# DISCRETE PYROS



## KEY FEATURES

1. **BROAD SPECTRAL RESPONSE**
   From 0.1 to 1000 µm

2. **EASY TO INTEGRATE FORMAT**
   TO5 and TO8 packages make the QS detectors small and easy to integrate in an existing system

3. **LARGE AREA SENSORS**
   5 mm Ø and 9 mm Ø diameter pyroelectric sensors make optical alignment easier

4. **SEVERAL IR WINDOWS IN OPTION**
   - Quartz: 0.2 – 3.0 µm
   - Barium Fluoride: 0.2 – 17.5 µm
   - Sapphire: 0.1 – 7.0 µm
   - Silicon: 1.1 – 9.0 µm and 50 – 1000 µm
   - AR Germanium: 8 – 14 µm

## AVAILABLE MODELS

5 families of products to choose from:

- QS-L Discrete Pyro Detectors, Low Noise Level
- QS-H Discrete Pyro Detectors, High Average Power
- QS-VL Hybrid Pyro Detectors, Voltage Mode, Low Noise Level
- QS-IF Hybrid Pyro Detectors, Current Mode, Fast Response
- QS-IL Hybrid Pyro Detectors, Current Mode, Low Noise Level

## ACCESSORIES

QS-I-TEST
Evaluation Test Box (current)

QS-V-TEST
Evaluation Test Box (voltage)

Permanent IR Windows
(Various types available)

Pelican Carrying Case

## SEE ALSO

# QS-L

Approved or in the process of being approved*

Discrete Pyro Detectors, Low Noise Level

## SPECIFICATIONS

| | QS1-L | QS2-L | QS3-L | QS5-L | QS9-L |
|---|---|---|---|---|---|
| **CURRENT RESPONSIVITY** | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| **EFFECTIVE APERTURE** | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| **PACKAGE** | TO5 | TO5 | TO5 | TO5 | TO8 |
| **MEASUREMENT CAPABILITY** | | | | | |
| Spectral Range | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm |
| Max Average Power | 50 mW | 50 mW | 50 mW | 50 mW | 50 mW |
| Capacitance (at 1000 Hz) | 15 pF | 22 pF | 60 pF | 90 pF | 250 pF |
| Current Responsivity (at 630 nm) | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| Thermal Frequency (3 dB) | 3.5 Hz | 1.6 Hz | 0.8 Hz | 0.5 Hz | 0.25 Hz |
| Temperature Coefficient | 0.2%/°C | 0.2%/°C | 0.2%/°C | 0.2%/°C | 0.2%/°C |
| **PHYSICAL CHARACTERISTICS** | | | | | |
| Effective Aperture | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| Package | TO5 | TO5 | TO5 | TO5 | TO8 |
| Sensor | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric |
| Absorber | MT | MT | MT | MT | MT |
| Dimensions | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 13.6Ø x 6.4D mm |
| Weight | 1.0 g | 1.0 g | 1.0 g | 1.0 g | 1.5 g |
| **ORDERING INFORMATION** | | | | | |
| Product Name | QS1-L | QS2-L | QS3-L | QS5-L | QS9-L |
| Product Number | 201657 | 201659 | 201662 | 201664 | 201666 |

