RS data

ΦE10 1500 Pyroelectric detector

Pyroelectric detectors

T-65-11

Stock numbers 302-592/609/615

The ceramic pyroelectric detectors available in the RS range (see below) are suitable for many applications, some of which are described in this Data Sheet. Each detector consists of an infrared-sensitive element, a low-noise electrical impedance-matching circuit, and an infrared window, all contained within a TO-5 encapsulation.

The sensitive element is an electrically-polarised ceramic slice, with metallic electrodes deposited on opposite faces. As a result of the pyroelectric nature of the ceramic, an electrical signal is obtained from the electrodes in response to changes in temperature.

Features

- Sensitive to changes in 'target' temperature (in field of view).
- Can be used in Intruder Alarms
- Diverse applications in pyrometry in general.
- Industrial uses, including conveyor sorting.
- Scientific and Development possibilities embrace spectral analysis and tool control (interference fringe detection).

Absolute maximum ratings

	RPY 89	RPY 95	RPY 96
Storage temperature (°C)	−40 to +50	−20 to +50	−40 to +70
Operating temperature (°C)	−40 to +100	−20 to +50	−40 to +60
Operating voltage (Vdc)	30	30	30

Note: The case potential must not be allowed to become positive with respect to the other two terminals.

Figure 1: **RPY89/RPY96**

RPY89
RPY96

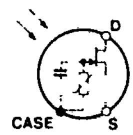


Figure 2: **RPY95**

RPY95

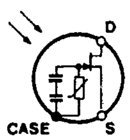
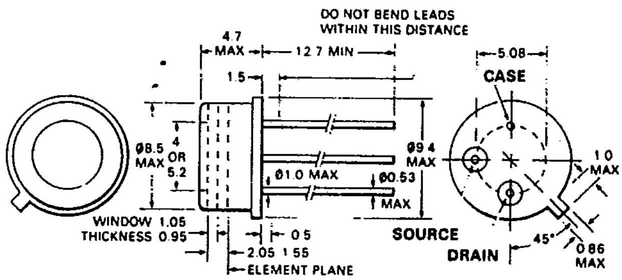


Figure 3: **Outline details**



Dimensions in mm

Product Selection Guide

RS Stock No.	Pro Electron Designation	Number of Elements	Element Spacing (mm)	Element Dimensions (mm)	Spectral Response (μm)	Window Diameter (mm)	Application
302-615	**RPY89**	1	–	2 x 2	1.0 x 15 (Silicon window)	5.2	General purpose
302-609	**RPY95**	2	1.0	2 x 1	6.5 to 14 (Daylight filter)	4.0	Intruder alarms
302-592	**RPY96**	1	–	2 x 1	6.5 to 14 (Daylight filter)	4.0	Intruder detection

Characteristics $T_A = 25°C$

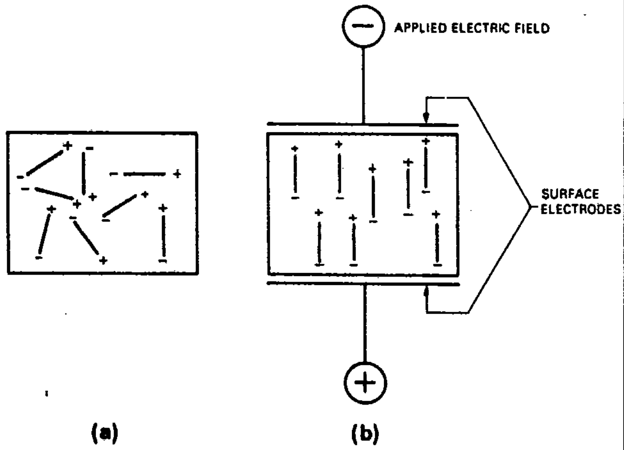
Parameter	RPY89 Min.	RPY89 Typ.	RPY89 Max.	RPY95 Min.	RPY95 Typ.	RPY95 Max.	RPY96 Min.	RPY96 Typ.	RPY96 Max.	Units
Spectral response	1		15	6.5		14	6.5		14	μm
Responsitivity	188	250		250	450			130		V/W
Noise Equivalent Power (NEP)		2×10^{-9}	3×10^{-9}		2.1×10^{-9}	6×10^{-9}		3.5×10^{-9}	9×10^{-9}	W/Hz
Field of View (FOV)		112			110			105		Degrees
Operating Voltage	8	9	10	8	9	10	8	9	10	V
Frequency Range	01		1000	0.1		1000	0.1		1000	Hz

Pyroelectricity

An explanation of pyroelectricity is given here as a fore-runner to the Design Notes and Applications information.

