

IEEE Standard for Electrothermic Power Meters

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, Inc.

IEEE Standard for Electrothermic Power Meters

1. Purpose

The purpose of this standard is given as follows: To provide potential purchasers and others with a common means for making comparisons between instruments and to provide a uniformity of information among manufacturers. This standard also documents the minimum information that users of electrothermic power meters may need.

2. Scope

This standard applies to electrothermic power meters as complete instruments and to their constituent parts: electrothermic elements, electrothermic units, and electrothermic power indicators. Electrothermic power measurement instrumentation is generally used to measure (below 3 W and above 2 MHz) the average power of an electromagnetic wave propagating in a single mode in waveguide or coaxial transmission lines. The power range can be extended by the use of attenuators or directional couplers, or both.

3. Definitions

accuracy. The degree of correctness with which a measurement device yields the true value of a measured quantity; quantitatively expressed by uncertainty. See also: **uncertainty**.

assigned value. The best estimate of the value of a quantity. The assigned value may be from an instrument reading, a calibration result, a calculation, or other.

calibration factor (electrothermic-coupler unit). The ratio of the substituted reference¹ power (dc, audio, or rf) in the electrothermic unit attached to the side arm of the directional

coupler to the power incident upon a nonreflecting load connected to the output port of the main arm of the directional coupler for the same dc output voltage from the electrothermic unit at a prescribed temperature. If the electrothermic unit is attached to the main arm of the directional coupler, the calibration factor is the ratio of the substituted reference¹ (dc, audio, or rf) power in the electrothermic unit attached to the main arm of the directional coupler to the power incident upon a nonreflecting load connected to the output port of the side arm of the directional coupler for the same dc output voltage from the electrothermic unit at a prescribed temperature.

calibration factor (electrothermic unit)². The ratio of the substituted reference¹ power (dc, audio, or rf) in the electrothermic unit to the power incident upon the electrothermic unit for the same dc output voltage from the electrothermic unit at a prescribed temperature.

dual-element electrothermic unit. An assembly consisting of two thermopile elements and an electrothermic mount in which they are supported. The thermopile elements are effectively in series to the output voltage and in parallel to the rf power. The thermopiles also serve as the power absorber.

effective efficiency (electrothermic unit)². The ratio of the substituted reference¹ power (dc, audio or rf) in the electrothermic unit to the power dissipated within the electrothermic unit for the same dc output voltage from the electrothermic unit at a prescribed frequency, power level, and temperature.

² Calibration factor and effective efficiency are related as follows:

$$\frac{K_b}{\eta_c} = 1 - |\Gamma|^2 \quad (\text{IEEE Std 100-1972 (ANSI C42.100-1972), p 70.})$$

where K_b , η_c and Γ are the calibration factor, effective efficiency, and reflection coefficient of the electrothermic unit, respectively.

¹ The reference frequency is to be supplied with the calibration factor.

electrothermic-coupler unit. A three-port directional coupler with an electrothermic unit attached to either the side arm or the main arm which is normally used as a feed-through power measuring system. Typically, an electrothermic unit is attached to the side arm of the coupler so that the power at the output port of the main arm can be determined from a measurement of the power in the side arm. This system also can be used as a terminating power meter by terminating the output port of the directional coupler.

electrothermic element. A power absorber and a thermocouple (or thermopile) which are either two separate units or where the thermocouple (or thermopile) is also the power absorber.

electrothermic mount. A waveguide or transmission line structure which is designed to accept the electrothermic element. It normally contains internal matching devices or other reactive elements to obtain specified impedance conditions at its input terminal when an electrothermic element is installed. It usually contains a means of protecting the electrothermic element and the immediate environment from thermal gradients which would cause an undesirable thermoelectric output.

electrothermic power indicator. An instrument which may or may not amplify the low level dc output voltage from the electrothermic unit and provides a display, usually in the form of the D'Arsonval type indication or a digital readout.

electrothermic power indicator error. Ability of the metering circuitry to indicate exactly the substituted power within an electrothermic unit. Included are such factors as meter calibration, open loop gain, meter linearity, tracking errors, range switching errors, line voltage errors, and temperature compensation errors.

electrothermic power meter. This consists of an electrothermic unit and an electrothermic power indicator.

electrothermic substitution power. The power at a reference frequency which, when dissipated in the electrothermic element, produces the same dc electrothermic output voltage that the element produces when subjected to radio frequency power.

electrothermic technique of power measurement. A technique wherein the heating effect of power dissipated in an electrothermic element (which consists of an energy absorber and a thermocouple or thermopile) is used to generate a dc voltage. The power is dissipated either in a separate absorber or in the resistance of the electrothermic element. The resultant heat causes a temperature rise in a portion of the element. This temperature rise is sensed by the thermocouple which generates a dc output voltage proportional to the power.

electrothermic unit. An assembly consisting of the electrothermic element installed in the electrothermic mount.

feed-through power meter or measuring system. A device which is inserted or incorporated in a waveguide or transmission line and provides a means for measuring (monitoring) the power flow through or beyond the system.

