The wavelength at this frequency is approximately 11 meters, which means that, because of the proximity to the source, power may vary greatly with only a slight change of probe position.

A sample survey sheet – *Heat Sealer Record* – is shown on page 123. This form can be modified for other industrial surveys.

Australia, Canada, the United Kingdom and the United States have limitations on contact current. In the U.S. there are also limitations on induced body currents. Such limitations should be considered when planning to perform low frequency (<100 MHz) surveys. In a document published in 1989, the U.S. National Institute of Occupational Safety and Health (NIOSH) stated that measuring the induced body current may provide the most direct indication of absorbed energy. Compliance measurements at frequencies below 100 MHz now include both field and current measurements. If field measurements approach standard or guidance limits, you should measure currents.

C. TRANSMISSION LINE LEAKAGE

A common example of leakage measurements is testing waveguide flanges. Waveguide flanges and bends are likely points of leakage in high power systems. Gaskets in flanges may deteriorate after being cycled over temperature many times. Bends also tend to form stress cracks from temperature and mechanical stress. When testing waveguide systems, most people will probe as closely as possible to the suspected areas. Normally, defective flanges can be tightened, while bends have to be removed from the system for repair or replacement.

In many systems the waveguide may be positioned so close it will be difficult to test certain points. In the past it was common to use a waveguide antenna to search for leaks. This approach is often difficult and time consuming because of the amount of equipment available. A new, and safer method is to use the Narda Model 8783D Flexible Probe which has a very small detector housing. Its long length keeps your hands away from the high voltage that is normally present in high power amplifiers.

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