A pyroelectric ceramic is composed of a mass of minute crystallites, each of which behaves as a small electric dipole. Above a certain temperature, known as the Curie temperature, the crystallites have no dipole moment. Below the Curie temperature, in freshly manufactured material, the electric dipole in each crystallite is oriented randomly with respect to the dipoles in other crystallites (see Figure 4a). If the material is heated to just below the Curie temperature and an electric field is applied to it, the dipoles tend to line up with the applied field (see Figure 4b). After the material has cooled and the applied field has been removed, the dipoles remain in the 'poled' position giving rise to a remanent polarisation of the ceramic. (This is a somewhat simplified explanation that ignores the effect of domains in the crystallites.) To perform the poling process, electrodes are deposited on opposite faces of the material. The charge on the surface of the ceramic is captive within the lattice structure of the crystallites, but the equal and opposite induced charge on the electrodes is free to move. Thus the electrode which was positive during the poling process acquires a positive charge.

Figure 4: **Orientation of electric dipoles a) unpoled b) poled**



The magnitude of the charge appearing at the surface is related to the internal charges by the 'dipole moment'; that is, the product of charge and separation, as shown in Figure 5. The dipole moment M of the bulk is given by:

$$M = PAd.$$

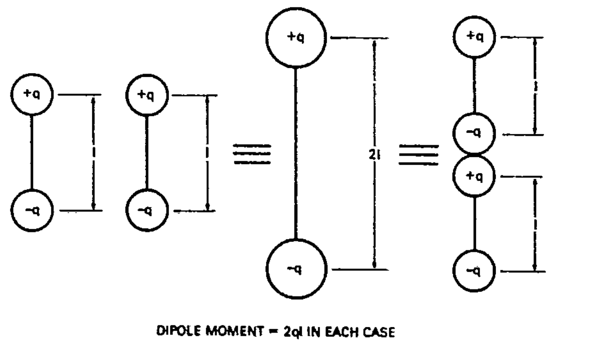
where P is the dipole moment per unit volume, A is the area of an electrode, and d is the separation of the electrodes.

he charge at the surface Q_s has a dipole moment of $Q_s d$. This must equal the total dipole moment, so that:

$$Q_s = PA.$$

The pyroelectric effect arises because of a charge in polarisation with temperature and may occur in several ways. For example, the individual dipoles may shorten with increasing temperature, or the total dipole moment may be reduced by an increase in the randomness of the orientation of the dipoles due to thermal agitation. Thus, when the temperature of the material increases, the captive surface charge is reduced. This leaves a surfeit of induced charge on the electrodes, so that electric potential across the devices rises according to Q = CV (where Q is charge, C is the capacitance, and V is the potential). The excess charge gradually leaks away through the circuit to which the pyroelectric element is connected.

Figure 5: **The same dipole moment resulting from three possible arrangements of dipoles**



The magnitude of the excess charge is related to the pyroelectric coefficient λ which is the rate of charge of polarisation with temperature. As Figure 6 shows, λ is a function of temperature.

For a small temperature change δT, the excess charge δQ is given by:

$$\delta Q = \lambda A \delta T$$

The charge will give rise to a potential change δV, given by:

$$\delta V = \frac{\delta Q}{C_E} = \frac{\lambda A \delta T}{C_E}$$

where C_E is the electrical capacitance between the surface electrodes.

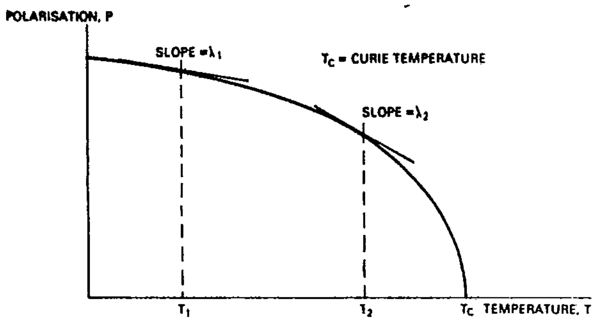
To maximise the pyroelectric effect in an infrared detector, the sensitive element is made thin. This results in a larger temperature change for the same incident radiation.