indicated value. The uncorrected value determined by observing the indicating display of the instrument.

interaction factor. The ratio of power incident from an rf source to the power delivered by the source to a nonreflecting load; mathematically, $|1 - \Gamma_g|^2$ where Γ_g is the complex reflection coefficient of the source.

limit of error. A synonym of the preferred term **uncertainty**.

maximum safe input power (electrothermic unit). The maximum peak pulse or cw input power which will cause no permanent change in the calibration or characteristics of the electrothermic unit. Specify in watt-microseconds the maximum (safe) input energy per pulse and the applicable pulse repetition frequency in hertz or in kilohertz. Specify in watts or milliwatts the maximum (safe) input peak pulse power.

measured value. An estimate of the value of a quantity obtained as a result of a measurement. Indicated values may be corrected to give measured values.

mismatch factors. Resulting from a combination of interaction factor and reflection factor resulting from reflective source and load impedances which relate incident, absorbed, and delivered power to a nonreflection load. (For mathematical details, see the appendix.)

mismatch uncertainty. Uncertainty in an assigned value that is caused by uncorrected or uncertain values for the phase of one or both of the mismatch factors. See the appendix.

power sensitivity error. The maximum deviation from linearity over each power range of either the electrothermic unit or the electrothermic power meter. Expressed in percent.

random errors. The errors that cannot be predicted except on a statistical basis.

reflection factor. The ratio of the power absorbed in, to the power incident upon, a load; mathematically, $1 - |\Gamma_t|^2$, where $|\Gamma_t|$ is the magnitude of the reflection coefficient of the load.

resolution. The smallest discrete or discernible change in power that can be measured. In this standard, resolution includes the estimated uncertainty with which the power changes can be determined on the readout scale.

response time (electrothermic power meter). The time required for the electrothermic power indication to reach 90 percent of its final value after a fixed amount of rf power is applied to the electrothermic unit.

sensitivity of electrothermic-coupler unit. The ratio of the dc output voltage of the electrothermic unit on the side arm of the directional coupler to the power incident upon a nonreflecting load connected to the output port of the main arm of the directional coupler at a prescribed frequency, power level, and temperature. If the electrothermic unit is attached to the main arm of the directional coupler, the sensitivity is the ratio of the dc output voltage of the electrothermic unit attached to the main arm of the directional coupler to the microwave power incident upon a nonreflecting load connected to the output port of the side arm of the directional coupler at a prescribed frequency, power level, and temperature.

sensitivity of electrothermic unit (dissipated power). The ratio of the dc output voltage of the electrothermic unit to the microwave power dissipated within the electrothermic unit at a prescribed frequency, power level, and temperature.

sensitivity of electrothermic unit (incident power). The ratio of the dc output voltage of the electrothermic unit to the microwave power

incident upon the electrothermic unit at a prescribed frequency, power level, and temperature.

stability. For a constant input rf power, constant ambient temperature and constant power line voltage, the variation in rf power indication over stated time intervals. *Long term* stability or drift is the maximum acceptable change in 1 hour. *Short term* stability or fluctuation is the maximum (peak) change in 1 minute.

systematic error. The inherent bias (offset) of a measurement process or one of its components.

temperature coefficient of sensitivity. The change in rf sensitivity (microvolts/milliwatts) resulting from a specified temperature change of the electrothermic unit at a specified power level. Expressed in percent per degree centigrade.

terminating power meter or measuring system. A device which terminates a waveguide or transmission line in a prescribed manner and contains provisions for measuring the incident or absorbed power.

thermocouple. A pair of dissimilar conductors so joined at two points that an electromotive force is developed by the thermoelectric effects when the junctions are at different temperatures (IEEE Std 100-1972, ANSI C42.100-1972).

thermopile. A group of thermocouples connected in series aiding. This term is usually applied to a device used either to measure radiant power or energy or as a source of electric energy.

time constant (electrothermic unit). The time required for the dc electrothermic output voltage to reach $1 - (1/e)$, or 63 percent of its final value after a fixed amount of power is applied to the electrothermic unit.

uncertainty. The assigned allowance for the systematic error, together with the random error attributed to the imprecision of the measurement process.

zero carryover (electrothermic power meter). A characteristic of multirange direct reading electrothermic power indicators which is a measure of the ability of the meter to maintain a zero setting from range to range without readjust-

ment after initially being set to zero on the most sensitive range. Expressed in terms of percentage of full scale.

4. Required and Optional Information to Be Supplied

4.1 Required (Minimum) Information. Information and equipment description, operating conditions, and performance characteristics shall be supplied on, at least, each of the items listed in Table 1 under "Required."

4.2 Optional (Additional) Information. Listed in Table 1 under "Optional" are some items that may be important in some applications. Information on these items may be optionally supplied by the manufacturer or requested by the user. Any additional information deemed desirable may also be supplied by the manufacturer.

4.3 Standards for Information. All of the following sections are for the purpose of establishing a common understanding of meaning, content, conditions, and validity of information that is supplied or requested in accordance with this standard.

