STANDARD PROCEDURE FOR TESTING INFRARED DETECTORS AND FOR DESCRIBING THEIR PERFORMANCE

PREPARED BY

DR. R. CLARK JONES
DR. DERYCK GOODWIN
DR. GEORGE PULLAN

12 SEPTEMBER 1960

261625

OFFICE OF THE DIRECTOR
OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON 25, D. C.

$5.60

STANDARD PROCEDURE FOR TESTING INFRARED DETECTORS AND FOR DESCRIBING THEIR PERFORMANCE

* * *

Prepared by

Dr. R. Clark Jones, USA
Dr. Deryck Goodwin, UK
Dr. George Pullan, Canada

Office of Director of Defense Research and Engineering
Washington 25, D. C.

12 September 1960

PREFACE

For some time there has been concern over the lack of homegeneity in the technical data reported on infrared detectors. To ensure that such data are obtained under the same conditions and reported in a universally acceptable manner, the development of a joint set of standards on infrared detector measurements was considered to be highly desirable.

A working panel composed of representatives from the United States, the United Kingdom, and Canada was therefore established to prepare a joint standard on infrared detector measurements. The panel was requested to propose specific tests for infrared detectors, standard test conditions, standard units of measurement, and a standard method of presenting the test results.

Members appointed to this working panel were:

For the United States

Chairman: Dr. R. Clark Jones
Polaroid Corporation
730 Main Street
Cambridge, Massachusetts, USA

For the United Kingdom

Dr. Deryck W. Goodwin
Royal Radar Establishment
Great Malvern, Worcestershire
England

For Canada

Dr. George T. Pullan
Canadian Armament Research and
Development Establishment
P. O. Box 1427
Quebec, P.Q., Canada

The working panel decided to exclude from the standard any consideration of the means for measuring and describing the nonlinear properties of detectors--the properties that describe the lack of proportionality of the electrical output to the radiation input. Also excluded from the standard is the specification of any particular modulation frequency or any particular black-body temperature.

With respect to a particular modulation frequency, the position adopted is that a knowledge of the way the responsivity and detectivity depend on frequency is an essential part of the description of the detector but that a statement of the performance for all detectors at the same modulation frequency is apt to be misleading.

With respect to a particular black-body temperature, the position adopted is that, important as black-body sources are in establishing the absolute calibration of the responsivity and the detectivity, the user desires information on the dependence of these quantities on the wavelength rather than on the black-body temperature. A plot similar to that in figure 3 of Appendix A, in which the abscissa were the black-body temperatures of the sources, would be a useful addition to the descriptive curves, but such a plot would not be an acceptable substitute for this figure 3. The position is that a statement of the performance for all detectors at the same black-body temperature is apt to be misleading.

The measurement of the absolute responsivity as a function of the wavelength and frequency involves the use of a blackbody whose absolute radiance must be known and of a thermal detector whose relative absorptance must be known as a function of the wavelength. The opinion of the members of the working panel is that the accuracy with which these properties can now be measured is not fully satisfactory. Further research is needed to establish reliable basic standards for measuring the absolute responsivity of detectors.

The working panel feels that since the field of infrared detectors is rapidly evolving, the methods recommended in this standard are unlikely to long remain the best procedures. The working panel recommends, therefore, that the task of revising this standard be begun 1 January 1963, the revision to be completed by 31 December 1963.

Anyone who may have suggestions for the 1963 revision should send them to the member who represents his country on the working panel.

CONTENTS

CONTENTS (continued)

1. INTRODUCTION

1.1 Purpose.

The purpose of this standard is to recommend the kind of tests to be made on infrared detectors and the manner of presenting the test results, with the following two major aims:

(1) The method of presentation shall be such that reports of any testing laboratory will be immediately intelligible to infrared workers in all three countries.

(2) The test results shall have maximum utility for the users of detectors. Tests primarily of interest to the manufacturers of radiation detectors are not considered herein.

1.2 Scope.

This standard is intended primarily to include all common types of visible and infrared detectors that provide a useful measure of the total radiation incident on the responsive area. Thus, devices such as image tubes and mosaic detectors are not specifically considered in this standard, although many of the parameters herein discussed can be used to describe the performance of such devices.

The intent of this standard is that enough measurements will be made and sufficient data will be presented to permit a user to estimate the performance of a detector in a particular application.

Since this standard is concerned only with detectors whose output is a continuous function of the radiant input, devices such as cooled multiplier phototubes that are operated for counting individual photons are excluded.

Also excluded is any consideration of (1) the nonlinear properties of radiation detectors--that is, the properties that describe the lack of proportionality of the electrical output to the radiation input--and (2) detectors whose output is not electrical.

2. DEFINITIONS

2.1 The Detector and Its Components.

2.1.1 Detector: The word "detector" is used in this standard to denote a device that provides an electric output that is a useful measure of the radiation incident on the device. It is intended to include not only the responsive element, but also the physical mounting of the responsive element, as well as any other elements --such as windows, area-limiting apertures, Dewar flasks, internal reflectors, etc.--that form an integral part of the detector as it is received from the manufacturer. If, as an integral part of the device, the manufacturer includes equipment for amplification or impedance transformation, then the term detector applies to the combination of the responsive element, the other elements listed in the foregoing sentence, and the amplifier or transformer.

2.1.2 Responsive Element: The term "responsive element" indicates that part of the detector which, when radiation falls on it, undergoes a change in physical properties that results in an electrical signal.

2.1.3 Individual Detector: An individual detector is a single sample of a given type of detector. An example is: indium antimonide cell No. 3483 manufactured by X Corporation.

2.1.4 Type of Detector: A type of detector is a class of individual detectors that have one or more relevant properties in common. Examples are: heat detectors, bolometers, thermistor bolometers, photoconductive cells, lead sulfide photoconductive cells, evaporated lead sulfide photoconductive cells with evaporated gold electrodes mounted in stainless steel capsules having silver chloride windows.

2.2 The Radiation Incident on the Detector.

This section is concerned primarily with the radiation, not with the detector.

The radiation incident on a detector is characterized by the distribution of the radiant power with respect to wavelength, modulation frequency, position on the responsive element, and the direction of arrival.

(1) The power that is instantaneously incident on the responsive element of a detector is denoted P and is measured in watts.

(2) The power per unit area incident on the responsive element of the detector is called the irradiance H and is measured in watts per square centimeter.

(3) In testing radiation detectors, one causes to be incident on the responsive plane of the detector a signal power P_s. When the radiation is uniformly incident on the responsive plane of the detector, the radiation can be described also in terms of the signal irradiance H_s. The signal power is usually modulated by a chopper.

(4) The ambient power P_a and the ambient irradiance H_a describe the steady radiation incident on the detector. Examples are: radiation emitted by the mounting and the windows and steady radiation arising outside of the detector. It is usually not feasible to make the ambient radiation zero.

(5) The signal power and the ambient power are completely described by stating the distribution of the incident power with respect to radiation wavelength λ, modulation frequency f, position coordinates x, y on the adopted responsive plane (see section 2.4) and angular coordinates θ, ϕ.

(a) The radiation wavelength λ is the value in vacuum and is measured in microns.

(b) The modulation frequency f is measured in cycles per second.

(c) The peak wavelength λ_p and the peak modulation frequency f_p are the values of λ and f that simultaneously maximize the detectivities D_1 and D^* (see section 2.11).

(6) The distribution of the radiant power with respect to radiation wavelength λ is described by stating the spectral power P_λ, defined as the power per unit wavelength interval. More precisely, if ΔP is the power in the wavelength interval $\Delta\lambda$, P_λ is the ratio $\Delta P/\Delta\lambda$ with $\Delta\lambda$ suitably small compared with λ. P_λ is measured in watts per micron.

(7) The power P normally incident on the detector is calculated by multiplying the irradiance H in the adopted responsive plane of the detector by the adopted area A_a.

$$P = A_a H \qquad (2.2\text{-}7)$$

(8) The distribution of the irradiance with respect to radiation wavelength λ is described by stating the spectral irradiance H_λ, defined as the irradiance per unit wavelength interval. More precisely, if ΔH is the irradiance in the wavelength interval $\Delta\lambda$, H_λ is the ratio $\Delta H/\Delta\lambda$, $\Delta\lambda$ being suitably small compared with λ. H_λ is measured in the unit: watt/cm^2-micron.

(9) In testing detectors, the radiation incident on the detector is usually modulated periodically in time. The usual way to achieve this modulation is to place a multibladed wheel between the radiation source and the detector and rotate the wheel at a constant angular velocity. The modulating device is called a chopper. The basic repetition frequency produced by the chopper is denoted f. The instantaneous power P(t) incident on the detector can be represented as the sum of Fourier components:

$$P(t) = P_0 + P_1 \cos(2\pi ft + \phi_1) + P_2 \cos(4\pi ft + \phi_2) + \ldots \qquad (2.2\text{-}9a)$$

where each component has an amplitude P_k and a phase ϕ_k. Each component represents a sinusoidally modulated radiation signal, and the components have the frequencies f, 2f, 3f, etc. The fundamental component is the sinusoidal component with the frequency f. The root-mean-square amplitude of the fundamental component is defined as the peak-to-peak amplitude of this component divided by $2^{3/2}$:

$$P_{rms} = 2^{-1/2} P_1 \qquad (2.2\text{-}9b)$$

(The peak-to-peak amplitude is $2P_1$.)

(10) In some special circumstances, expression of the input radiation in terms of the number of photons per second instead of in watts may be desirable. Responsivities and detectivities with photons per second as the measure of the input radiation may be useful as an alternative method of describing those detectors that have a responsivity (in volts per watt) that is proportional to the wavelength over a substantial range of wavelengths.

2.3 The Electrical Output of the Detector.

It is convenient to distinguish two additive components in the electrical output of the detector--the signal voltage V_s (or signal current I_s) and the noise voltage V_n (or the noise current I_n). Over a sufficiently long period of time, the two voltages (or currents) can be distinguished exactly by the criterion that the signal voltage is fully coherent with the signal power, whereas the noise voltage is completely incoherent with the signal power. The output can be described by giving the distribution of the voltage (or current) with respect to time or frequency.

In this section and in sections 2.8 and 3.6 the fundamental frequency f of the chopper must be distinguished from the frequency ν of any component in the output of the detector. In all other sections to distinguish between f and ν is unnecessary, however, and the symbol f is used for both types of frequency. The frequencies f and ν are both measured in cycles per second.

(1) The electrical signal voltage V_S (or current I_S) in the output of the detector is the part of the output that is coherent with the signal power incident on the detector.

(2) In the special case where the radiation power is periodic in time, the electrical signal output is also periodic in time. The instantaneous signal voltage V(t) can be represented as the sum of Fourier components:

$$V(t) = V_0 + V_1 \cos(2\pi ft + \theta_1) + V_2 \cos(4\pi ft + \theta_2) + \ldots \qquad (2.3\text{-}2a)$$

The root-mean-square amplitude of the fundamental component is defined as the peak-to-peak amplitude of this component divided by $2^{3/2}$:

$$V_{s,rms} = 2^{-1/2} V_1 \qquad (2.3\text{-}2b)$$

(The peak-to-peak amplitude is $2V_1$.)

(3) In addition to the signal voltage V_S appearing at the output of the detector, electrical noise also is always present. When there is no signal power, the only electrical output from the detector is the electrical noise.

(4) Unlike the electrical signal which has components only at frequencies ν equal to f, 2f, 3f, etc., the electrical noise has components at every frequency--that is to say, the spectrum of the electrical noise is continuous. The magnitude of the noise voltage as observed by a suitable voltmeter depends on the range of frequencies accepted by the voltmeter. To define the band of frequencies accepted by the voltmeter, we let $g(\nu)$ denote the gain of the voltmeter as a function of the frequency ν. Then, the noise bandwidth $\Delta\nu$ of the measuring equipment is defined by:

$$\Delta\nu = \int_0^\infty \left[g(\nu) \right]^2 d\nu / g_m{}^2 \qquad (2.3\text{-}4)$$

where g_m is the maximum value of the gain with respect to frequency ν. The frequency ν_m that maximizes $g(\nu)$ is called the center frequency of the passband.

(5) The root-mean-square voltage (or current) of the electrical noise is defined as the square root of the time average of the square of the difference between the instantaneous voltage (or current) and the time average voltage (or current).

$$V_{n,rms} = \left[\langle (V_n - \langle V_n \rangle_{Av})^2 \rangle_{Av} \right]^{\frac{1}{2}} \qquad (2.3\text{-}5a)$$

$$I_{n,rms} = \left[\langle (I_n - \langle I_n \rangle_{Av})^2 \rangle_{Av} \right]^{\frac{1}{2}}$$

The average values of V_n and I_n will nearly always be zero in practice, since the voltage or current will usually have passed through an amplifier whose dc gain is zero. When this condition holds, the above two equations reduce to

$$V_{n,\,rms} = \left[\langle (V_n)^2 \rangle_{Av}\right]^{\frac{1}{2}} \qquad (2.3\text{-}5b)$$

$$I_{n,\,rms} = \left[\langle (I_n)^2 \rangle_{Av}\right]^{\frac{1}{2}}$$

(6) The power spectrum $W(\nu)$ of the electrical noise is defined as the time average of the square of the difference between the instantaneous noise voltage (or current) and the time average voltage (or current), divided by the noise bandwidth $\Delta\nu$ of the measuring equipment.

$$W(\nu) = (V_{n,\,rms})^2/\Delta\nu$$
$$W(\nu) = (I_{n,\,rms})^2/\Delta\nu \qquad (2.3\text{-}6)$$

In this definition, it is supposed that the voltmeter has a bandwidth $\Delta\nu$ that is small compared with ν. $W(\nu)$ is measured in volt^2/cps or in ampere^2/cps.