Consider an infrared signal of intensity W watts r.m.s. per unit area whose amplitude varies sinusoidally at a radial frequency ω. If the thermal capacitance of the sensitive element is C_{th} (JK^{-1}), then, by analogy with electrical theory, the temperature signal δT is given by:

$$\delta T = \frac{WA}{j\omega C_{th}}$$

for all values of $\omega C_{th} R_{th}$ greater than unity, where R_{th} is the thermal resistance. (The value of ω that

Figure 6: **Variation of polarisation with temperature**



equals $1/C_{th}R_{th}$ is termed the thermal break frequency. For the detectors described in this publication $\omega \simeq 1$ Hz.) The temperature signal will give rise to an electrical signal δV given by:

$$\delta V = \frac{\lambda A \delta T}{C_E} = \frac{\lambda A^2 W}{j\omega C_{th} C_E}$$

It can be seen, therefore that the voltage developed decreases as the frequency of the radiation signal increases. Also, the voltage lags the radiation signal by 90° (above the thermal break frequency). The signal current i available into a short-circuit is given by:

$$i = \delta V j\omega C_E, \quad = \frac{\lambda W A^2}{C_{th}}$$

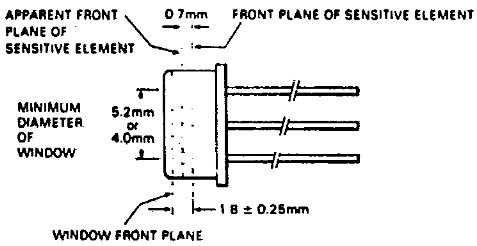
which is independent of frequency and in phase with the incident radiation. The pyroelectric element is of necessity a high-resistivity insulator, so that the dominant noise source at low noise frequencies is the current noise of the amplifier. Therefore, the ratio of signal current to noise current is independent of frequency until the point at which other noise mechanisms predominate.

Device construction

The encapsulation is a low-profile T0-5 type fitted with an infrared window as shown in Figure 7. Two types of window are available: either silicon, with a substantially flat transmission over the wavelength range from 1 μm to beyond 15 μm; or a 'daylight' filter, which transmits in the narrower range 6.5. μm to greater than 14 μm (thereby making the device insensitive to short-wavelength infrared, as emitted by the sun). A practical point to note is that because the window material has a high refractive index, the apparent position of the front plane of the sensitive element is moved 0.7 mm towards the window front plane (as shown in Figure 7).

The detectors contain either a single or dual pyroelectric element, and electrically each device can be represented by one or two capacitors, an

Figure 7: **Section through a ceramic pyroelectric detector**



n-channel FET, and a non-linear network, connected as shown in Figures 1 and 2. The non-linear network contributes greatly to the usefulness of the detectors: it protects the gate of the FET (which forms part of the impedance-matching circuit) from excessive negative voltages, and progressively limits the pyroelectric voltage resulting from large changes in the ambient temperature. Thus, signals may be obtained under conditions which would otherwise either overload the preamplifier or require it to have a very large dynamic range.

The dual-element devices have two differentially-connected sensitive areas with a single impedance-converting amplifier to provide immunity from common mode signals such as those generated by variations in ambient temperature, background radiation, and acoustic noise.

The pyroelectric ceramic material, a lead zirconate titanate, is doped so as to optimise the properties required for infrared detectors. It is insensitive to water and is extremely rugged. Thus it can be handled by mass-production techniques similar to those used in the manufacture of conventional semiconductor devices.

Design notes

Preamplifier

Each detector includes a low-noise FET with its source and drain brought out to external connections (Figures 1 and 2). This allows a great deal of freedom in the design of the preamplifier to match the sensitive element to subsequent amplifiers.