Specifications are subject to change without notice

# QS-H

Approved or in the process of being approved*

Discrete Pyro Detectors, High Average Power

## SPECIFICATIONS

| | QS1-H | QS2-H | QS3-H | QS5-H | QS9-H |
|---|---|---|---|---|---|
| **CURRENT RESPONSIVITY** | 500 mW | 500 mW | 500 mW | 500 mW | 500 mW |
| **EFFECTIVE APERTURE** | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| **PACKAGE** | TO5 | TO5 | TO5 | TO5 | TO8 |
| **MEASUREMENT CAPABILITY** | | | | | |
| Spectral Range | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm |
| Max Average Power | 500 mW | 500 mW | 500 mW | 500 mW | 500 mW |
| Capacitance (at 1000 Hz) | 3 pF | 12 pF | 30 pF | 90 pF | 250 pF |
| Current Responsivity (at 630 nm) | 0.25 µA/W | 0.25 µA/W | 0.25 µA/W | 0.25 µA/W | 0.25 µA/W |
| Thermal Frequency (3 dB) | 5 Hz | 5 Hz | 5 Hz | 5 Hz | 5 Hz |
| Temperature Coefficient | 0.2%/°C | 0.2%/°C | 0.2%/°C | 0.2%/°C | 0.2%/°C |
| **PHYSICAL CHARACTERISTICS** | | | | | |
| Effective Aperture | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| Package | TO5 | TO5 | TO5 | TO5 | TO8 |
| Sensor | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric |
| Absorber | MT | MT | MT | MT | MT |
| Dimensions | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 13.6Ø x 6.4D mm |
| Weight | 1.0 g | 1.0 g | 1.0 g | 1.0 g | 1.5 g |
| **ORDERING INFORMATION** | | | | | |
| Product Name | QS1-H | QS2-H | QS3-H | QS5-H | QS9-H |
| Product Number | 201658 | 201661 | 201663 | 201665 | 201667 |

Specifications are subject to change without notice

# QS-VL

Approved or in the process of being approved*

Hybrid Pyro Detectors, Voltage Mode, Low Noise Level

## SPECIFICATIONS

| | QS1-VL | QS2-VL | QS3-VL | QS5-VL | QS9-VL |
|---|---|---|---|---|---|
| **VOLTAGE RESPONSIVITY** | 900 V/W | 200 V/W | 90 V/W | 25 V/W | 15 V/W |
| **CURRENT RESPONSIVITY** | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| **EFFECTIVE APERTURE** | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| **PACKAGE** | TO5 | TO5 | TO5 | TO5 | TO8 |
| **MEASUREMENT CAPABILITY** | | | | | |
| Spectral Range | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm |
| Max Average Power | 50 mW | 50 mW | 50 mW | 50 mW | 50 mW |
| Noise Equivalent Power [a] | $3x10^{-10}$ W/(Hz)$^{½}$ | $6x10^{-10}$ W/(Hz)$^{½}$ | $1x10^{-9}$ W/(Hz)$^{½}$ | $2x10^{-9}$ W/(Hz)$^{½}$ | $5x10^{-9}$ W/(Hz)$^{½}$ |
| Detectivity [a] | $2.9x10^{8}$ cm(Hz)$^{½}$ /W | $3.0x10^{8}$ cm(Hz)$^{½}$ /W | $2.7x10^{8}$ cm(Hz)$^{½}$ /W | $2.2x10^{8}$ cm(Hz)$^{½}$ /W | $1.6x10^{8}$ cm(Hz)$^{½}$ /W |
| Capacitance (at 1000 Hz) | 15 pF | 22 pF | 60 pF | 90 pF | 250 pF |
| Current Responsivity (at 630 nm) | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| Voltage Responsivity [b] | 900 V/W | 200 V/W | 90 V/W | 25 V/W | 15 V/W |
| Thermal Frequency (3 dB) | 3.5 Hz | 1.6 Hz | 0.8 Hz | 0.5 Hz | 2.5 Hz |
| Load Resistor | 300 GΩ | 300 GΩ | 100 GΩ | 100 GΩ | 100 GΩ |
| Supply Voltage | +9 to +15 V | +9 to +15 V | +9 to +15 V | +9 to +15 V | +9 to +15 V |
| **PHYSICAL CHARACTERISTICS** | | | | | |
| Effective Aperture | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| Package | TO5 | TO5 | TO5 | TO5 | TO8 |
| Sensor | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric |
| Absorber | MT | MT | MT | MT | MT |
| Dimensions | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 13.6Ø x 6.4D mm |
| Weight | 1.0 g | 1.0 g | 1.0 g | 1.0 g | 1.5 g |
| **ORDERING INFORMATION** | | | | | |
| Product Name | QS1-VL | QS2-VL | QS3-VL | QS5-VL | QS9-VL |
| Product Number | 201673 | 201674 | 201676 | 201677 | 201678 |