5. Standard for Required and Optional Information

This section gives standards for the content and scope of the information to be supplied on the items listed in Table 1.

5.1 Identification. Give the manufacturer's name and address and the type or model and serial number for the equipment.

5.2 Types. Using the list on Table 2 as a guide, classify the equipment for which information is being supplied.

5.3 Physical Description. Give outside dimensions, weight, and other important physical properties such as whether the equipment is portable, rack-, or bench-mounted. A sketch or photograph showing front-panel controls should be included. Specify the type of connector used for connecting the electrothermic unit to the power to be measured.

5.4 Power Ranges. State full scale power ranges in microwatts, milliwatts, watts or decibels above one milliwatt. Meter scale and control dial subdivisions and marking shall be included in the description.

5.5 Frequency Range. Give the recommended frequency range for the spectrum of electromagnetic waves applied at the input for power measurement.

5.6 Accuracy. Clearly define the uncertainty in percent or decibels with which the value of a quantity can be measured or assigned. For complete power meters, it is the combined uncertainty in the electrothermic unit or coupler unit and the power indicator. For electrothermic units, it is the uncertainty in the assigned value for calibration factor or in the assigned value for effective efficiency. For electrothermic coupler units it is the uncertainty in the assigned value for calibration factor. And for power indicators, it is the uncertainty in the measurement of the dc calibration voltage. Specify frequency ranges, input power levels (full-scale values), and operating conditions (reference) for which the statement is valid. Typical types of uncertainty statements are the following:

(1) Worst case uncertainty for direct readings without corrections (in this standard, worst case means the maximum possible uncertainty that can occur)

(2) Worst case uncertainty using manufacturer-supplied correction data

(3) Statistical uncertainty

When supplying statistical uncertainty, the manufacturer shall list all factors that contribute significantly to systematic error together with each of their assigned allowances for systematic error. The overall limits (three standard deviations) to the random error shall also be stated, and the method for combining these components to arrive at the total uncertainty shall be specified.

The manufacturer must state which of the above three cases is specified.

5.7 Operating Conditions. For the equipment (operating), give (1) minimum, (2) nominal (reference), and (3) maximum values for the items listed in Table 1. State what reduction (if any) in range and accuracy can be expected at the minimum and maximum value.

Table 1
Required and Optional Information

	Required	Optional	Electro- thermic Power Meters	Electro- thermic Power Indicators	Electro- thermic Units	Electro- thermic Elements
Identification (5.1)	X		X	X	X	X
Types (5.2)	X		X	X	X	X
Physical Description (5.3)	X		X	X	X	X
Power Ranges (5.4)	X		X	X		
Frequency Range (5.5)	X		X		X	X
Accuracy (5.6)	X		X	X	X	
Operating Conditions (5.7)						
Range of ambient temperature and humidity	X		X	X	X	
Range of line power or battery voltage	X		X	X		
Extreme Conditions (5.8)						
Maximum (safe) input power (when inserted) (5.8.1)	X		X		X	X
Tolerance to environmental stresses (5.8.2)		X	X	X	X	X
Electromagnetic compatibility (5.8.3)		X	X	X	X	
RF power amplitude modulation restrictions (5.8.4)		X	X		X	X
Operation and Maintenance (5.9)	X		X	X	X	
Performance Characteristics (5.10)						
Standing wave ratio (SWR) (5.10.1)	X		X		X	
Complex reflection coefficient (5.10.2)		X	X		X	
Zero carry-over (5.10.3)	X		X	X		
Long-term stability (5.10.4)		X	X			
Short-term stability (5.10.5)	X		X	X		
Supply voltage variation effect (5.10.6)	X		X	X		
Ambient temperature variation effect (5.10.7)	X		X	X	X	
Resolution (5.10.8)	X		X	X		
Calibration factor (5.10.9)	X		X		X	
Effective efficiency (5.10.10)	X		X		X	
Effective efficiency variations (5.10.11)		X	X		X	
Mismatch uncertainty (5.10.12)		X	X		X	
Minimum measurable power (5.10.13)		X	X	X	X	X
Power indicator response time (5.10.14)	X		X	X		
Nominal rf impedance (5.10.15)	X		X		X	X
Element resistance (5.10.16)	X		X		X	X
Sensitivity (5.10.17)	X				X	X
Power sensitivity error (5.10.18)	X		X		X	X
Power capabilities (5.10.19)	X		X		X	X
Compatible Instrumentation (5.11)		X	X	X	X	X

Table 2
Classification

Electrothermic Elements	Electrothermic Mounts or Units	Power Indicators	Electrothermic Power Meter
Combined load—thermopile	Mounts with element output unmodified	Analog readout	Appropriate combinations of the three preceding categories
Separate load—thermopile	Mounts containing output amplifying means	Digital readout	
		Manual range switching	
		Automatic range switching	
		Programmable	
		Remote analog readout	
		Remote digital	
		Readout, specify language	
	Temperature-compensated mounts		
	Uncompensated mounts		