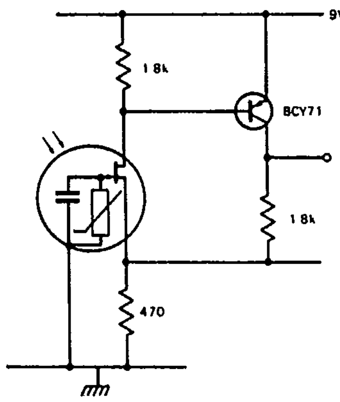
The recommended preamplifier (shown in Figure 8) is the configuration which is the least dependent on the FET characteristics. It has a gain of 4.8, set by the 1.8 kΩ and 470Ω resistors connected to the source. The noise level at the output is typically $250 nVHz^{½}$ at 10 Hz and the output impedance is approximately 200 Ω. The d.c. output, with zero input, will lie between 2 and 7 V. This spread is the main reason for limiting the gain, although higher gains can be achieved if the resistors are selected to match each FET. The gain provided by this amplifier is important where low noise is necessary, since the noise introduced by subsequent standard operational amplifiers would otherwise prove obtrusive.

Amplifier

If the amplifier stages subsequent to the preamplifier are to increase the noise level by less than one-third of the preamplifier output noise; that is, their input noise should be less than $80\ nVHz^{-½}$ (approximately one-third of $250\ n\ VHz^{-½}$) at 10 Hz.

Various operational amplifiers may be employed. In fact the ubiquitous 741 op amp typically has a noise level of $70VHz^{-1/2}$. Depending on the particular circuit requirements an amplifier with or without external compensation may be chosen.

Figure 8: **Recommended preamplifier**



If the system design can tolerate some degradation in the overall signal-to-noise ratio, a wide range of operational amplifiers can be considered. A particularly useful device is the 324, a quad operational amplifier, which is ideally suited to single-supply operation.
The typical voltage noise for the 324 is 170 n $VHz^{-1/2}$ at 10Hz. With four independent amplifiers in a single package, this device provides a compact and economical solution to a variety of application problems. The use of the RS 741N (low noise version of the 741) should also be considered.
However, it should not be forgotten that the input bias current should preferably be as low as possible, say less than 100nA. Also, it must be kept in mind that, since time-constants for the circuits are generally large, low-leakage capacitors must be employed.

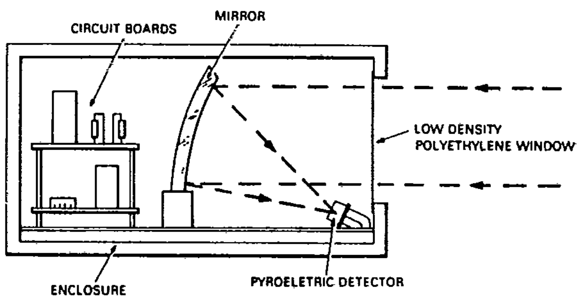
Applications.

The pyroelectric element will only produce an output signal if the flux of infrared radiation incident on it changes. This may be achieved either by moving the object of interest into and out of the field of view, or by interrupting the radiation incident on the detector. Both methods are used in the following applications.

Intruder alarm

To detect an intruder within the area protected by the field of view of the alarm, use is made of the intruder's movement to cause a change in the radiation reaching the detector. The circuit is designed so as to require two or more signals to exceed a preset threshold within a defined time, thus reducing the possibility of false alarms.
One arrangement of an alarm is shown in Figure 9. Infrared lenses tend to be expensive, and as a consequence the alarm employs a relatively inexpensive moulded plastic mirror. However, the surface quality of the mirror is important, especially for dual-element detectors which require a well-focused image to achieve maximum sensitivity. A horizontal section through the mirror is shown in Figure 10. The mirror is constructed from five segments, each being an off-axis section from a sphere of radius 80 mm. The segments are mounted on a circle of radius 40 mm so that their foci are coincident. With this type of off-axis design, the detector can be mounted at the focus without obscuring the field of view. Five images of the detector are projected on to the protected area, ensuring the necessary multiple triggering of the alarm. It is possible to increase the number of facets up to twenty in any one plane (the limit being set by the detector field of view of 112° for a 5.2 mm aperture window) and rows could be added above and below to increase coverage in the vertical direction.
The recommended detectors are those which do not respond to wavelengths below μm. Therefore, the major part of the radiation from the sun is not sensed so that an intermittently illuminated background will not trigger the alarm. The dual-element type RPY95 has been designed specifically for intruder alarm applications, the differential connections of the elements minimising the risk of false alarms caused by environmental effects.