(7) If the distribution of the noise voltage (or current) about the time average mean value is Gaussian and if the statistical properties are stationary in time, then the statistical properties of the noise are fully described by the power spectrum. But if the distribution is not Gaussian, further description is necessary for a complete characterization of the statistical properties of the noise.

(8) The root power spectrum $N(\nu)$ is the square root of the power spectrum $W(\nu)$. $N(\nu)$ is measured in volt/(cps)$^{\frac{1}{2}}$ or in ampere/(cps)$^{\frac{1}{2}}$.

(9). The term "voltmeter" as used in this section is equivalent to the combination of the low-noise amplifier, tunable filter, and voltmeter, as described separately in sections 3.5, 3.6, and 3.7.

2.4 Geometrical Properties of the Detector.

(1) The responsive properties of a detector are defined in terms of the radiation incident on a selected plane surface associated with the detector. The plane selected by the testing laboratory is called the adopted responsive plane, and is denoted S.

(2) Usually there is no ambiguity in selecting the responsive plane S. If the responsive element itself is in the form of a thin flat layer, as with evaporated photoconductive cells or metal bolometers, the adopted responsive plane is simply the plane in which the responsive element lies. But there are detectors where the responsive plane must be chosen otherwise. Examples: With doped germanium detectors in which the responsive element is more or less cubical and is located within a chamber with reflecting walls, the adopted reference plane S is the plane that contains the entrance aperture of the chamber. With photoemissive tubes with curved photocathodes, the adopted reference plane is the plane that contains the straight edges of the photocathode.

(3) With some detectors the selection of the adopted reference plane is more or less arbitrary. With a detector that incorporates a number of refracting elements, for example, the testing laboratory may find it convenient to refer the measurements to the plane that contains the rim of the most accessible optical element.

(4) Let a coordinate system x, y be established on the adopted responsive plane S.

(5) Let the direction of incidence of a pencil of radiation that is incident at the point x, y be defined by the two angles θ, φ of a spherical coordinate system, with the polar angle θ measured from the normal to the adopted responsive plane.

(6) Detector Area A. The several kinds of detector areas measured on the adopted reference plane need to be distinguished:

(a) The nominal area A_n is any value of the responsive area, quoted by a source other than the testing laboratory, that purports to represent an approximation of the actual responsive area of the detector. Thus, for example, the nominal area may be the manufacturer's design-center value for the area of an evaporated-film detector, or the nominal area may be an area quoted to one significant figure that is used as a label to distinguish between the given detector and other detectors of widely different area.

(b) The adopted area A_a is the area that is adopted by the test laboratory to convert the irradiance H on the detector to the power P incident on the detector:

$$P = A_a H \tag{2.4 -6b}$$

The test laboratory will often select either the nominal area or the effective area as the adopted area.

(c) The effective area A_e of a detector is defined by physical measurements, as follows: The position on the adopted responsive plane S of the detector is defined by a rectangular cartesian x, y coordinate system. The responsivity R(x, y) is measured with a very small spot of radiation at each point of the plane. The effective area A_e is defined by

$$A_e = \iint_S R(x, y)dxdy/R_{max} \tag{2.4 -6c}$$

where R_{max} is the maximum value of R(x, y).

(7) Detector solid angle. It is often desirable to know the solid angle from which the detector can receive radiation from outside the detector. This information is needed to calculate D^{**} for at least two situations of practical interest: cooled detectors equipped with cooled radiation shields and room temperature detectors whose responsive element is immersed in a lens of high index. Actually, the solid angle that one wishes to know for a flat detector element is the solid angle weighted at each angle by the cosine of the angle of incidence. This is called the weighted solid angle and is denoted by Ω. Several kinds of weighted solid angles need to be distinguished.

(a) The nominal weighted solid angle Ω_n of a detector may be a value used in the specification of the detector or it may be the value used to identify the detector.

(b) The adopted weighted solid angle Ω_a of a detector is the solid angle that is adopted by the test laboratory to calculate the value of D**.

(c) The effective weighted solid angle Ω_e of a detector is defined by physical measurements, as follows: The responsivity at the point x, y on the adopted responsive plane S of the detector for radiation coming from the direction θ, φ is denoted $R(x, y, \theta, \varphi)$. The angles θ and φ are the polar and azimuthal angles of a spherical coordinate system with the axis normal to the surface of the responsive plane. The effective weighted solid angle Ω_e of the detector in steradians is defined by:

$$\Omega_e = \iint_S dxdy \int_0^{\pi/2} \cos\theta \sin\theta \, d\theta \int_0^{2\pi} R(x, y, \theta, \varphi) d\varphi \Big/ \left[A_e R_{max}(0, 0) \right] \qquad (2.4\text{-}7c)$$

where $R_{max}(0, 0)$ is the maximum value of $R(x, y, 0, 0)$. It is, of course, scarcely contemplated that any laboratory will ever measure $R(x, y, \theta, \varphi)$ as a function of all four variables and then perform the quadruple integration. But the above expression for Ω_e does indicate (in a way that no words can) the exact conceptual meaning of the effective weighted solid angle.

(8) If the responsivity of a detector is independent of the angles θ and φ, the detector is called a Lambertian detector.

(9) With some detectors, it is considered to be an adequate approximation to suppose that the responsivity is independent of the azimuthal angle φ. Then, the detector is said to have circular symmetry.

(10) For detectors with circular symmetry, the total cone angle Θ may be used instead of the weighted solid angle Ω. The total cone angle Θ is defined in terms of Ω by:

$$\Omega = \pi \sin^2(\Theta/2) \qquad (2.4\text{-}10a)$$

The relation between the total cone angle and the ordinary unweighted solid angle ω is:

$$\omega = 2\pi \left[1 - \cos(\Theta/2) \right] \qquad (2.4\text{-}10b)$$

As the solid angle Ω in equation 2.4-10a is identified with the nominal, adopted, or effective weighted solid angle, the equation defines the nominal, adopted, or effective total cone angle, respectively.

(11) The weighted solid angle of a Lambertian detector is $\Omega = \pi$. The unweighted solid angle of a Lambertian detector is $\omega = 2\pi$.

2.5 The Detector as a Circuit Element.

Most detectors have two electrical terminals. When the radiation incident on the detector is steady, the detector may be considered a circuit element and can be described as a circuit element. It should be held in mind, however, that the properties of the detector as a circuit element will usually depend on the frequency and will sometimes depend on the amount of ambient power P_a and on the dc current I_0 through the detector.

(1) The impedance Z of the detector is defined by:

$$Z = \frac{dE}{dI} \qquad (2.5\text{-}1a)$$

where E is the instantaneous voltage across the terminals of the detector and I is the instantaneous current through the detector. The impedance Z is complex:

$$Z = \overline{R}_Z + iX_Z \qquad (2.5\text{-}1b)$$

(2) The value of $\overline{R}_Z$ at zero frequency is called the dc impedance and is denoted $\overline{R}_{Z0}$.

(3) The unqualified term resistance $\overline{R}$ is used to describe the ratio of the dc voltage to the dc current:

$$\overline{R} = E_0/I_0 \qquad (2.5\text{-}3)$$

(4) The impedance Z, both its real and imaginary parts, and the resistance $\overline{R}$ are measured in ohms.

(5) The impedance Z of some detectors may be conveniently represented by an equivalent circuit that is appropriate to the detector in question. Examples: As a capacitance C and dynamic resistance $\overline{R}_d$ in parallel for high impedance photoconductive cells; as an inductance L and dynamic resistance $\overline{R}_d$ in series for thermistor bolometers.

(6) When radiation detectors are tested the detector is connected to an amplifier and in some cases to bias sources. The load impedance Z_L is the impedance of the external circuit as seen from the terminals of the detector. Often, the impedance is almost purely resistive. In this case, the load impedance can be represented by the load resistance $\overline{R}_L$. Z_L and $\overline{R}_L$ are measured in ohms.

2.6 The Detector Temperature.

Detectors that operate without refrigeration have responsive elements that have a temperature equal to or slightly higher than the ambient temperature. The actual temperature of the responsive element is often nonuniform and is difficult to measure experimentally. The user of the detector normally has little interest in the actual temperature of the responsive element.

In this standard, the term detector temperature T indicates the ambient temperature if the detector is not refrigerated or the nominal temperature of the coolant if the detector is refrigerated.

The detector temperature T is measured in degrees Kelvin.

2.7 The Bias.

Most kinds of individual detectors have externally adjustable parameters that permit a variation of the responsivity (and of the detectivity). Examples of these adjustable parameters are the biasing current in bolometers and photoconductive cells, the applied potentials in multiplier phototubes and simple phototubes, the biasing voltage in back-biased junctions, the emitter current in phototransistors, the several adjustable parameters of the Golay detector, and the magnetic field in photoelectromagnetic detectors. Indeed, only the thermocouple is free of such adjustable parameters.

All of these parameters have the effect of varying the performance of the detector. The term "bias" will be used as a generic term to refer to any of these adjustable parameters. When the bias is the biasing current of a photoconductive cell, the recommended unit is the ampere and the recommended symbol is i.

(1) The optimum bias b_p is the bias that maximizes the detectivity when it is measured with radiation with a wavelength near λ_p and a chopping frequency near f_p.

(2) The maximum value of the bias b_m is the maximum value recommended by the manufacturer.

2.8 The Test Equipment: Radiation Sources and Voltmeters.

2.8.1 Radiation Sources: In measuring the responsivity of radiation detectors, it is customary to use three different kinds of modulated sources. All of the sources are equipped with choppers. One is a black-body source; the second is a monochromatic source; and the third is a variable frequency source.

(1) With the black-body source, the wavelength distribution from the black body is supposed to be known on an absolute basis and is described by the spectral irradiance $H_{\lambda, rms}$.

(2) The monochromatic source is characterized by the wavelength λ of its output.

(3) The variable frequency source is characterized by the fundamental frequency f of its output. The fundamental frequency of the chopped radiation is denoted by f, and the amplitude of the power (or irradiance) of the chopped radiation is measured by the root-mean-square amplitude of the Fourier component with the fundamental frequency.

2.8.2 Voltmeters: The term voltmeter as used in this section is equivalent to the combination of the low-noise amplifier, tunable filter, and voltmeter, as described in sections 3.5, 3.6, and 3.7.

The signal voltage (or current) in the output of the detector is measured with a voltmeter such that the gain $g(\nu)$ of the voltmeter has its maximum value when ν is equal to the chopping frequency f, and such that the gain $g(\nu)$ is negligible relative to g(f) when ν is equal to any of the harmonics of f--that is to say, when ν is equal to 2f, 3f, 4f, etc.

The voltmeter is to be such that it indicates the root-mean-square voltage of the component of frequency f.

(Note: Henceforth, in this standard except in section 3.6 it is unnecessary to distinguish between the chopping frequency f and the frequency ν of the electrical output of the detector. The symbol f will be used to denote both ν and f.)

2.9 The Responsivity.

The responsivity is here defined only for periodically modulated radiation. Furthermore, it is supposed that, as described in section 2.8, the electrical measuring equipment has its maximum gain at the chopping frequency of the radiation input and a negligible gain at the harmonic frequencies.

The responsivity of a detector is usually measured with an amplifier connected between the detector output terminals and the instrument that measures the voltage. If the output of the amplifier is (mistakenly) taken as the output of the detector, one obtains a responsivity R_{zg} that is increased by the gain g of the amplifier and is influenced by the finite load impedance Z_L.

(1) The responsivity in general is the ratio of the rms value of the fundamental component of the electrical output of the detector to the rms value of the fundamental component of the input radiation power when the power is incident normally on the adopted responsive plane. The responsivity is measured in volts per watt or in amperes per watt.

(2) The responsivity R_z is the responsivity referred to the terminals of the detector but influenced by the finite load impedance Z_L.

(3) The responsivity R is the responsivity referred to the terminals of the detector and referred to an infinite load impedance. R may be termed the open-circuit responsivity.

(4) The responsivities defined above may be called absolute responsivities to distinguish them from a relative responsivity. A relative responsiviiy is an absolute responsivity multiplied by a constant whose value may or may not be known.

(5) A simple, widely used procedure permits the measurement of R directly without first measuring R_{zg}. This procedure involves the injection of a calibrating voltage in series with the detector under test by the mechanism of a small resistance between the detector's ground terminal and ground. The details are given in sections 3 and 4.

