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Comparison of microwave power density meters

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This report presents a comparison of several types of survey instruments designed to detect and measure microwave power density emitted from microwave ovens. The units, which have been tested by the Bureau of Radiological Health, are evaluated according to accuracy, sensitivity, dynamic range, reliability, ease of measurement, thermal stability, battery life, and cost.

MICROWAVE ENERGY is currently being employed in several different ways, and increasingly in consumer products. When used as a source of power for a consumer product, microwaves are generally intended to be used in a completely shielded enclosure which allows no access while the microwave source is operating. Because there is concern about the biological effects of such radiation, it is necessary to detect and quantify leakage from products using this type of energy source.

All of the commerical instrumentation available at the time of this evaluation respond to electric field intensity and are calibrated in terms of power density measured in free space.

Types of instrumentation

Several classification methods for microwave power density instrumentation are possible. The three categories we have chosen are intended use, method of detection, and method of indication. There are two distinct equipment use categories, either as a laboratory instrument or as a survey instrument. A laboratory instrument would ideally be sensitive enough to measure whatever power densities are desired with the capability of covering an extremely wide dynamic range. It should not create disturbance to the propagating field and should be stable with a very fast response time. It should be able to indicate accurately at any distance from the source.

If the instrument is designed for survey use, it should meet additional major requirements, i.e. it should be lightweight, battery operated with low battery drain, easily readable, rugged and have a minimum number of switch settings. The probe should be burnout-proof and directionally independent. For operator safety, it is also very important that a survey device should not read low when it is in a potentially hazardous field.

The detection methods category can be divided into thermal detectors and electrical detectors. Thermal detectors act on the principle of producing a detectable physical change (temperature) in a thermally sensitive element. This change is then measured, usually electrically. There are three general types of thermally sensitive elements in use today. The first is the thermistor. The resistance of the thermistor decreases when its temperature rises. The thermistor is heated by coupling it to the electromagnetic field. It is the r.f. current which causes the heating of the thermistor, but the detection of this heating is done by measuring the d.c. resistance of the thermistor. Another device closely akin to the thermistor is the baretter which has a positive temperature coefficient of resistance rather than a negative one. These are both known as bolometer detectors, a term which means any device which changes its resistance as it changes temperature.

Another type of temperature-sensitive device is the thermocouple. A thermocouple produces a voltage when heated. Therefore, all that is necessary to make a detection device from a thermocouple is an antenna and a current or voltage measuring device. Voltage and current levels encountered when using these detectors are very small, so that a sensitive meter must be used, generally in conjunction with some type of direct-current amplifier.

A third and novel approach to thermal microwave measurement is the air-pressure system. This system involves measurement of a small pressure change in a confined gas when its container is heated slightly by absorbing some r.f. energy. The gas container is usually some sort of electrical insulator covered by a carbon compound which absorbs r.f. energy.

These three thermal detection schemes have individual and common deficiencies. They all are, of course, ambient temperature dependent in their simple form. Methods of measuring the difference in output from matched thermal detectors with only one exposed to r.f. heating have been developed and such instruments are superior for general application.

A different approach to power density measurement is that of direct electrical energy conversion. The detected r.f. power directly activates the meter needle for measurement. This effect is accomplished by using a semiconductor diode. This rectifies the alternating r.f. current into direct current which is then applied to a meter movement calibrated to indicate power. Knowing the effective antenna area, the power density can be calculated. The diode detector type of indicator can be made extremely sensitive. In fact, this is one of the drawbacks of high-frequency diodes – even moderate signal strengths must be attenuated before reaching the detector to avoid overload. This is sometimes complicated and may lead to measurement inaccuracies. This is no doubt why thermal detectors are preferred over diode detectors for survey-type power density meters.

With the exception of the air-pressure detector, all detectors or sensors require an antenna to convert the propagating radio-frequency wave into wire-conducted radio-frequency currents which are then detected by either a thermistor, thermocouple, or diode. It is this antenna that determines the major characteristics of the measuring instrument. There are two attributes of an antenna which are important to the user of the instrument: directionality and polarization sensitivity. Directionality of an antenna is the dependence of its response on the direction from which the wave comes. One would like an antenna which is directional so that the effect of reflections from survey personnel will be minimal, but at the same time not too directional so that orientation toward the source becomes critical.

The second attribute is polarization sensitivity. Polarization of an electromagnetic wave refers to the direction of the electric field vector. This vector may be varying in orientation (random polarization), fixed in orientation (plane polarization), rotating in orientation at the radio frequency (elliptical polarization), or any combination of these. There is no single antenna which will respond to all polarizations simultaneously. This causes a great problem in antenna design. To achieve true polarization independence, one must use two antennas which are identical to each other except that they accept orthogonal polarizations. The power captured by these antennas must be added arithmetically in the metering circuit, which places added constraints on the design. Generally this is accomplished by using two perpendicular dipole antennas with independent detectors. But to design a survey meter with true polarization independence is not easy.

The third category for classification of microwave power density instrumentation is method of indication. Quantitative methods used are an analog scale and digital indication, calibrated either in milliwatts per square centimeter or decibels relative to some reference. These methods seem to be the most practical in a laboratory or survey meter. If the instrument is used to measure product performance against a standard then it is very helpful to have the indication in the same terms as set forth in the standard. Visual qualitative devices such as variously colored gaseous glows or an audible alarm which sounds when some power density limit is exceeded are useful devices under certain conditions, especially for quickly locating microwave leakage from an oven.