Specifications are subject to change without notice

a. 630 nm, 5 Hz, 1 Hz Bandwidth
b. 630 nm, 15 Hz

## QS-V-TEST EVALUATION TEST BOX

| | QS-V-TEST |
|---|---|
| Batteries | +9V |
| $R_f$ Resistors | $10^{5}$ - $10^{10}$ Ω |
| $C_f$ Compensating | NO |
| Package | 101.6H x 127W x 58.4D |
| Optical Mount | ¼-20 Threaded |
| Front Bezel | SM1 (1.035-40) |
| Product Number | 201694 |

** For details, contact your Gentec-EO representative*


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# QS-IF

Approved or in the process of being approved*

Hybrid Pyro Detectors, Current Mode, Fast Response

## SPECIFICATIONS

| | QS1-IF | QS2-IF | QS3-IF | QS5-IF | QS9-IF |
|---|---|---|---|---|---|
| **VOLTAGE RESPONSIVITY** | 100 V/W | 50 V/W | 50 V/W | 25 V/W | 25 V/W |
| **CURRENT RESPONSIVITY** | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| **EFFECTIVE APERTURE** | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| **PACKAGE** | TO5 | TO5 | TO5 | TO5 | TO8 |
| **MEASUREMENT CAPABILITY** | | | | | |
| Spectral Range | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm |
| Max Average Power | 50 mW | 50 mW | 50 mW | 50 mW | 50 mW |
| Noise Equivalent Power [a] | $5x10^{-8}$ W/(Hz)$^{½}$ | $8x10^{-8}$ W/(Hz)$^{½}$ | $8x10^{-8}$ W/(Hz)$^{½}$ | $1.6x10^{-7}$ W/(Hz)$^{½}$ | $1.6x10^{-7}$ W/(Hz)$^{½}$ |
| Detectivity [a] | $1.8x10^{6}$ cm(Hz)$^{½}$ /W | $2.2x10^{6}$ cm(Hz)$^{½}$ /W | $3.3x10^{6}$ cm(Hz)$^{½}$ /W | $2.8x10^{6}$ cm(Hz)$^{½}$ /W | $5.0x10^{6}$ cm(Hz)$^{½}$ /W |
| Capacitance (at 1000 Hz) | 15 pF | 22 pF | 60 pF | 90 pF | 250 pF |
| Current Responsivity (at 630 nm) | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| Voltage Responsivity [b] | 100 V/W | 50 V/W | 50 V/W | 25 V/W | 25 V/W |
| Thermal Frequency (3 dB) | 3.5 Hz | 1.6 Hz | 0.8 Hz | 0.5 Hz | 0.25 Hz |
| Feedback Resistor | 100 MΩ | 100 MΩ | 100 MΩ | 100 MΩ | 100 MΩ |
| Supply Voltage | ± 12 V | ± 12 V | ± 12 V | ± 12 V | ± 12 V |
| **PHYSICAL CHARACTERISTICS** | | | | | |
| Effective Aperture | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| Package | TO5 | TO5 | TO5 | TO5 | TO8 |
| Sensor | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric |
| Absorber | MT | MT | MT | MT | MT |
| Dimensions | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 13.6Ø x 6.4D mm |
| Weight | 1.0 g | 1.0 g | 1.0 g | 1.0 g | 1.5 g |
| **ORDERING INFORMATION** | | | | | |
| Product Name | QS1-IF | QS2-IF | QS3-IF | QS5-IF | QS9-IF |
| Product Number | 201679 | 201680 | 201681 | 201682 | 201683 |

Specifications are subject to change without notice

a. 630 nm, 15 Hz, largeur de bande de 1 Hz
b. 630 nm, 15 Hz

## QS-I-TEST EVALUATION TEST BOX

| | QS-I-TEST |
|---|---|
| Batteries | +9V/-9V |
| $R_f$ Resistors | $10^{5}$ - $10^{10}$ Ω |
| $C_f$ Compensating | Yes |
| Package | 101.6H x 127L x 58.4P |
| Optical Mount | ¼-20 Threaded |
| Front Bezel | SM1 (1.035-40) |
| Product Number | 201693 |