(6) The responsivity R of an individual detector usually depends on all of the following parameters:

(a) The spectrum of the radiation (λ)
(b) The chopping frequency (f)
(c) The detector temperature (T)
(d) The bias (b)

(7) The responsivity $R_m(f)$ is the responsivity R at the peak wavelength λ_p. The responsivity R and detectivity D have their maxima with respect to wavelength at the same wavelength λ_p.

(8) The responsivity $R_\mu(\lambda)$ is the responsivity R at the peak modulation frequency f_p, which is defined as the frequency that maximizes the detectivity D_1 with respect to the modulation frequency f. The use of the subscript μ instead of m is intended to emphasize that $R_\mu(\lambda)$ is not the maximum value of R with respect to the modulation frequency f.

(9) The responsivity $R_{m\mu}$ is the value of the responsivity R at the peak wavelength λ_p and the peak modulation frequency f_p. R has its maximum at the same wavelength λ_p as does D_1, but unless the root power spectrum of the noise is flat, the responsivity R and the detectivity D_1 do not have their maxima at the same modulation frequency.

2.10 The Detector Noise.

The electrical noise in the output of a detector is usually measured with an amplifier connected between the detector output terminals and the instrument that measures the noise. If the output of the amplifier is (mistakenly) taken as the output of the detector, the measurement yields a root power spectrum N_{zng} that is influenced by the gain g and the noise n of the amplifier and by the finite load impedance Z_L.

(1) The root power spectrum N_{zn} is the root power spectrum referred to the terminals of the detector but not corrected for the noise of the amplifier and not referred to an infinite load impedance.

(2) The root power spectrum N_n is the root power spectrum referred to the terminals of the detector and referred to an infinite load impedance but not corrected for the noise of the amplifier.

(3) The root power spectrum N_z is the root power spectrum referred to the terminals of the detector and corrected for amplifier noise but not referred to infinite load impedance.

(4) The root power spectrum N is the root power spectrum referred to the terminals of the detector, referred to an infinite load impedance, and corrected for amplifier noise.

(5) A simple and widely used procedure permits the measurement of N_n directly without first measuring N_{zng}. This procedure involves the injection of a calibrating voltage in series with the detector under test, by the mechanism of a small, known resistance connected between the detector's ground terminal and ground. The details are given below in sections 3 and 4.

(6) The root power spectrum N of an individual detector usually depends on all of the following parameters:

(a) The frequency (f)
(b) The detector temperature (T)

(c) The ambient power (P_a)
(d) The spectrum of the ambient power (λ)
(e) The bias (b)

2.11 The Detectivity.

The detectivity of a detector can be defined in any of three equivalent ways: as the reciprocal of the noise equivalent input, as the signal-to-noise ratio divided by the incident power, or as the responsivity divided by the noise. The last definition is used in this standard.

(1) The detectivity D is defined, in general, as the ratio of the responsivity to the rms noise:

$$D = \frac{R}{V_{n,\,rms}} \qquad (2.11\text{ -1a})$$

where R is in volts/watt, or

$$D = \frac{R}{I_{n,\,rms}} \qquad (2.11\text{ -1b})$$

where R is in amperes/watt. This ratio does not depend on whether the right-hand quantities are measured at the output of the amplifier or at the detector terminals, nor does it depend on whether the quantities are referred to a finite or infinite load resistance. But the value obtained for D does depend on whether the rms noise is corrected for the noise of the amplifier. If uncorrected, the detectivity is denoted D_n, and if corrected, D. D is measured in reciprocal watts.

(2) The detectivity D_1 is called the detectivity for unit bandwidth of noise and is corrected for the noise of the amplifier. The corresponding quantity not corrected for the noise of the amplifier is written D_{1n}. One has:

$$D_{1n} = \frac{R_{zg}}{N_{zng}} = \frac{R_z}{N_{zn}} = \frac{R}{N_n} = (\Delta f)^{\frac{1}{2}} D_n \qquad (2.11\text{ -2a})$$

and

$$D_1 = \frac{R_{zg}}{N_{zg}} = \frac{R_z}{N_z} = \frac{R}{N} = (\Delta f)^{\frac{1}{2}} D \qquad (2.11\text{ -2b})$$

where Δf is the noise bandwidth defined by equation 2.3 -4. D_1 is measured in the unit: $(\text{cps})^{\frac{1}{2}}$/watt. (The bandwidth $\Delta\nu$ of section 2.3 is identical with Δf in this section.)

(3) The detectivity D*, pronounced "D star," is the detectivity D_1 reduced to unit area by the root-area relation

$$D^* = A_a^{\frac{1}{2}} D_1 = (A_a \Delta f)^{\frac{1}{2}} D \qquad (2.11\text{ -3})$$

D* is measured in the unit: cm-$(\text{cps})^{\frac{1}{2}}$/watt.

(4) The detectivity D**, pronounced "D double star," is the detectivity D_1 reduced to unit area and to a weighted solid angle of π steradians.

$$D^{**} = (A_a \Omega_a / \pi)^{\frac{1}{2}} D_1 \qquad (2.11\text{ -4})$$

D** is measured in the unit: cm-$(\text{cps})^{\frac{1}{2}}$/watt.

(5) The detectivities D, D_1, D*, and D** of an individual detector usually depend on all of the following parameters:

(a) The spectrum of the radiation (λ)
(b) The chopping frequency (f)
(c) The detector temperature (T)
(d) The ambient power (P_a)
(e) The spectrum of the ambient power (λ)
(f) The bias (b)

The detectivity D depends also on the noise bandwidth Δf used in the measurement.

(6) The detectivities D, D_1, D*, and D**, as well as the corresponding quantities not corrected for the noise of the amplifier, all differ by factors that depend neither on the wavelength λ nor on the modulation frequency f. Therefore, the wavelength and frequency that maximize one of these detectivities maximize all of the others. The peak wavelength λ_p and the peak modulation frequency f_p are the values of λ and f that simultaneously maximize the detectivity. The values of the detectivities at the peak wavelength λ_p and at the peak modulation frequency f_p are denoted by D_{mm}, D_{1mm}, D^*_{mm}, D^{**}_{mm}.

(7) The detectivities measured at the peak modulation frequency f_p are denoted by $D_m(\lambda)$, $D_{1m}(\lambda)$, $D^*_m(\lambda)$, $D^{**}_m(\lambda)$.

(8) The detectivities measured at the peak wavelength λ_p are denoted by $D_m(f)$, $D_{1m}(f)$, $D^*_m(f)$, $D^{**}_m(f)$.

(9) The reciprocal of each of the detectivities is a noise equivalent power. For example, the noise equivalent power P_N may be defined as the reciprocal of D:

$$P_N = 1/D \qquad (2.11\text{-}9)$$

2.12 Energy Detectivity.

(1) The concepts of responsivity and detectivity defined in the preceding sections have been formulated in terms of a periodically modulated radiation signal. In this section, the radiation signal is supposed to be in the form of a pulse. E denotes the total energy of the pulse and is measured in joules.

(2) The detector is supposed to be connected to a noiseless amplifier with the gain g(f). At the output of the amplifier, the total rms noise voltage is denoted V_n. The maximum voltage of the electrical signal pulse with respect to time is denoted V_{sp}. The energy detectivity is defined by:

[illegible] $= \frac{V_{sp}}{EV_n}$ (2.12-2)

The energy detectivity [illegible] is measured in reciprocal joules.

(3) The energy detectivity [illegible] is the reciprocal of the noise equivalent energy E_N, which is defined as the value of the pulse energy E that makes the signal-to-noise ratio V_{sp}/V_n equal to unity.

(4) The value of the energy detectivity Δ depends on the shape of the radiation pulse and on the amplifier gain function g(f). It can be shown that the maximum possible value of Δ is achieved if the following three conditions are satisfied:.

(a) The pulse is very short--specifically, the duration of the pulse is very small compared with the detective time constant τ_d.

(b) The gain g(f) is of the form:

$$g(f) = \text{constant } R/N^2 \tag{2.12 -4b}$$

(c) The sum of the phase shift in the detector and the phase shift of the amplifier is directly proportional to the frequency.

When these three conditions are satisfied, the energy detectivity is given by

$$\Delta_m(\lambda) = 2\left[\int_0^\infty [D_1(\lambda, f)]^2 df\right]^{\frac{1}{2}} = D_{1m}(\lambda)/\tau_d^{\frac{1}{2}} \tag{2.12 -4c}$$

$\Delta_m(\lambda)$ is measured in reciprocal joules.

(5) The energy detectivity Δ^*, pronounced "delta star," is the energy detectivity Δ reduced to unit area by the root area relation:

$$\Delta^* = \frac{A^{\frac{1}{2}} V_{sp}}{V_n E} \tag{2.12 -5}$$

Δ^* is measured in cm/joule.

(6) The energy detectivity $\Delta^*_m(\lambda)$ is the energy detectivity $\Delta_m(\lambda)$ reduced to unit area by the root area relation

$$\Delta^*_m(\lambda) = 2\left[\int_0^\infty [D^*(\lambda, f)]^2 df\right]^{\frac{1}{2}} = D^*_m(\lambda)/\tau_d^{\frac{1}{2}} \tag{2.12 -6}$$

(7) The energy detectivity Δ^*_{mm} is the energy detectivity $\Delta^*_m(\lambda)$ measured at the peak wavelength λ_p.

2.13 The Time Constant.

If the complex responsivity depends on the frequency in accordance with the relation:

$$R(f) = R_0/(1 + 2\pi i f \tau) \tag{2.13}$$

then there is general agreement that the (responsive) time constant is equal to τ. Other than in this paragraph, all of the responsivities dealt with in this standard represent the modulus of the complex responsivity rather than complex responsivity per se.

When the responsivity does not depend on the frequency in accordance with the above relation, controversy sets in. Some persons believe that no effort should be made to define a time constant. Others assert that some particular definition should be used. Among the definitions that have been proposed are the following:

(a) The reciprocal of the angular frequency at which the responsivity is 0.707 times the zero frequency responsivity.

(b) The reciprocal of the angular frequency where the low- and high-frequency asymptotes intersect (in a plot of log R versus log f).

(c) The reciprocal of the angular frequency where the slope of the log R versus log f curve is minus one-half (minus 3 decibels per octave).

(d) The reciprocal of the angular frequency where the phase lag is 45 degrees.

(e) Any of the times required for approach to a steady state after a transient radiation signal.

All of these time constants are equal when the above equation holds; otherwise all of them may differ.

All of the time constants represent an effort to measure the speed of response of the detector or, in different words, to measure the bandwidth of the detector. Accordingly, the writers of this standard have elected to define the time constant in terms of the bandwidth.

The time constants defined in (3) and (4) below involve measurements made over the entire frequency range of the detector. To determine whether a detector satisfies a specification, such measurements are not always desirable. Accordingly, (5) and (6) provide a pair of alternative definitions for use only in specifications. These two alternative definitions are based on measurements made at two pre-assigned frequencies.

Chopping frequencies up to about 50,000 cps are considered to be practical for achievement in a small testing laboratory. Time constants greater than about 5×10^{-6} second can be measured on the basis of the definitions given in (3) and (4) below. Time constants shorter than about 5×10^{-6} second are not easy to measure. The only simple method to measure time constants much shorter than 5×10^{-6} second is to observe the response to a square pulse of radiation. The pulse time constant in (7) is based on this approach.

Because of the distributed and shunt capacity of the detector itself, all of the time constants defined in this section will depend to a greater or lesser extent on the value of the load resistor R_L. Although the method of measurement recommended in section 4.1 completely eliminates the effect of the shunt capacity of the input of the preamplifier, it does not eliminate the effect of the shunt capacity of the detector itself.

(1) The responsive bandwidth $(\Delta f)_r$ is defined by:

$$(\Delta f)_r = \int_0^\infty [R(f)]^2 df / [R_{max}]^2 \qquad (2.13\text{ -}1)$$

where $R(f)$ is the responsivity and R_{max} is the maximum value of R with respect to frequency. Note that R_{max} is not identical with $R_\mu(\lambda)$.

(2) The detective bandwidth $(\Delta f)_d$ is defined by:

$$(\Delta f)_d = \int_0^\infty [D^*(\lambda, f)]^2 df / [D^*_m(\lambda)]^2 \qquad (2.13\text{-}2)$$

Both bandwidths are measured in cycles per second.

(3) The responsive time constant τ_r is defined by

$$\tau_r = 1/(4(\Delta f)_r) \qquad (2.13\text{-}3)$$

(4) The detective time constant τ_d is defined by:

$$\tau_d = 1/(4(\Delta f)_d) \qquad (2.13\text{-}4)$$

(5) The specification-type responsive time constant τ_{rs} is defined by:

$$\tau_{rs} = \frac{1}{2\pi}\left[\frac{[R(f_1)]^2 - [R(f_2)]^2}{[f_2R(f_2)]^2 - [f_1R(f_1)]^2}\right]^{\frac{1}{2}} \qquad (2.13\text{-}5a)$$

where f_1 and f_2 are frequencies that must be included in the specification. (For some specifications it may be convenient to define f_1 and f_2 by:

$$f_1 = \frac{1}{20\tau'_{rs}} \qquad f_2 = \frac{1}{2\tau'_{rs}} \qquad (2.13\text{-}5b)$$

where τ'_{rs} is a specified design-center responsive time constant.)