Commercial instruments tested

The commercial survey instruments tested in the DEP laboratory include

- a pocket dosimeter employing a multiturn coil as antenna (model C-1 Dosimeter, Scientific Protection Devices Inc.)
- a preignited neon/mercury tube designed to indicate a microwave field (model 285 Microlite, International Crystal Mfg Co.)
- a survey meter and a dipole antenna with a thermocouple detector (model 8100, Narda Microwave Inc.)
- a survey meter employing a horn antenna with a thermistor detector (model 1200, Ramcor Inc.)
- a survey meter employing a left-hand helix antenna with diode detector (model Rad 200, Wayne Kerr Co. Ltd.)

The pocket dosimeter was totally unsuitable as a quantitative instrument. It exhibited marked differences from theoretical values because of r.f. leakage of the instrument components. Response of the unit was severely dependent on radiation polarization and exposure to extremes of temperature.

The inexpensive instrument utilizing a preignited neon/mercury tube as detector and readout was unreliable for quantitative measurements because of:

> Variation of sensitivity between instruments. As stated by the manufacturer of the neon/mercury tube used in the instrument: The tube was never designed for this application and consequently the gas pressure and other important parameters are not controlled for this type of application[1]
>
> Variation with time. It has been reported that a tube left unused for some time will often change its ignition threshold appreciably[2]. A tube which glows fully at 10mW/cm^2 may later fail to detect a considerably stronger field.

Variation with direction. Different evaluations of the field will be obtained for different orientations of the instrument. Optimally the instrument flows fully at a level of approximately 10mW/cm^2 in the most favorable orientation – thus when the instrument is in any other orientation, the field will be underestimated.

Subjective nature of determination. There is no definite threshold for ignition or for full tube-length glow. Even with no microwave power present, a faint blue glow is discernible at the ignition end of the tube. As power level is increased, small blue flashes begin to appear, and their size and frequency are continuous functions of power. There is a wide range between the power density for the first flash which extends the length of the tube, for instance, and that at which the full tube can be said to be glowing.

Lack of warning of high power density. At power density levels between 20 and 100mW/cm^2 no change was seen in the quality of the light emitted by the tube.

Variation with lighting conditions. Visibility of the blue flashes is considerably enhanced by viewing the tube against a black background or at low ambient light levels, especially at low power density levels.

The principal advantage of this instrument is its low cost, about $30. It can be used to detect microwave leakage, but with considerable uncertainty as to the power density level of the leaks detected. A glowing tube indicates the presence of microwave power; but a tube that does not glow is no indication that high levels are absent.

Instrument characteristics

The following tabulation compares the characteristics of commercial devices utilizing thermocouple sensing elements, thermistors in a bridge circuit, and an helix antenna with a diode detector circuit. Although these devices operate over different frequency ranges, they are all designed to include 2450MHz; therefore the devices will be compared at this frequency using a plane electromagnetic wave. (This frequency was chosen because it is used for microwave ovens.)

Sensitivity: smallest readable indication

Thermocouple device: 0.01mW/cm^2

Thermistor device: 1mW/cm^2

Helix with diode detector: 0.5mW/cm^2

Readable range:

Thermocouple device: 0.01mW/cm^2 to 200mW/cm^2

Thermistor device: 1mW/cm^2 to 500mW/cm^2 with external attenuators

Helix with diode detector: 0.5mW/cm^2 to 10mW/cm^2

Ease of measurement

Thermocouple device. Completely portable. Three probes used with the meter are restricted to one metre of cable attached to each probe. Sensing end of the probe is pointed toward the source of the radiation for optimum effect.

Thermistor device. Completely portable. Antenna can be fastened to the instrument body either directly or through a coaxial cable. Meter scale is small and difficult to interpret, and the antenna responds only to an electric field parallel to the wand or across the short dimension of the antenna horn, depending on the model used.

Helix with diode detector. Portable and self-powered with the exception of mercury cells to operate a circuit to check meter operation. Antenna must be oriented toward the microwave source and has a beamwidth at half-power response of about 55°.

Accuracy (manufacturers specification)

Thermocouple device. Approximately ± 25% at level of calibration of each probe.

Thermistor device. Approximately ± 25% at 10mW/cm^2.

Helix with diode detector. – 0% and + 59%. Inaccuracy approaches 59% at the higher and of the scale.

Reliability and ease of repair

Thermocouple device. Instrument did not exhibit polarization sensitivity. However, it suffers probe failures at overloads of 50% above maximum range. Once a probe is burned out the sensing device must be replaced and calibrated by a factory technician.

Thermistor detector. Markedly affected by polarized microwave radiation. Either the probe must be held parallel to a linearly-polarized electric field or else two readings 90° apart must be taken to achieve accurate results. Instrument is not troubled by overloads with the exception of the attenuator mounted in series between the detector and the meter. However, the meter is troubled by zero drift.

Helix with diode detector. Responds correctly to any direction of plane polarization, but does not respond correctly to elliptically-polarized waves. No experience of repair.

Cost

Thermocouple device: $885

Thermistor device: $605

Helix with diode detector: $450.

Stability

Thermocouple instrument is stable and its accuracy has little temperature dependence (8% change from initial value when brought from 5 to 22°C). Thermistor device has an unstable zero adjustment and its accuracy specifications are exceeded at extremes of temperature (30% change from initial value when brought from 5 to 22°C). No information about stability or temperature dependence of measurement accuracy of the instrument using the helix with the diode detector is presently available.

Conclusion

There are advantages and limitations for all the various instruments described in this report. Almost all of the instruments serve some useful purpose within their limitations. A change of frequency and test conditions may change the selection of one device over another. As a result of the tests outlined in this report it was found that the thermocouple device is best suited to measure leakage close to a slot source—such as a microwave oven—at the frequency of 2450MHz.

References

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