** For details, contact your Gentec-EO representative*

# QS-IL

Approved or in the process of being approved*

Hybrid Pyro Detectors, Current Mode, Low Noise Level

## SPECIFICATIONS

| | QS1-IL | QS2-IL | QS3-IL | QS5-IL | QS9-IL |
|---|---|---|---|---|---|
| **VOLTAGE RESPONSIVITY** | 50 kV/W | 25 kV/W | 25 kV/W | 13 kV/W | 13 kV/W |
| **CURRENT RESPONSIVITY** | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| **EFFECTIVE APERTURE** | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| **PACKAGE** | TO5 | TO5 | TO5 | TO5 | TO8 |
| **MEASUREMENT CAPABILITY** | | | | | |
| Spectral Range | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm | 0.1 - 1000 µm |
| Max Average Power | 50 mW | 50 mW | 50 mW | 50 mW | 50 mW |
| Noise Equivalent Power [a] | $8x10^{-10}$ W/(Hz)$^{½}$ | $2x10^{-9}$ W/(Hz)$^{½}$ | $2x10^{-9}$ W/(Hz)$^{½}$ | $6x10^{-9}$ W/(Hz)$^{½}$ | $6x10^{-9}$ W/(Hz)$^{½}$ |
| Detectivity [a] | $1.1x10^{8}$ cm(Hz)$^{½}$ /W | $9.0x10^{7}$ cm(Hz)$^{½}$ /W | $1.3x10^{8}$ cm(Hz)$^{½}$ /W | $7.0x10^{7}$ cm(Hz)$^{½}$ /W | $1.3x10^{8}$ cm(Hz)$^{½}$ /W |
| Capacitance (at 1000 Hz) | 15 pF | 22 pF | 60 pF | 90 pF | 250 pF |
| Current Responsivity (at 630 nm) | 1 µA/W | 0.5 µA/W | 0.5 µA/W | 0.25 µA/W | 0.25 µA/W |
| Voltage Responsivity [b] | 50 kV/W | 25 kV/W | 25 kV/W | 13 kV/W | 13 kV/W |
| Thermal Frequency (3 dB) | 3.5 Hz | 1.6 Hz | 0.8 Hz | 0.5 Hz | 0.25 Hz |
| Feedback Resistor | 100 GΩ | 100 GΩ | 100 GΩ | 100 GΩ | 100 GΩ |
| Supply Voltage | ± 5 to ± 12 V | ± 5 to ± 12 V | ± 5 to ± 12 V | ± 5 to ± 12 V | ± 5 to ± 12 V |
| **PHYSICAL CHARACTERISTICS** | | | | | |
| Effective Aperture | 1 mm Ø | 2 mm Ø | 3 mm Ø | 5 mm Ø | 9 mm Ø |
| Package | TO5 | TO5 | TO5 | TO5 | TO8 |
| Sensor | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric | Pyroelectric |
| Absorber | MT | MT | MT | MT | MT |
| Dimensions | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 8.3Ø x 6.4D mm | 13.6Ø x 6.4D mm |
| Weight | 1.0 g | 1.0 g | 1.0 g | 1.0 g | 1.5 g |
| **ORDERING INFORMATION** | | | | | |
| Product Name | QS1-IL | QS2-IL | QS3-IL | QS5-IL | QS9-IL |
| Product Number | 201684 | 201685 | 201686 | 201687 | 201688 |

Specifications are subject to change without notice

a. 630 nm, 5 Hz, 1 Hz Bandwidth
b. 630 nm, 15 Hz

## QS-I-TEST EVALUATION TEST BOX

| | QS-I-TEST |
|---|---|
| Batteries | +9V/-9V |
| $R_f$ Resistors | $10^{5}$ - $10^{10}$ Ω |
| $C_f$ Compensating | Yes |
| Package | 101.6H x 127L x 58.4P |
| Optical Mount | ¼-20 Threaded |
| Front Bezel | SM1 (1.035-40) |
| Product Number | 201693 |

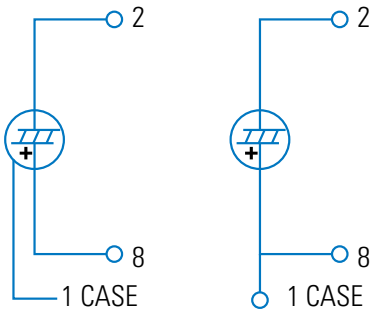
** For details, contact your Gentec-EO representative*