(6) The specification-type detective time constant τ_{ds} is defined by:

$$\tau_{ds} = \frac{1}{2\pi}\left[\frac{[D^*(f_1)]^2 - [D^*(f_2)]^2}{[f_2D^*(f_2)]^2 - [f_1D^*(f_1)]^2}\right]^{\frac{1}{2}} \qquad (2.13\text{-}6a)$$

where f_1 and f_2 are frequencies that must be included in the specification. (For some specifications it may be convenient to define f_1 and f_2 by:

$$f_1 = \frac{1}{20\tau'_{ds}} \qquad f_2 = \frac{1}{2\tau'_{ds}} \qquad (2.13\text{-}6b)$$

where τ'_{ds} is a specified design-center detective time constant.)

(7) The pulse time constant τ_p is measured by exposing the detector to a rectangular pulse of radiation. Because the pulse time constant is a type of responsive time constant, the result depends on the gain-versus-frequency curve of the amplifier used and on the magnitude of the resistance that is in shunt with the detector. The gain should be flat up to frequencies that are large compared with $2\pi/\tau_p$. The result usually depends markedly on the value of the shunt resistance. When the shunt resistance is made so small that the RC time constant is small compared with the value measured, the pulse time constant is called the intrinsic time constant.

The rise and fall times of the radiation pulse must be short compared with the pulse time constant being measured. The rise time constant is equal to the time required for the signal voltage (or current) to rise to 0.63 times its asymptotic value. The fall time constant is equal to the time required for the signal voltage to fall to 0.37 of the asymptotic value. If the detector and amplifier are linear, the rise and fall time constants are equal and are called the pulse time constant τ_p. If the rise and fall times are unequal, the detector-amplifier system is nonlinear and the system lies outside the scope of this standard.

2.14 The Two Classes of Detectors.

The various types of radiation detectors tend to fall into one or the other of two mutually exclusive classes according to the way that the energy detectivity $D^*_m(\lambda)$ of the given detector can be traded for detective bandwidth.

(1) In Class I detectors the detectivity $D^*_m(\lambda)$ is independent of the detective time constant τ_d. Examples of Class I detectors are (a) those whose detectivity is limited by radiation noise or generation recombination noise and (b) all photoemissive detectors.

(2) In Class II detectors, the energy detectivity $\Lambda^*_m(\lambda)$ is independent of the detective time constant τ_d. Examples of Class II detectors are thermocouples, bolometers, and some kinds of photoconductive cells that have a detectivity limited by 1/f noise.

2.15 The Detective Quantum Efficiency.

(1) If nearly monochromatic radiation from an unmodulated thermal source is incident on a detector, the mean square fluctuation in the power is given by:

$$\langle(\Delta P)^2\rangle_{Av} = 2EP_a \text{[illegible]} \Delta f \qquad (2.15\text{-}1)$$

where [illegible] is the Bose-Einstein coherence factor that may be taken equal to unity for all practical purposes. (The formal condition for [illegible] to be close to unity is that the product of the wavelength and the temperature of the source be less than about 5000 micron-degrees.) E is the energy of a photon of the wavelength in question, P_a is the ambient power, and Δf is the noise bandwidth.

(2) If there is no other radiation incident on the detector <u>and</u> if the power emitted by the detector is negligible compared with P_a <u>and</u> if there is no other source of noise in the detector, then the detectivity D is the reciprocal of $\langle(\Delta P)^2\rangle_{Av}^{\frac{1}{2}}$:

$$D = 1/(2EP_a\Delta f)^{\frac{1}{2}} \qquad (2.15\text{-}2a)$$

and the detectivity D_1 is given by:

$$D_1 = 1/(2EP_a)^{\frac{1}{2}} \qquad (2.15\text{-}2b)$$

In the presence of the given ambient radiation, the expressions 2.15-2a and 2.15-2b indicate the maximum possible detectivity. No actual detector can have a higher detectivity, and all detectors in practice have a lower detectivity.

(3) The detective quantum efficiency is defined in general by:

$$Q_D = \left[\frac{\text{Measured detectivity } D_1}{\text{Maximum possible detectivity } D_1}\right]^2 \qquad (2.15\text{-}3)$$

(4) In the special case of sections (1) and (2), where the incident unmodulated radiation is nearly monochromatic, the detective quantum efficiency is given by:

$$Q_D = 2EP_a\,(\text{Measured } D_1)^2 \qquad (2.15\text{-}4)$$

(5) When the incident radiation is not nearly monochromatic, the calculation of the maximum possible detectivity becomes more complex--the result depending both on the way the detectivity depends on the wavelength and on the spectrum of the incident power. For the very special case in which the incident radiation has the spectrum of a black body with temperature T_{bb}, and in which the detector has equal detectivity for all wavelengths, one has:

$$Q_D = 8kT_{bb}P_a(\text{Measured } D_1)^2 \qquad (2.15\text{-}5)$$

where k is the Boltzmann constant.

(6) The detective quantum efficiency $Q_{Dm}(\lambda)$ is the detective quantum efficiency Q_D measured at the peak modulation frequency f_p.

(7) The detective quantum efficiency $Q_{Dm}(f)$ is the detective quantum efficiency Q_D measured at the peak wavelength λ_p.

(8) The detective quantum efficiency Q_{Dmm} is the detective quantum efficiency Q_D measured at the peak modulation frequency f_p and at the peak wavelength λ_p.

2.16 The Factorability Property.

The factorability property permits the responsivity of a detector, considered as a function of the wavelength and of the modulation frequency, to be represented as the product of two factors, one of which depends only on the wavelength and the other of which depends only on the frequency:

$$R(\lambda, f) = \text{constant } L(\lambda)F(f) \qquad (2.16)$$

The factorability property is nearly always assumed (often without comment) in the description of the performance of radiation detectors.

(1) For a detector that has this property, a very important simplification is possible in the measurement and definition of the responsivity. It permits the detector's responsivity to be completely determined by measurement of the responsivity as a function of wavelength at a single frequency and by measurement of responsivity as a function of the frequency at a single wavelength.

(2) Many important detectors have the factorability property, but there is an important class of photoconductive detectors whose responsivity is not at all factorable.

(3) Every detector has a responsivity that is factorable if the radiation is confined within one, two, or more wavelength bands. With some doped germanium detectors, for example, the responsivity is factorable if all of the radiation is shorter than about 1.6 microns or if all of it is longer than about 2.0 microns. The wavelength bands are called factorability bands. With most detectors, the user will usually be interested in the factorability band comprising the longest wavelengths. For most purposes, it is sufficient to measure within this one band.

(4) A radiation filter that is opaque to radiation not within a factorability band is called a factorability filter.

3. STANDARD TEST EQUIPMENT

The test laboratory shall use equipment that conforms with the requirements of this section or alternative equipment that is capable of equivalent precision of measurement for the detectors under test.

3.1 Calibrated Signal Generator.

The calibrated signal generator shall produce at its output terminals a sine wave voltage of accurately known rms amplitude with a frequency adjustable over the range over which the responsivity is to be measured. In a comprehensive test laboratory, this range will be from about 1 cps to about 100,000 cps. The output voltage should be approximately 1 volt rms.

3.2 Calibrated Attenuator.

The calibrated attenuator receives the signal from the signal generator and reduces the amplitude by a known amount.

3.3 The Detector Circuit.

The detector circuit is the circuit in which the detector is placed. This circuit includes the detector, the detector's load resistor, and means of coupling the detector to the amplifier. The circuit also includes a resistor $\overline{R}_{cal}$ to inject the signal from the signal generator and means of connection to the bias sources, if any. The resistance $\overline{R}_{cal}$ should be very small compared with Z ; a 1-ohm resistor is often used. Figure A of Appendix A shows a detector circuit for the special case in which the detector is a photoconductive detector or a bolometer. The resistor $\overline{R}_A$ has a resistance equal to the characteristic impedance of the attenuator.

3.4 Bias Supplies.

The bias supplies produce the biasing voltages or currents that the detector requires for its operation. The internal impedance of each voltage supply shall be negligible compared with its load impedance.

3.5 Low-Noise Amplifier.

The low-noise amplifier amplifies the signal received from the detector circuit to a level where it may be filtered and measured without appreciable introduction of additional noise. The low-noise amplifier shall have stable gain and, preferably, uniform gain over the range over which the responsivity is to be measured.

3.6 Tunable Filter.

The tunable filter shall have a center frequency ν_m that can be varied over the range over which the responsivity is to be measured. The tunable filter shall have stable gain, and the maximum gain g_m shall preferably be independent of the tuning of the filter and shall not vary irregularly as the center frequency is varied. When used in connection with the measurement of the responsivity, the tunable filter shall have a gain $g(\nu)$ that is negligible compared to $g(f)$ when ν is equal to any of the harmonics of f (see 3.8.2). When used in connection with measuring the power spectrum of the detector noise, the tunable filter shall have a bandwidth $\Delta\nu$ that is not greater than the larger of 5 cps and $0.232\ \nu_m$. (The condition $\Delta\nu = 0.232\ \nu_m$ corresponds to a one-third octave filter.)

3.7 Multirange Voltmeter.

The multirange voltmeter measures the signal voltages and the noise voltages. The calibration of the voltmeter shall be known over the range over which the responsivity and noise are to be measured. This voltmeter preferably will be of the type that reads the true root-mean-square amplitude of an arbitrary waveform. (If the voltmeter is of the common type that is calibrated to read the rms amplitude of a sine wave but that actually measures the time average of the absolute value of the difference between the instantaneous voltage and the time average voltage, the meter will read low by the factor $2^{3/2}/\pi = 0.9003$ on a noise with a Gaussian distribution of amplitudes.)

The noise bandwidth Δf (defined by equation 2.3 -4) of the combination of low-noise amplifier, tunable filter, and voltmeter shall be known as a function of the frequency setting of the tunable filter. If the low-noise amplifier and the voltmeter have gains that are independent of frequency, the over-all noise bandwidth is the same as the noise bandwidth of the tunable filter.

3.8 Radiation Sources.

The test laboratory shall use the following three radiation sources.

3.8.1 Black-Body Source: The black-body source shall be chopped and stable in temperature. The chopper may be for a single fixed frequency f_c. The black-body source shall produce an accurately known spectral irradiance in the adopted reference plane of the detector, and the irradiance shall be uniform over the area of the detector. The measure of the spectral irradiance that shall be known is the rms amplitude of the fundamental component of the spectral irradiance. This amplitude is denoted $H_{\lambda,\text{rms}}$. In the process of determining $H_{\lambda,\text{rms}}$, the radiation from the chopper must be taken into account. Furthermore, if radiation filters are used to eliminate radiation outside of a chosen factorability band, the absorptance and emittance of the filter must be taken into account. The result of correcting for the chopper radiation (and for a filter, if used) is a spectral irradiance that does not match exactly the spectral irradiance of any black body.

The total irradiance H_{rms} is given by:

$$H_{rms} = \int_0^{\infty} H_{\lambda,rms}\, d\lambda \qquad (3.8.1)$$

The means used to secure an accurate calibration of the black-body source lie outside the scope of this standard which requires only that the best available physical procedures be used.

3.8.2 Monochromatic Source: The monochromatic source shall consist of a stable source of radiation and a monochromator (preferably double-pass) with a chopper placed between the source and the monochromater. The source shall be capable of providing a wavelength band of radiation that is not wider than one-thirtieth of the center wavelength. The chopper may be for a single fixed frequency which shall be the same as the frequency f_c of the black-body source. When feasible, the irradiance produced by the monochromatic source shall be uniform over the responsive surface of the detector.

3.8.3 Variable-Frequency Source: The variable-frequency source shall consist of a stable source of radiation and a variable-frequency chopper. In most cases, the source of radiation will be a black-body source equipped, when necessary, with a factorability filter. Several sources may be used to cover the entire frequency range of interest; but, if several are used, their frequency ranges must overlap. The irradiance produced by the variable-frequency source shall be uniform over the responsive surface of the detector. The frequency of the variable-frequency source need not be continuously adjustable; a series of fixed frequencies may be used.