Figure 9: **Prototype intruder alarm**

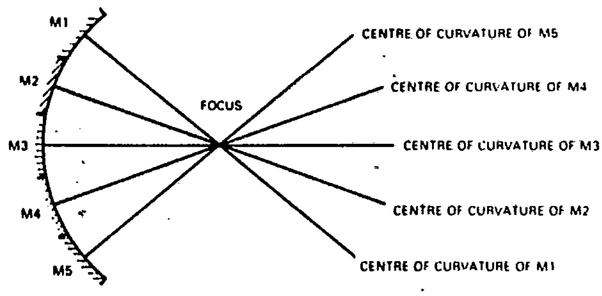


The detector and mirror are housed in an enclosure that has an infrared window made from low-density polyethylene sheeting, which transmits 95% of the radiation in the range of interest. (Plastic 'bin liner' material is often a good substitute.) False triggering effects caused by the thermally-induced motion of the atmosphere are thus minimised.
If, for example, a man in shirt sleeves enters the field of view up to 30 m from the detector, this combination of optics and detector is sufficiently sensative to trigger the alarm circuit.

Practical alarm circuit

The alarm circuit shown in Figure 11 utilises a simple single-shot threshold detector as a trigger.

Figure 10: **Section through multi-faceted mirror**



Some adjustment of sensitivity can be achieved by varying R_{13}. The use of a dual-element detector provides some degree of false alarm immunity; however, this could be further improved by adopting a more sophisticated double-pulse triggering technique. Note, however, that the circuit will work with the single-element devices.

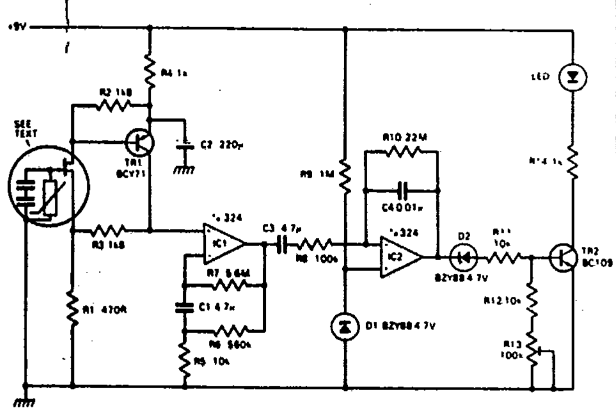
Further application ideas

These ideas are given as a guide to the general possibilities of pyroelectric detectors, circuits or guarantees that they will prove satisfactory cannot be supplied.

Staircase light-switch

The alarm circuit described above can be used to sense the presence of someone in a dark corridor or staircase, and then to switch on the lighting. The circuitry can be simplified, if required, as the possibility of false triggering is normally unimportant. The addition of a light-level sensor and a delay switch will provide a fully automatic system. The same principle may be applied to switch off lighting, heating, etc. when a room (e.g. in a hotel) is unoccupied.

Figure 11: **Circuit of low-cost intruder alarm**



NOTE. R4 may be shorted out in some applications and R2 may be selected around 1k8 for optimum performance.

Fire alarm

The detectors can also find application in fire alarm systems. The flickering nature of a flame and hot gases provide the necessary modulation of the infrared radiation received by the detector. Since flames are copius sources of infrared energy, the use of collecting optics is unnecessary.

The false immunity of such detector systems can be greatly improved by using a window with a narrow bandpass characteristic which restricts incoming radiation to a specific wavelength.

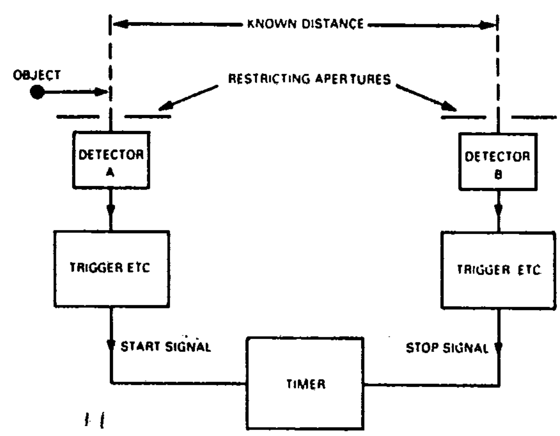
Speed indicator

The detectors can be used for speed measurement. Two detectors are separated by a known distance and each is connected to a circuit consisting of preamplifier, amplifier, and trigger (see Figure 12). The speed of an object moving past the detectors is measured by determining the time between signals from two circuits. (As an alternative to the use of two detectors, a single detector may be used in conjunction with a beam splitter.)