# DISCRETE PYROS



## PYROELECTRIC THERMAL DETECTORS

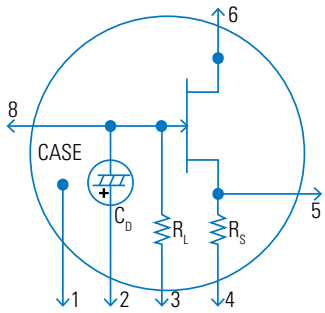
Our pyroelectric detectors are a class of room temperature thermal detectors that produce a current output that is directly proportional to the rate of change of temperature when exposed to a source of radiation. They are best described by an AC current source, capacitor and resistor. Their current output is governed by the equation ***I = p(T)·A·dT/dt***, where ***I*** is current, ***p(T)*** is the Pyro Coefficient, ***A*** is the area as defined by the front electrode, and ***dT/dt*** is the rate of temperature change of the pyro crystal. The advantages of a pyroelectric detector over other IR detectors are: room temperature operation, broad spectral response, high sensitivity (D*) and fast response (sub-nsec into 50 Ω).




QS-L (left) and QS-H (right) Pin-Outs

## QS-L AND QS-H DISCRETE PYROS

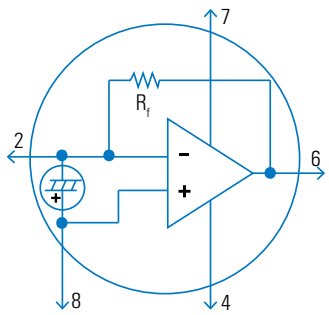
Our passive Discrete Pyroelectric Detectors range from 1 to 9 mm in diameter and are provided in two configurations: high sensitivity or high average power. They present a pyroelectric detector element covered with our metallic coating (MT) and are packaged in a miniature TO-5 or TO-8 can. The diagram shown left identifies the Pin-out for both types of detectors. Our organic black coating (BL), increases the optical absorption and helps flatten the spectral response. We also offer a number of permanent IR Windows that can be added to the TO can. These discrete pyro detectors are ideal for pulsed laser applications.




QS-VL Pin-Out

## QS-VL VOLTAGE MODE HYBRID PYROS

Pyroelectric Detectors are high impedance (>$10^{13}$ Ω) devices that require use in an impedance converting circuit when trying to achieve the highest sensitivity (high D*). Our QS-VL Series detectors include our pyroelectric element mated to an ultra-low noise FET in a source follower circuit. These are in turn packaged in a miniature TO-5 or TO-8 can. The equivalent circuit and Pin-out for this series are shown at the left. They are also available is sizes ranging from 1 to 9 mm diameter. These models are ideal for analytical instrumentation applications like Broadband IR Radiometers, Optical Pyrometer, and/or FTIR Spectrometers.

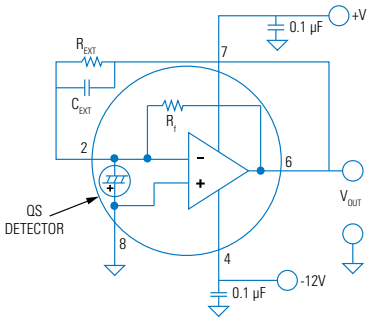



QS-IF and QS-IL Pin-Out

## QS-IF AND QS-IL CURRENT MODE HYBRID PYROS

These detectors offer high gain (>$10^5$ V/W) and/or high bandwidth (>10 MHz). In this configuration, the pyroelectric detector element is combined to a low noise operational amplifier. The QS-IL models are designed for high performance at low to medium frequencies, while the QS-IF models offer good performance at medium to high frequencies. These detectors are very easy to use. Simply supply the +/- 10 to 15 V to power the operational amplifier and add an external resistor, if required, to adjust the bandwidth and you are ready to measure pulsed, modulated or chopped sources, from nJ to mJ and nW to W. These detectors also make great candidates for any variety of broadband analytical instruments or laser measurement products.