3.9 Thermal Detector.

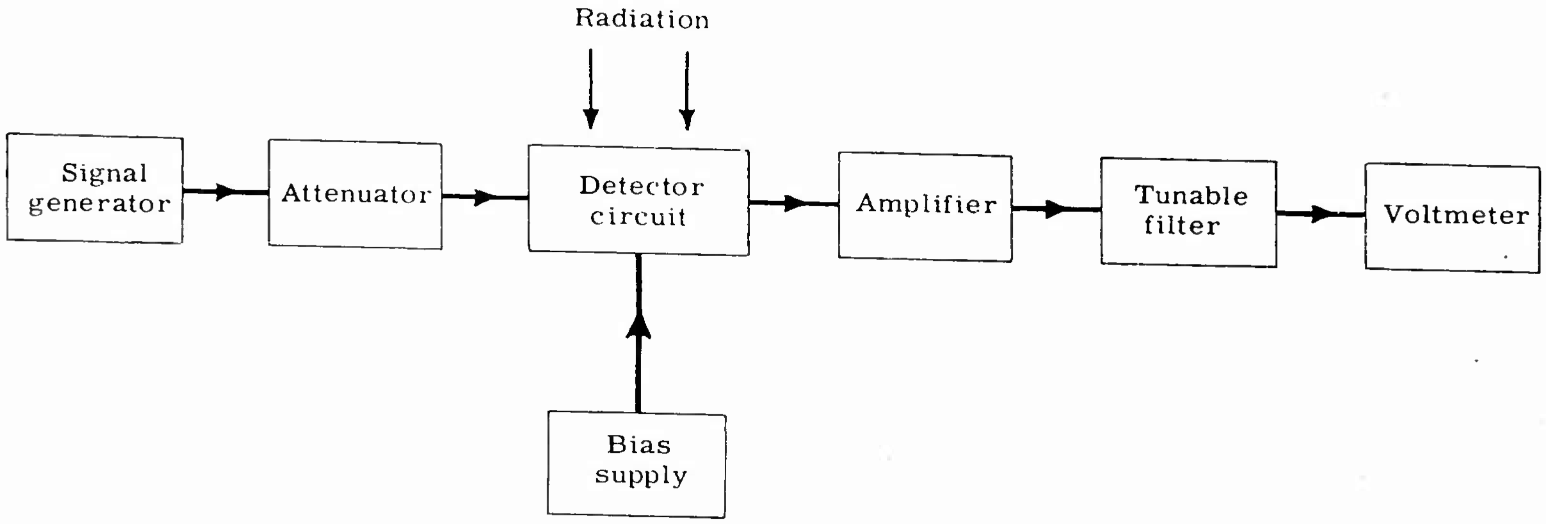
The test laboratory shall use a thermal detector for calibration.

The variation with wavelength of the responsivity of the thermal detector shall be known as accurately as possible. Although the method of calibrating such a detector is beyond the scope of this standard, the following suggestions may be of some value.

It is suggested that one standard laboratory in each country establish a reference thermal detector. Each test laboratory can then calibrate its own thermal detector against the reference detector. A possible method of obtaining a reference detector is by a process of elimination among several detectors of a type known to have an emissivity approximately independent of wavelength. This exercise can be coupled with the calibration of a black-body source. The variation with temperature of the spectral radiance of a black-body source is calculable, and the variation of the total radiance with temperature and wavelength provides possibilities for comparison of the absorptance-versus-wavelength function of several thermal detectors.

3.10 Equipment for Measuring Impedance and Other Circuit Elements.

The test laboratory shall have the usual equipment needed to measure the impedance of the detector and other circuit elements. It shall also have the equipment required to keep the other equipment in calibration. In particular, the test laboratory shall have equipment to calibrate the output of the signal generator.



The Detector Circuit: Electrical Equipment Connections

3.11 Equipment for Measuring Responsivity Contours.

The test laboratory shall have means for irradiating a very small spot on the surface of the detector. This device shall consist of a source, a chopper, and a microscope equipped with a mechanical stage and shall have provision for inserting factorability filters. Reflection-type objectives shall be used.

3.12 Equipment for Measuring Pulse Time Constants.

If pulse time constants are to be measured, the test laboratory shall have appropriate equipment, including a wide-band amplifier and oscilloscope.

4. STANDARD TEST PROCEDURES

This section recommends a straight-forward set of test procedures that summarises the most advanced methods of the current state of the art according to the representatives of a number of test laboratories. Other test procedures than those recommended here may be employed; but, if departures are made from the recommended procedures, the test laboratory making the departures must assume the burden of establishing, by actual test, that the modified procedures give results of equivalent accuracy. Furthermore, if procedures are employed that differ from those described herein, the departures shall be described in the standard report or in the explanation that accompanies the standard report (see section 5).

The test procedures may be divided into two independent groups. In the first group are the measurements that yield the responsivity, and in the second group are the measurements that yield the root power spectrum of the noise. From these results the detectivity is calculated.

For both groups of measurements, the electrical equipment shall be connected as shown in the diagram on the opposite page. This diagram shows the arrangement for the special case where the detector requires a single bias voltage.

4.1 The Responsivity.

The determination of the responsivity involves three separate series of measurements with radiation sources and one numerical integration.

In all of the measurements described in section 4.1, the signal radiation shall be normally incident on the detector; specifically, the signal radiation shall all have a direction of propagation within 10 degrees of the normal to the adopted responsive plane of the detector.

In all of the measurements described in section 4.1 the amount of signal radiation shall be confined to the range in which the output signal (V_S or I_S) is proportional to the incident power P_S. Confirmation of this linearity shall be obtained with each detector.

(1) The measurement of the responsivity involves the use of the factorability property. For those detectors where this property does not hold for the entire

range of wavelengths that may be of interest, the black-body source and the variable-frequency source shall both be equipped with a factorability filter that confines the radiation to one of the bands of wavelengths within which the factorability property holds.

(2) The first step is to establish approximate values of the peak wavelength λ_p, the peak modulation frequency f_p, and the optimum bias b_p (or biases, if there are more than one). Experience with similar detectors will usually indicate a first approximation for λ_p and f_p. The determination of λ_p is easier than of the others since no noise measurements need be made. Then, with the variable-frequency source, equipped with a factorability filter if needed, the modulation frequency and the bias are adjusted independently until the values are found that simultaneously maximize the detectivity D_1. Thus, one finds λ_p, f_p, and b_p. The detailed procedures to be used in this step are identical with those described in the sections 4.1 through 4.3. It may be that the optimum bias b_p will exceed the manufacturer's maximum recommended bias for continuous operation. In such event, the maximum recommended bias shall be used instead of b_p. The actual value of f_p may be greater than the highest frequency f_h available with the variable-frequency chopper. In such event, the results shall be given for the frequency f_h instead of f_p, and the peak wavelength λ_p and peak bias b_p will then be redefined as the wavelength and bias that maximize $D^*(\lambda, f_h)$.

(3) With the bias set at b_p and the tunable filter set at f_c, the black-body source, equipped with a factorability filter if needed, is used to irradiate the detector, with the signal generator set at zero output. The reading E of the multirange voltmeter is noted. Then the irradiation is removed, the signal generator is set to the frequency f_c, and the attenuator is adjusted to the value that gives the same reading E on the multirange voltmeter. The open-circuit-detector signal voltage $V_{s,rms}$ is the voltage across the calibrating resistor $\overline{R}_{cal}$.

(4) The power P_{rms} incident on the adopted responsive area of the detector is obtained from the known irradiance H_{rms} upon multiplication by the adopted area A_a:

$$P_{rms} = A_a H_{rms} \tag{4.1-4a}$$

The corresponding responsivity is given by:

$$R_{ss} = \frac{V_{s,rms}}{P_{rms}} \tag{4.1-4b}$$

where the subscript ss is used (instead of the more obvious bb) to emphasize that the spectrum of the radiation produced by the black-body source is not necessarily a a black-body spectrum.

(5) With the bias set at b_p and the tunable filter set at f_c, the detector is irradiated by the monochromatic source. The center wavelength of the monochromator is then varied over the wavelength range of interest, and the relative signal voltage $E_{s,rms}$ indicated by the multirange voltmeter is recorded as a function of wavelength. The detector under test is then replaced by the thermal detector, and the relative signal voltage $E_{s,rms,th}$ is recorded as a function of the wavelength.

(6) The relative responsivity is then calculated by:

$$L(\lambda) = \frac{E_{s,\,rms}\,\epsilon(\lambda)}{E_{s,\,rms,\,th}} \qquad (4.1\text{-}6)$$

as a function of the wavelength, where $\epsilon(\lambda)$ is the relative responsivity of the thermal detector if it is known to differ from a constant.

(The determination of the ratio of voltages in the last equation is tedious if it is done manually for each wavelength. Several methods have been used to record $L(\lambda)$ directly. One of these methods uses a modification of a commercial double-beam infrared spectrometer. In this modification, the radiation falls alternately on the two detectors, with a frequency of alternation equal to f_c. The two output voltages are then compared and actuate a servo system that moves a nonselective attenuator--a comb, for example--in the path of the radiation to the thermal detector, so that the two output voltages have a constant ratio. The chart of the spectrometer then records $L(\lambda)$ directly.)

(7) With the bias set at b_p, the variable-frequency source, equipped with a factorability filter if needed, is used to irradiate the detector. As the frequency of the source is varied, the center frequency of the tunable filter is continuously adjusted to the chopping frequency. The signal voltage $E_{s,\,rms}$ read on the multirange voltmeter is recorded as a function of the frequency. The source is then removed, and the signal generator with a fixed attenuator setting is varied over the same range of frequencies. As the frequency is varied, the center frequency of the tunable filter is continuously adjusted to the same frequency. The voltage $E_{c,\,rms}$ read on the multirange voltmeter is recorded as a function of frequency. (If a chopper is employed that modulates the radiation sinusoidally, so that P_2, P_3, P_4, etc., of equation 2.2 -9a are all zero, then the tunable filter may be removed from the electronic system. This method provides an appreciable simplification of the method of measurement.)

(8) The relative responsivity F(f) is then computed by:

$$F(f) = \frac{E_{s,\,rms}\,e(f)}{E_{c,\,rms}} \qquad (4.1\text{-}8)$$

where e(f) is the relative voltage produced by the signal generator if the voltage is not the same at all frequencies.

(9) From the experimental results described in foregoing paragraphs (4), (6), and (8) the absolute responsivity as a function of the wavelength λ and the modulation frequency f is given by:

$$R(\lambda, f) = R_{BB} \cdot \frac{L(\lambda)P_{rms}}{\int L(\lambda)P_{\lambda,\,rms}\,d\lambda} \cdot \frac{F(f)}{F(f_c)} \qquad (4.1\text{-}9)$$

where $P_{\lambda,\,rms}$ is the spectral power of P_{rms}. Note that the value of $R(\lambda, f)$ is not changed if either $L(\lambda)$ or F(f) is multiplied by a constant. Nor is $R(\lambda, f)$ changed if P_{rms} and $P_{\lambda,\,rms}$ are multiplied by the same constant.

(10) The responsivity $R_m(f)$ at the peak wavelength λ_p (involved in figure 1 described in section 5.4.1) is given by:

$$R_m(f) = R_{bb} \frac{L(\lambda_p)P_{rms}}{\int L(\lambda)P_{\lambda, rms}d\lambda} \cdot \frac{F(f)}{F(f_c)} \qquad (4.1\text{ -10})$$

(11) The responsivity ratio $R_\mu(\lambda)/R_{m\mu}$ involved in figure 3 described in section 5.4.1 is given by:

$$\frac{R_\mu(\lambda)}{R_{m\mu}} = \frac{L(\lambda)}{L(\lambda_p)} \qquad (4.1\text{ -11})$$

4.2 The Noise.

In the measurement of the noise of a radiation detector, good judgment and experience are essential for ensuring that the only noise that appears at the multirange voltmeter is that generated in the detector and in the amplifier. Continuous vigilance is required to prevent other sources of noise from influencing the results. In particular, the bias supplies must not contribute appreciable noise.

(1) With the bias set at b_o, with all of the radiation sources removed, and with the signal generator producing zero signal, the root-mean-square noise voltage indicated by the multirange voltmeter is recorded as a function of the center frequency of the tunable filter. The voltage read is denoted $E_{o, rms}$.

(2) The signal generator is set to the frequency at which the tunable filter has maximum gain, and the attenuator is adjusted to the value that produces on the multirange voltmeter a reading that is K times $E_{o, rms}$. The constant K is the same constant for all frequencies and is preferably taken in the range from 10 to 100. The voltage across the calibrating resistor R_{cal} is denoted $V_{c, rms}$.

(3) The signal generator is returned to zero output and the terminals of the detector are connected together so that the detector is electrically short circuited. The root-mean-square noise voltage indicated by the multirange voltmeter is recorded as a function of the center frequency of the tunable filter. The voltage read is denoted $E_{sh, rms}$.

(4) The root power spectrum N (which is referred to the terminals of the detector, referred to an infinite load impedance, and corrected for amplifier noise) is calculated by the formula:

$$N = \frac{(1 - k^2)^{\frac{1}{2}}}{(K^2 - 1)^{\frac{1}{2}}} \frac{V_{c, rms}}{(\Delta f)^{\frac{1}{2}}} \qquad (4.2\text{ -4a})$$

where k is defined by:

$$k = \frac{E_{sh, rms}}{E_{o, rms}} \qquad (4.2\text{ -4b})$$

and where Δf is the noise bandwidth at the frequency f.