Sorter

The detectors can be employed to sort objects with different temperatures, emissivities, thermal conductivities, or radiation transmission. For example, identical objects on a conveyor belt can be made to pass across the field of view of a detector. The magnitude of the output signal from the detector will be a measure of the temperature of each object with respect to the background. The output signal can control an accept/reject mechanism. A similar technique can be used to mark material in a continuous strip process.

Figure 12: **Speed measurement with two detectors**



Simple radiometer

A simple radiometer may be constructed by placing a mechanical chopper in front of the detector and defining the field of view with an aperture. The signal S from the detector is given by:

$$S = ß\,(e_2T_2^4 - e_1T_1^4),$$

where e_1 is the emissivity of the chopper blade, T_1 is its temperature (in kelvin), e_2 is the emissivity of the target, T_2 is the temperature of the target, and ß is a constant. Variations in T_1 can be compensated by using a linear temperature transducer. A calibrated gain control can be used to allow for variations in emissivity of the target.

Radiometer with compensation for target emissivity
A radiometer that eliminates errors due to variations in target emissivity can be constructed. The target radiation is split into two spectral regions using filters and the radiation from each spectral region is allowed to fall alternatively on to the detector. The ratio of the two output signals from the detector depends only on the temperature of the target. The radiation from the target must be chopped prior to filtering in order that the radiation emitted by the filter can be eliminated as a source of error.

Simple switch
A circuit may be constructed to detect, for example, the presence of a human hand nearby, and thus be used as a proximity switch.

Applications using choppers with collecting optics

Radiometer
The use of collecting optics will increase the radiation energy incident on a detector, in the ratio of the area of the collecting aperture to the area of the sensitive element in the detector. As a result, the temperatures of areas of a remote control radiant object can be measured (if its emissivity is known). The area of the distant object observed is defined by the image of the sensitive element in the collecting optics.

Level sensor
A dual-element detector can be used with a chopper and focused optical system to form a level sensor capable of the remote detection of small temperature discontinuities. A practical application for such an instrument is in the detection of solid or liquid levels in vertical storage tanks and silos. In containers of this type, there is usually a temperature difference between the full and empty parts of the tank. By employing a dual-element detector (elements in series opposition) and a chopper blade which simultaneously masks and exposes both elements; a difference signal is produced. The instrument can thus be used to scan a field of view and produce a maximum difference signal at the level discontinuity.

Spectral analysis
The ceramic pyroelectric detectors may be used in infrared spectrometers. However, the noise equivalent power is a factor of ten higher than that of a Golay cell. Therefore, the bandwidth of the instrument would need to be reduced by 100 times to achieve the same resolution. Some bandwidth, and hence speed, can be recovered by controlling the charts speed so that the writing speed is maintained constant. The lower resolution and speed would, however, probably be acceptable in spectrometers intended for teaching applications.

Gas analysis
The presence of some gases can be detected by the amount of infrared radiation that they absorb at characteristic wavelengths. To detect a particular gas, infrared radiation at the characteristic absorption wavelength of that gas (the radiation is selected by narrowband filters) is passed through a reference chamber, which does not contain the gas, and a sample chamber. The relative transmission of infrared radiation through the two chambers is a measure of the amount of the sought-after gas. The absorption of the gas is likely to be small, so that a long radiation path-length will be needed for a high sensitivity. The long path-length can be accommodated in a small space by the use of multiple reflection between mirrors. This type of system can be used to detect alcohol in the breath ('breathalyser'), and to analyse industrial pollution and car exhaust gases.

Machine tool control
These detectors are sufficiently rugged to allow them to be used in the control of machine tools. A control system might use a detector to count the passage of inteference fringes that are made to move as the work piece or tool is moved. The distance travelled by the work piece or tool is related to the fringe count and the wavelength of the infrared radiation.

General recommendations for the use of Ceramic Pyroelectric Infrared Detectors

1) Care should be taken to avoid damage to or contamination of the window. Finger grease in particular is very difficult to remove and will adversely affect the transmission properties. Solvents other than water should not be used for cleaning windows.

2) The printed circuit board and socket in the neighbourhood of the preamplifier and detector should be thoroughly cleaned. Also, all components should be low-noise or low-leakage types to ensure the best possible performance.