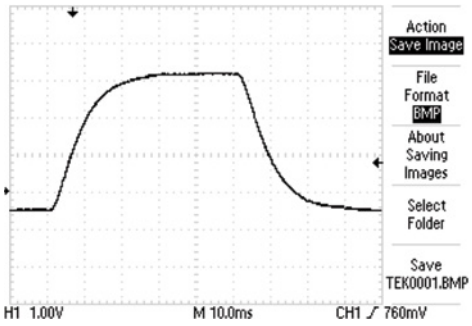
# DISCRETE PYROS




QS-VL and QS-IL Circuitry

## VOLTAGE OUTPUT VS. FREQUENCY

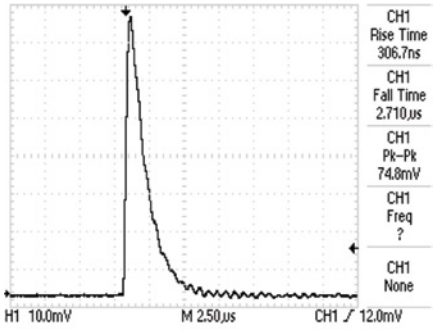
Our QS-VL and QS-IL Hybrid Detectors are designed to maximize voltage output at low frequencies and therefore include load and feedback resistors in the 100 GΩ to 300 GΩ range. They are also designed into 8-pin TO packages that allow the addition of an "external resistor" to lower the output and increase the bandwidth. The circuit diagram at the left shows a typical hook up for our QS5-IL detector (with our MT coating), using external resistors and capacitors. Our QS-IF series, on the other hand, are designed for high bandwidth applications and therefore include a smaller feedback resistor of 100 MΩ. For expert help on designing a detector circuit please contact us info@gentec-eo.com.




Typical QS-IL Voltage Output in Power Measurement Mode

## OPERATION IN POWER MEASUREMENT MODE

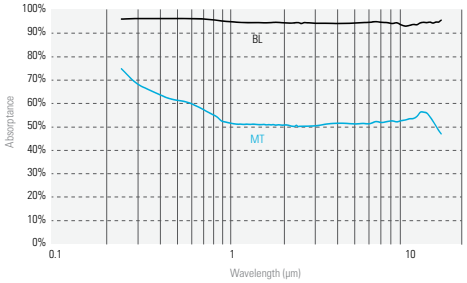
When using our QS-IL Hybrid Detector to measure the Power (in Watts) of your CW or High Rep Rate source (Quasi-CW), you will need to employ an optical chopper. The diagram at the left shows the typical voltage output of a QS5-IL when used with our QS-I-TEST evaluation test box. Note that the voltage output is an approximate "square wave" whose rise and fall times are governed by the RC time constant of the circuit. The optical power is directly proportional to the peak voltage minus the baseline voltage. We calibrate these devices when operating in this mode.




Typical QS-IL Voltage Output in Energy Measurement Mode

## OPERATION IN ENERGY MEASUREMENT MODE

Our Pyroelectric Detectors are an ideal choice when measuring the performance of your pulsed laser in the range of nJ to mJ, across the full spectrum! The scope trace at the left represents the typical output from a QS9-IL, when used with our QS-I-TEST set up as an integrating Joulemeter. Note the fast rise to a peak and then slower decay governed by the RC time constant selected for the integrating circuit. In this configuration you can measure absolute pulse energy, rep rate, and pulse-to-pulse stability. The maximum pulse width of your source is determined by the RC time constant you select and there is no limit as to how short the pulse can be!




Absorption Curves of QS Pyroelectric Detectors

## BROAD SPECTRAL RESPONSE

Unlike photoconductive and photovoltaic detectors, our Pyroelectric Thermal Detectors are not limited to a small part of the electromagnetic spectrum. They are truly broad spectrum detectors, sensitive from 0.1 µm to 3000 µm (EUV, FAR IR, and THz). Any and all radiation absorbed by our coatings or pyro crystal will result in a measurable signal. The two plots at the left show the relative spectral response of detectors with MT and BL coatings. Note that the well documented, NIST traceable calibrated portion of these curves runs from 0.25 µm to 15 µm. There are currently no traceable optical standards for measurements > 15 µm.