(5) For frequencies at which the ratio k is close to unity, the two voltages $E_{sh, rms}$ and $E_{o, rms}$ should be measured close together in time in order to reduce

the effect of draft in the gain of the measuring equipment. At frequencies where the difference between k and unity cannot be measured reliably, the root power spectrum and the detectivity cannot be measured with the equipment used.

4.3 The Detectivity.

The various kinds of detectivity are all calculated from the responsivity $R(\lambda, f)$ (see equation 4.1 -9) and the root power spectrum $N(f)$ (see equations 4.2 -4a and b).

4.4 Specifications on the Data Plotted in Figure 4.

The data plotted in figure 4 of the standard report (see 5.4.1 and Appendix A) shall be measured with the variable-frequency source, equipped with a factorability filter if needed, with the modulation frequency f_p.

The curve labeled R shall indicate the relative responsivity as the bias b is varied, the arbitrary multiplicative constant to be the same for all of the biases. If the impedance of the detector and of the other elements in the detector circuit do not vary as the bias is varied, then the relative responsivity is proportional to the output voltage $E_{s, rms}$ of the amplifier. But if any of these impedances do vary, then both $E_{s, rms}$ and $E_{c, rms}$ shall be measured at each value of the bias and the ratio taken in accordance with equation 4.1 -8.

The curve labeled N shall indicate the relative root power spectrum of the noise at the frequency f_p as the bias is varied, the arbitrary multiplicative constant to be the same for all of the biases.

The curve labeled D_1 shall be the ratio R/N.

The values of the bias shall cover the range from a value not more than one-tenth of the optimum bias b_p up to the maximum bias b_m.

4.5 Measurement of Responsivity Contours.

The definition of the effective area A_e of a detector involves the measurement of the responsivity $R(x, y)$ for radiation that falls on a very small area centered at the point x, y of the responsive plane.

The method of measuring $R(x, y)$ is not yet ready for full standardization. Some steps toward the standardization are given in this section, however.

(1) The microscope used to focus the radiation on the detector shall be of the reflection type. Refractive microscopes cannot pass the long-wavelength radiation that must be used with some detectors whose longest wavelength factorability band comprises no wavelengths shorter than 2 or 3 microns.

(2) The effective size of the spot of radiation shall be 5 to 10 microns in diameter.

(3) Extreme care shall be exercised to ensure that the detector is not responding nonlinearly to the radiation. The large numerical aperture that is usually used with a microscipe makes it easy to produce a very high irradiation of the spot.

4.6 Other Measurements.

The methods used to measure the impedance, resistance, and capacity of the detector are too well known to require detailed description here. These parameters shall be measured at the optimum bias b_p.

The method of measuring the pulse time constant is not ready for standardization. At present only rough values are quoted; and, until higher accuracy is felt to be needed, standardization is not required. Pulse measurements are not recommended unless the time constant is so short that it cannot be measured by the methods described in 2.13 (1) through (4).

5. THE STANDARD REPORT

5.1 Description of Detector.

A. Description of Detector in the standard report shall list as many of the following items as is feasible:

(1) Type of detector--e.g., PbS evaporated film detector; thermistor bolometer; InSb photoelectromagnetic detector.
(2) Name and address of manufacturer
(3) Identification number and serial number
(4) Date of manufacture*
(5) Date of test
(6) Electrode material*
(7) Window material (and thickness in cm if known)*
(8) Nominal size and shape of the responsive area (in cm and cm^2)
(9) Nominal responsive area in cm^2
(10) Manufacturer's recommended bias for optimum signal/noise ratio*
(11) Manufacturer's recommended maximum bias for continuous operation*
(12) Nominal electrical resistance under recommended operating conditions
(13) Nominal weighted solid angle (in steradians)
(14) Production status--e.g., random sample from production batch*
(15) Description of the physical size and shape of the complete detector (this should preferably include one or more photographs or sketches with the principal dimensions indicated)

5.2 Conditions of Measurement.

B. Conditions of Measurement in the standard report shall list the following items with respect to the test conditions:

(1) Detector temperature T (temperature of coolant in degrees Kelvin if detector is cooled or ambient temperature in degrees Kelvin if detector is not cooled) [2.6]

(2) Adopted area A_a in square centimeters [2.4(6)(b)]

(3) Position of adopted responsive plane if it is not obvious [2.4(1) - (3)]

---

*As stated by the manufacturer.

(4) Adopted weighted solid angle ω_a in steradians [2.4(7)(b)]

(5) The bias used in the test, if any [2.7(1), 4.1(2)]

(6) The temperature T_{bb} of the black-body source used in the measurement of the absolute responsivity, in degrees Kelvin [3.8.1]

(7) Description of the way that the spectral irradiance provided by the black-body source differs from an ideal black-body source: effect of mirrors and/or filters, including the factorability filter, if used [3.8.1]

(8) The chopping frequency f_1 of the black-body source [3.8.1]

(9) Description of the spectrum of the radiation used to measure the relative-responsivity-versus-frequency curve [3.8.3]

(10) The chopping frequency f_2 used to measure the relative-responsivity-versus-wavelength curve [3.8.2]

(11) Description of the ambient radiation incident on the detector. In many cases, this will consist of the temperature of the objects within the solid angle of the detector [2.2(4), 3.4(7)]

(12) The chopping frequency f_3 used to measure the data in figure 4 (see section 5.4.1).

(13) Description of the radiation used to measure the data in figure 4 (see section 5.4.1)

(14) If a mask is used over the detector to limit the area that is irradiated, a description of the mask including a sketch, if necessary.

5.3 Input Circuit.

C. Input Circuit of the standard report shall include a diagram of the input circuit used in the test. This diagram shall show the detector; its bias supply, if any and its connection to the first stage of the amplifier. The diagram shall also show the way the calibration voltage is introduced. The values of all important components shall be indicated. (Figure A of Appendix A suggests what is needed here.)

Components used in the input circuit that may be unfamiliar to workers in other countries may be referred to by the manufacturer's type number, but the standard report shall also include a brief description of the electrical characteristics of such components. This is particularly important for transformers. The input impedance of an input transformer shall be stated at all frequencies of interest.

If the pulse time constant is measured, the standard report shall state the load resistance $\overline{R}_L$ used in the test.

If the method of correcting for the noise of the low-noise amplifier differs from that described in section 4.2 the method used shall be described in detail.

5.4 Standard Test Results.

5.4.1 Plots: In the standard report, section D shall contain four plots:

Figure 1--Responsivity vs Frequency: This is a plot with logarithmic scales, the ordinate to be the responsivity $R_m(f)$ in volts per watt and the abscissa to be the modulation frequency f in cycles per second. The plot is to be for the optimum bias and for the peak wavelength λ_p.

Figure 2--Root Power Spectrum of the Noise: This is a plot with logarithmic scales, the ordinate to be the root power spectrum N in volts/(cps)$^{\frac{1}{2}}$ and the abscissa to be the frequency in cycles per second. The plot shall be for the optimum bias.

Figure 3: This is a plot with a logarithmic ordinate scale and a linear or logarithmic abscissa scale with the responsivity $R_\mu(\lambda)/R_{m\mu}$ as the ordinate and the wavelength λ as the abscissa. The curve shall be for optimum bias and for the peak modulation frequency f_p. The curve shall have a maximum value of unity and the ordinate shall be labeled "Relative Scale for R and D." (Optionally, a reciprocal scale may be shown on the right-hand ordinate and labeled "Relative Scale for P_N, Jones S" if the test laboratory chooses to tabulate these quantities also.)

Figure 4--Determination of Optimum Bias: This is a plot with logarithmic scales. The abscissa is the bias for all of the curves. The plot shows three curves labeled R, N, and D_1. The first curve shows the responsivity R measured in arbitrary units at the frequency f_p with radiation limited to the factorability range. The second curve shows the root power spectrum N measured in arbitrary units at the frequency f_p. The third curve, labeled D_1, shows the ratio R/N.

5.4.2 Tabular Data: The standard report shall contain the following tabular data concerning test results:

(1) Electrical resistance $\overline{R}$ in ohms at the optimum bias [2. 5(3)].

(2) Electrical capacity C in microfarads at the optimum bias [2. 5(5)].

(3) Wavelength λ_p in microns [2. 11(6), 4. 1(2)].

(4) Frequency f_p in cps or the frequency f_h used in the measurements for figures 3 and 4 if the peak frequency f_p cannot be reached by the variable-frequency source [2. 11(6), 4. 1(2)].

(5) Responsive time constant τ_r in seconds if it can be measured with the chopping frequencies available [2. 13(3)].

(6) The detective time constant τ_d in seconds if it can be measured with the chopping frequencies available [2. 13(4)].

(7) The pulse time constant in seconds if the above two time constants cannot be measured with the available chopping frequencies [2. 13(7)]. Usually the pulse time constant will be stated only when items (5) and (6) are not stated.

(8) The shunt resistance used in measuring the pulse time constant.

(9) The responsivity $R_{m\mu}$ in volts per watt /2.9(9)/.

(10) The detectivity D_{1mm} for a unit bandwidth of noise, in cps$^{\frac{1}{2}}$/watt /2.11(6)/.

(11) The detectivity D^*_{mm}, in cm-cps$^{\frac{1}{2}}$/watt /2.11(6)/.

(12) The detectivity D^{**}_{mm} in cm-cps$^{\frac{1}{2}}$/watt if the detector is refrigerated or non-Lambertian /2.11(6)/.

(13) The ratio $R_{m\mu}/R_{m\lambda}$ /2.9(9), 4.1(4)/.

(14) The energy detectivity $\mathcal{E}^*_{mm}$ in cm/joule /2.12(7)/.

5.5 Optional Data on Test Results.

The standard report may also contain any or all of the following optional data:

(1) Additional curves in figures 1, 2, and 3 for biases greater than the optimum bias; in particular, for the maximum bias.

(2) A plot of $D^*_m(f)$ versus the frequency f (see figure 5 of Appendix A).

(3) One or more plots showing the responsivity R(x, y) as a function of position on the surface of the responsive element.

(4) The detective quantum efficiency ϵ_{Dmm}.

(5) The intrinsic time constant.

The standard report shall not tabulate the responsivity or the detectivity for any single black-body temperature or for any frequency or wavelength other than f_m and λ_m. Exception may be made when the temperature, frequency, or wavelength is specified by the user.

5.6 Explanation.

The standard report will not be intelligible to the inexperienced user of detectors without some explanation. Thus, a short explanation should accompany the standard report. The test laboratory will often prefer to write its own explanation. The following brief explanation is offered for those who do not wish to prepare their own version.

> A. The two most important aspects of any radiation detector are its responsivity (signal out divided by radiation in) and the electrical noise in the output of the detector. The responsivity R depends on both the wavelength and the frequency, and the noise depends only on the frequency. Figure 1 shows the root power spectrum N of the noise, in volts per cps$^{\frac{1}{2}}$ (or in amperes per cps$^{\frac{1}{2}}$) plotted against the frequency.

B. The responsivity indicates how much electrical signal is produced for a given radiation signal, but does not indicate how effective the detector is for detecting small amounts of radiation. The ability of a detector to detect is measured by the detectivity D. When the detectivity is measured with a unit bandwidth of the noise, it is denoted D_1 and is equal to R divided by N:

$$D_1 = R/N \qquad \text{(B)}$$

C. The detectivity is usually expressed in terms of D* or D**, which are related to D_1 by

$$D^* = A_a^{\frac{1}{2}} D_1 \qquad \text{(Ca)}$$

and

$$D^{**} = (A_a^{\frac{1}{2}} \Omega_a^{\frac{1}{2}} / \pi) D_1 \qquad \text{(Cb)}$$

where A_a is the adopted area of the detector, and Ω_a is the adopted weighted solid angle of the detector, both tabulated in section B of the standard report.

D. The responsivity R, and also D* and D**, depend both on the wavelength λ and on the frequency f. It is very awkward to show graphically a function that depends on two variables. With radiation detectors, however, it is fortunately true that by suitable restrictions on the conditions of measurement, both the responsivity and the detectivity can be expressed as the product of two functions, one of which depends only on the wavelength, and the other of which depends only on the frequency. Under these conditions, the dependence on both the wavelength and the frequency can be completely presented by two curves in two plots.

E. The peak wavelength λ_p and the peak frequency f_p are defined as the wavelength and frequency that simultaneously maximize the detectivities D_1, D*, and D**. The values of R, D_1, D*, and D** at the wavelength λ_p and the frequency f_p are denoted R_{mm}, D_{1mm}, D^*_{mm} and D^{**}_{mm} and are tabulated in section D of the standard report.

F. In order to determine the responsivity R for a wavelength λ_1 and frequency f_1 other than λ_p and f_p, one proceeds as follows: The responsivity at the desired frequency f_1, but at λ_p, is read directly from figure 1, in volts per watt (or amperes per watt). The result is then multiplied by the number read off the ordinate of figure 3 for the wavelength λ_1 in question. The result is the responsivity for the desired wavelength λ_1 and frequency f_1.