3) The material is inherently piezoelectric as well as pyroelectric. That is, it will produce an electrical output if it is stressed, for example by vibration (mechanical microphony). However, this effect is likely to be small compared with the output signal produced by the variations in the incident radiation flux if the detector vibrates in a non-uniform radiation field (optical microphony). It is therefore important that the detector should be securely mounted, preferably in a standard TO-5 socket.

4) If the detector is to be soldered directly on to a printed circuit board, the leads should not be bent within 1.5mm of the header. This will prevent damage to the glass-to-metal seals in the header. The use of a heat-shunt is recommended during soldering.

5) The case must never be positive with respect to the source or drain terminals, since this is likely to damage the FET.

6) The detector is quite capable of operating at audio frequencies. Although the voltage signal decreases as frequency increases, the noise also decreases (but at a slower rate). The detector may work at higher frequencies still if the radiation is very intense. One obvious precaution is never to operate at mains related frequencies, unless special screening techniques are used.

7) For frequencies greater than the thermal break frequency (1Hz) the output waveform will be triangular for an incident squarewave radiation signal. If necessary, the squareness may be restored by differentiation.

8) The radiation from chopper blades must be subtracted when determining the temperature of a target in the field of view of a pyrometer. This is most important when there is little difference between the chopper and target temperatures.

9) The radiation from the background within the spectral range of the detector should not change within the electrical passband of the system.

10) The 'daylight' filter, fitted to the RPY95 and RPY96, prevents the passage of most of the radiation from a black-body source with its peak emission in the visible region. It blocks visible and short-wavelength infrared radiation but allows the majority of long-wavelength infrared radiation to pass.
The silicon window, fitted to the RPY89, prevents the passage of visible radiation but not short or long wavelength infrared radiation.

11) It is inadvisable to chop radiation on the detector side of the restricting aperture because this will cause an unwanted, modulated signal due to hot-spots within the detector field of view.

12) In a system operating at very low frequencies, air movement in the line of sight of a detector can cause unwanted signals. If the detector is enclosed in a box with an infrared window, air movement close to the detector is reduced. As a result the effect is much diminished.

Typical performance curves

Figure 13: **Responsivity vs. Frequency**

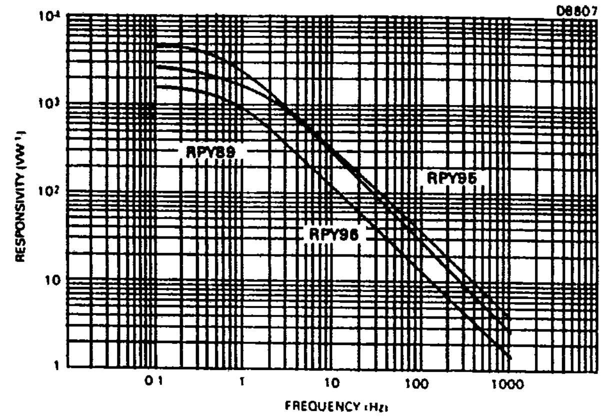


Figure 14: **N.E.P. vs. Frequency**

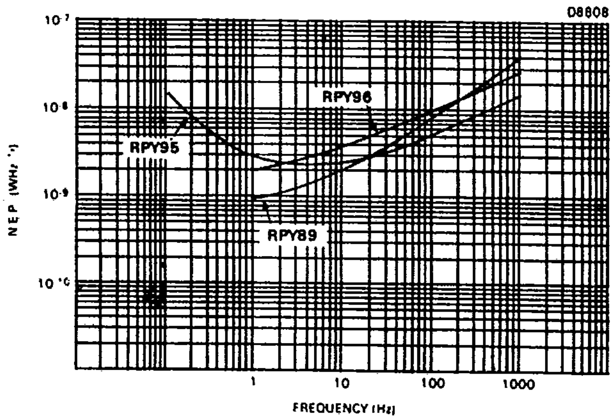
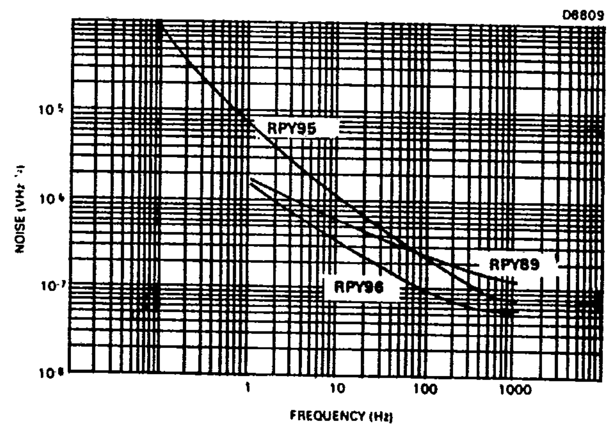


Figure 15: **Noise vs. Frequency**



RS data

Figure 16: **Responsivity vs. Temperature**

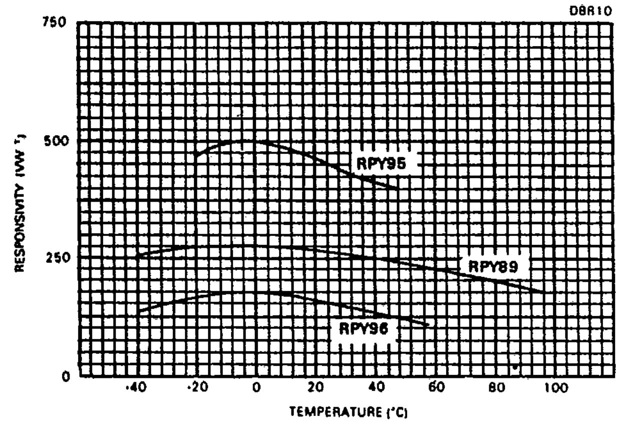


Figure 17: **N.E.P. vs. Temperature**

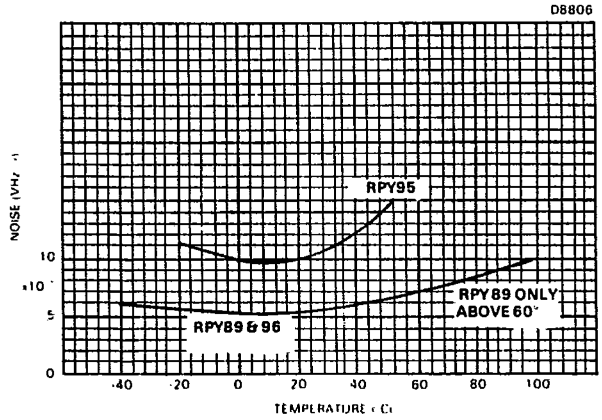


Figure 18: **Noise vs. Temperature**

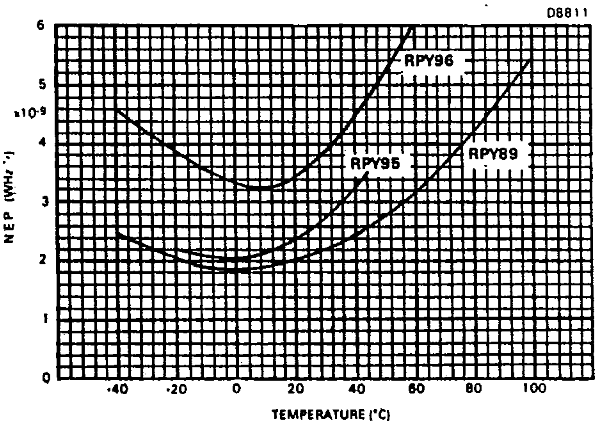
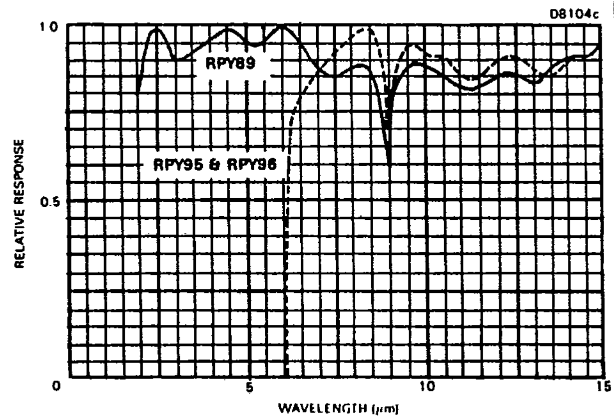


Figure 19: **Typical window transmission characteristics**



R.S. Components Ltd. PO Box 99, Corby, Northants, NN17 9RS
An Electrocomponents Group Company
Telephone: 0536 201234