G. The method of determining D_1, D*, or D** for a wavelength or frequency other than λ_p and f_p is a little more complicated. To obtain any of these quantities at λ_1, but at f_p, the value of D_{1mm}, D^*_{mm}, or D^{**}_{mm} tabulated in section D is multiplied by the ordinate of figure 3. The result is then multiplied by the ratio of the value of $R_m(f)/N$ at f_1, as calculated from the curves in figures 1 and 2, to the value of $R_m(f)/N$ at f_p, as calculated from figures 1 and 2.

H. Figure 3 shows not only how R, D_1, D^*, and D^{**} depend on the wavelength, but also how D, Λ, and Λ^* depend on the wavelength.

APPENDIX A

Model Report

This part contains a model report, whose purpose is to illustrate the appearance of a report that is prepared in accordance with this standard. For this report we are indebted to the Infrared Division, U.S. Naval Ordnance Laboratory, Corona, California.

This model report has one substantial imperfection: the measurements of the responsivity and the root power spectrum were carried out only to 10,000 cps, and the actual peak frequency is slightly above 10,000 cps. The report supposes that the peak frequency is 10,000 cps, with the result that the values of D^*_{mm} and the peak frequency are slightly incorrect. Furthermore, the absence of data above the peak frequency makes impossible more than a rough estimate of the detective time constant and the energy detectivity.

One feature of the test conditions to be noted is that the optimum bias current is greater than the manufacturer's recommended maximum bias. Since the test laboratory did not wish to exceed this recommended maximum bias, the true optimum bias could not be used in the tests.

The Tables A, B, and C of the model report contain the data called for in sections 5.1, 5.2, and 5.4(2), respectively. Figure A is the input circuit diagram required by section 5.3, and figures 1 through 4 are the four figures described in section 5.4(1). Figure 5, which is optional, is the plot suggested in section 5.5(2).

A. DESCRIPTION OF DETECTOR

Type	Ge (Au and Sb doped)
Manufacturer	Philco Corporation
Serial Number	GHC-101 ([illegible])
Date of manufacture*	Late 1959
Date of test	December, 1959
Electrode material*	Unknown
Window material*	Sapphire (1.0 mm thick)
Shape of sensitive area	Square, 1.5 mm x 1.5 mm
Nominal area	2.25 x 10^{-2} cm^2
Manufacturer's optimum bias*	[illegible] volts across cell and load for [illegible] cps chopping frequency
Manufacturer's maximum bias*	55 volts across cell
Nominal resistance	[illegible] x $10^{[illegible]}$ ohms
Nominal solid angle	Circular cone, total angle 100°
Production status*	Unknown

---

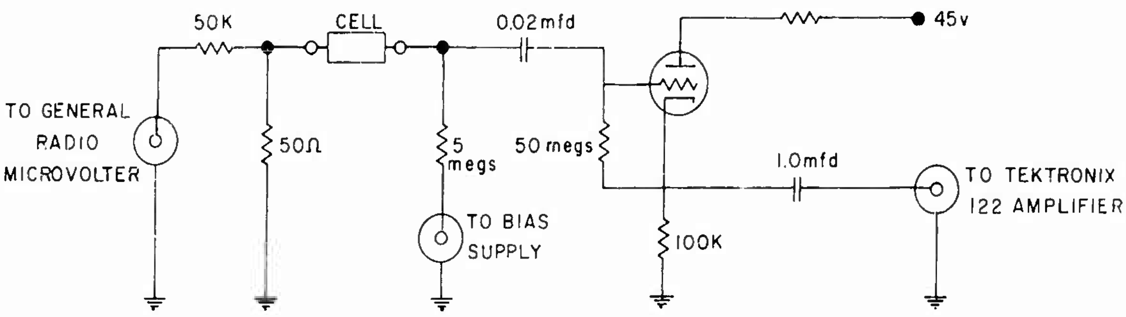
* As stated by manufacturer

B. CONDITIONS OF MEASUREMENT

Detector temperature, T	77°K
Adopted area, A	2.25×10^{-2} cm ^{2}
Adopted responsive plane (from window)	0.5 cm behind the window
Adopted solid angle, Ω_a	1.8 steradian
Bias used, i_b	4.0×10^{-6} ampere (36 volts across cell)
Blackbody temperature, T_{bb}	500°K
Filters and mirrors used with blackbody source	3 mm Ge filter
Chopping frequency of blackbody source, f_c	10^{4} cps
Radiation used to measure frequency response	Nernst Glower, 1800°K, plus 3 mm Ge filter
Chopping frequency used with the monochrometer, f_c	90 cps
Radiation used to measure optimum bias	500°K BB plus 3 mm Ge filter
Chopping frequency of optimum bias source, f_c	10^{4} cps
Ambient radiation on detector	300°K only

C. INPUT CIRCUIT

In addition to Figure A, sample below, this section of the standard report will include the data called for in section 5.3 of the standards, as appropriate.



INPUT CIRCUIT

FIGURE A

D. TEST RESULTS

Electrical resistance, $\overline{R}$ - - - - - - - - - 9.0 x 10^{5} ohms

Electrical capacity, C - - - - - - - - - - 9.5 x 10^{-6} microfarad

Peak wavelength, λ_p - - - - - - - - - - - 1.5 microns

Peak frequency, f_p - - - - - - - - - - - - - 1 x 10^{4} cps

Responsive time constant, τ_r - - - - - [illegible] x 10^{-6} second

Detective time constant, τ_d - - - - - - 5 x 10^{-6} second (estimated)

Pulse time constant, τ_p - - - - - - - - - Not measured

Shunt resistance for τ_p - - - - - - - - - Not measured

$R_{m\mu}$ - - - - - - - - - - - - - - - - - - - 1.5 x $10^{[illegible]}$ volts/watt

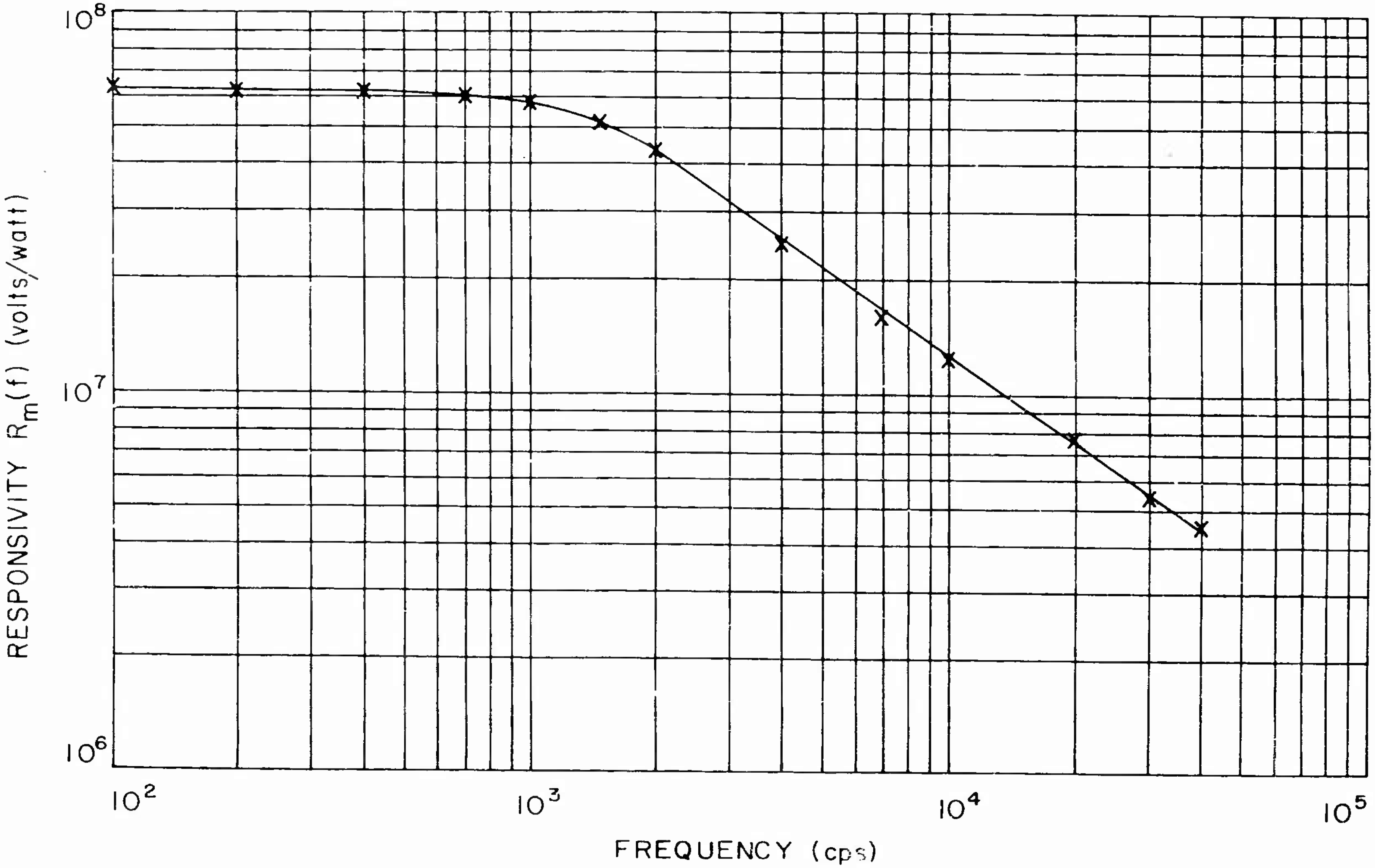
D_{1mm} - - - - - - - - - - - - - - - - - - 7.[illegible] x 10^{12} cps$^{1/2}$/watt

D^{*}_{mm} - - - - - - - - - - - - - - - - - - - 1.1 x 10^{12} cm-cps$^{1/2}$/watt

D^{**}_{mm} - - - - - - - - - - - - - - - - - - 8.5 x 10^{11} cm-cps$^{1/2}$/watt

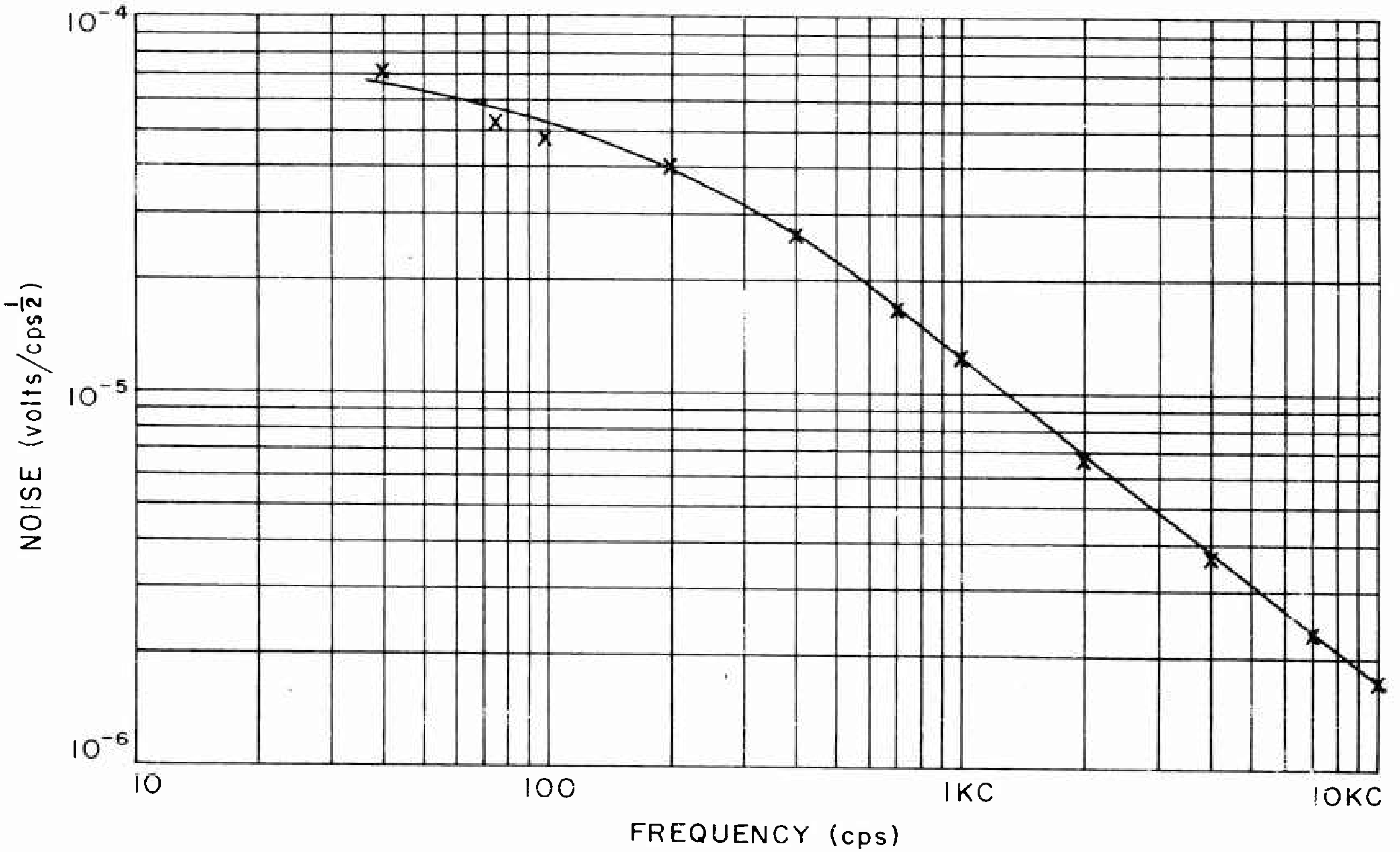
Δ^{*}_{mm} - - - - - - - - - - - - - - - - - - - 4.5 x 10^{14} cm/joule (estimated)

$R_{m\mu}/R_{\beta\beta}$ - - - - - - - - - - - - - - - - - 1.1 x 10^{2}



RESPONSIVITY vs FREQUENCY

FIGURE 1



ROOT POWER SPECTRUM OF THE NOISE

FIGURE 2

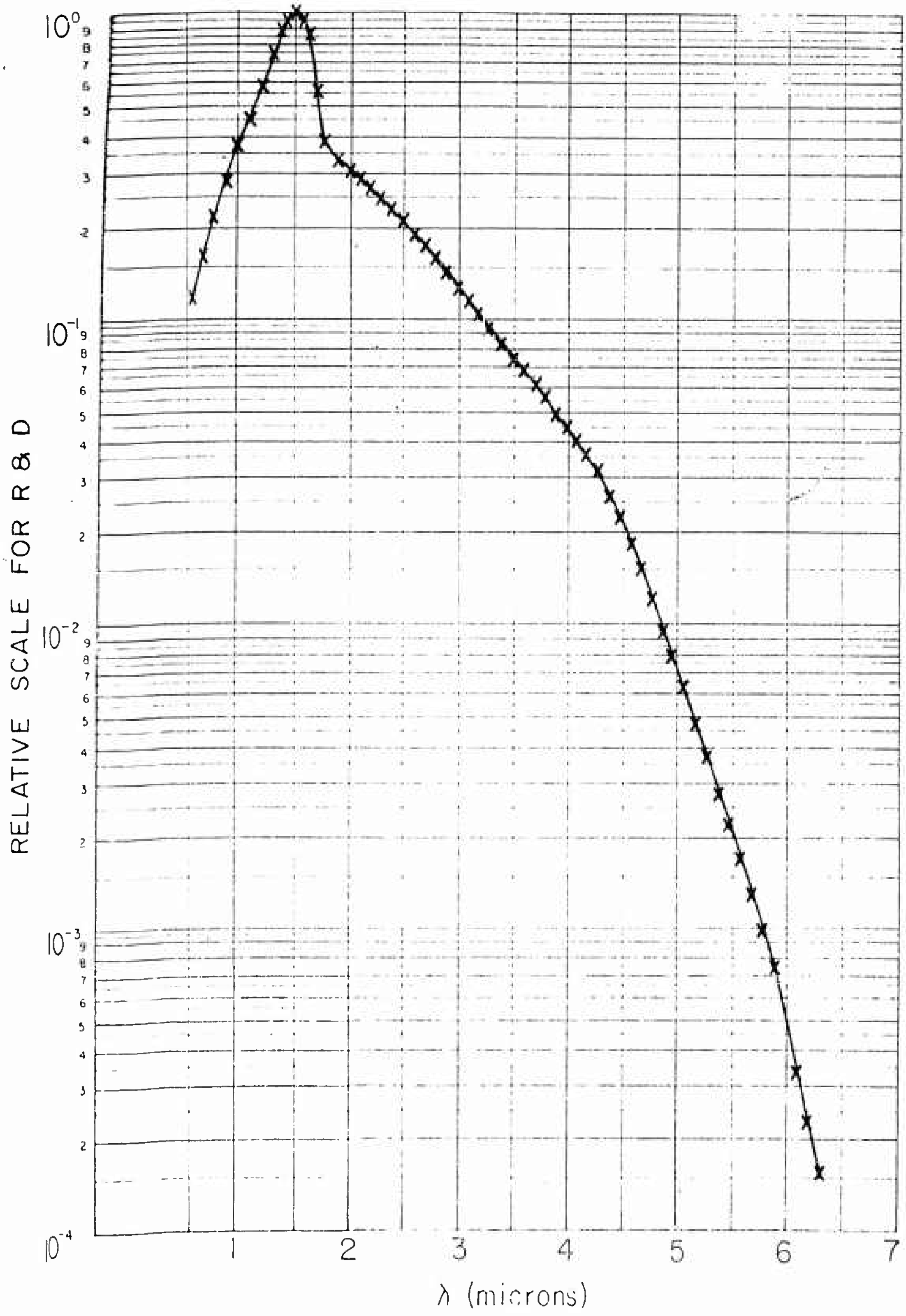
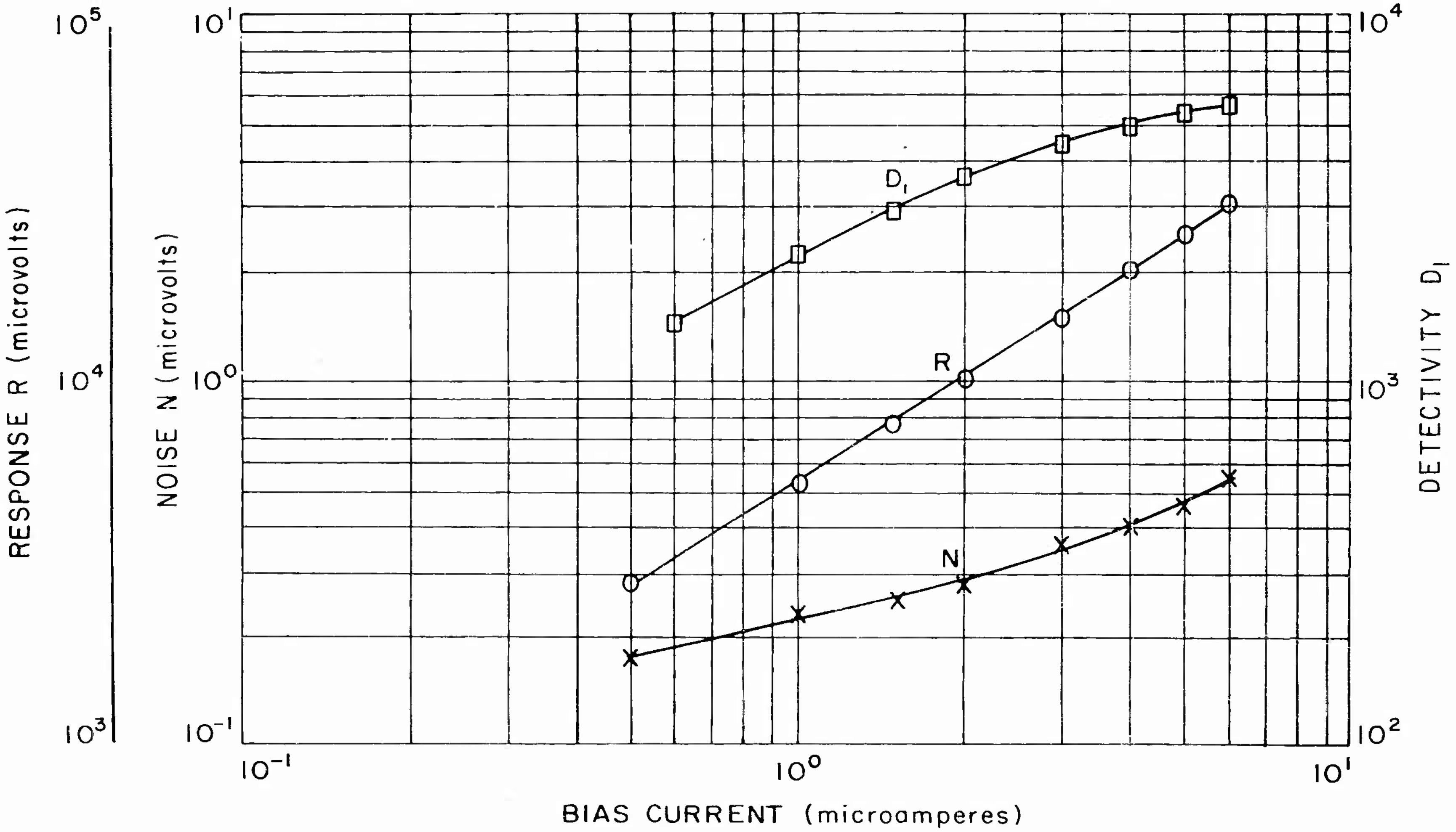
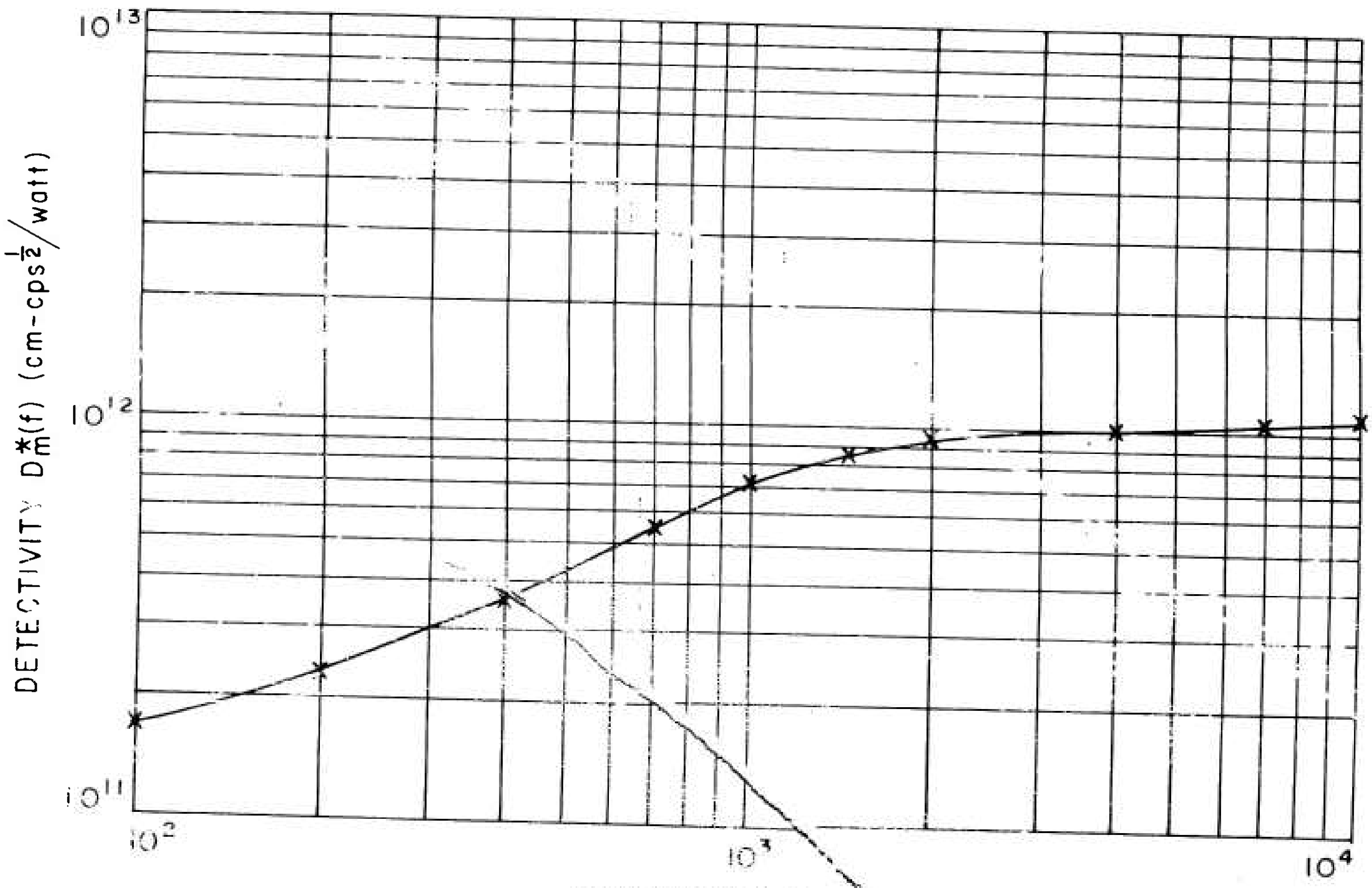

RELATIVE SCALE FOR R & D
10^0
10^-1
10^-2
10^-3
10^-4
9
8
7
6
5
4
3
2
1
2
3
4
5
6
7
λ (microns)

FIGURE 3



DETERMINATION OF OPTIMUM BIAS

FIGURE 4



DETECTIVITY vs FREQUENCY

FIGURE 5