TECHNICAL NOTE

OPTICAL TRAP DETECTORS FOR SPECTRAL CALIBRATION

TRAP7-Si-D-BNC & TRAP7-Si-C-BNC

ATTRIBUTES AND FEATURES OF OUR TRAP DETECTORS

- An absolute calibration reference from 440 to 980 nm
- Current Responsivity known to better than 1% in this spectral range
- Spatial Uniformity better than 0.05% over 2.5 mm radius
- Power measurement range 1 nW to 500 μW
- Used to calibrate silicon detectors, optical power meters, fiber optic power meters

WHAT IS AN OPTICAL TRAP DETECTOR?

It is a multi-element optical detector that uses 2 or 3 High Quantum Efficiency (QE) Silicon photodiodes. It is configured so as to bounce the laser light off the detectors 4 or 5 times, depending on the model type. When this occurs, nearly 100% of the photons are captured and generate a predictable current output: one electron for every photon. This defines a detector with 100% Quantum Efficiency (QE).

HISTORY OF THE OPTICAL TRAP DETECTOR

Gentec-EO's solution to this issue is to use a regular UP series power A version of the optical TRAP detector was originally designed and developed by Dick Duda while at United Detector Technology in the early 70's. It used 4 detectors and was claimed to achieve 100% quantum efficiency. It was their model QED-100.

Over the next decade or so, scientist at NIST (National Institute of Standards and Technology) developed this technology further for use as a spectral calibration transfer standard. They were calibrated against their Cryogenic Radiometer at multiple wavelengths from 406 to 950 nm (ref. Cromer Article in Applied Optics / Vol.35, No.22/8-01-96).

In 2007 the NIST optical TRAP technology was transferred to Spectrum Detector Inc., now a part of Gentec-EO, Inc. Design improvements were made to make them easier and more repeatable to manufacture.

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SO HOW DO OPTICAL TRAP DETECTORS WORK IN THEORY?

The equation for the Quantum Efficiency of a photodiode is shown below:

$$\eta_e = hc/en\lambda * R_i$$

where...

- η_e is Quantum Efficiency
- h is Planck's constant, 6.62608.10-34 Js
- c is the speed of light, 2.99792.108 m/s
- e is the electronic charge, 1.60218.10-19 C
- n is the index of refraction in air, 1.00029
- λ is the wavelength of the incident light in nanometers (nm)
- R_i is the current responsivity in A/W

Simplified, the equation for the Ri of a TRAP Detector becomes:

$$R_i = \eta_e * \lambda / 1239.5$$

For example, the absolute current responsivity for the TRAP7-Si-C-BNC at 632.8 nm, assuming a Quantum Efficiency of 99 % (0.99) is:

$$R_i = (0.99 * 632.8) / 1239.5$$
$$R_i = 0.5054 \text{ A/W @ } 632.8 \text{ nm}$$

LET'S TAKE A LOOK AT TWO GRAPHS THAT SHOW CURRENT RESPONSIVITY VS. WAVELENGTH

In the two plots below, we can see how the Quantum Efficiency of both our TRAP7-Si-D-BNC (4 bounce) and TRAP7-Si-C-BNC (5 bounce) are significantly enhanced by multi detectors (i.e. multiple reflections). The straight purple line represents R_i at 100% Quantum Efficiency; the red plot shows R_i for a single detector (i.e. 1 bounce); and the blue line shows the near 100% QE of our TRAP Detector.

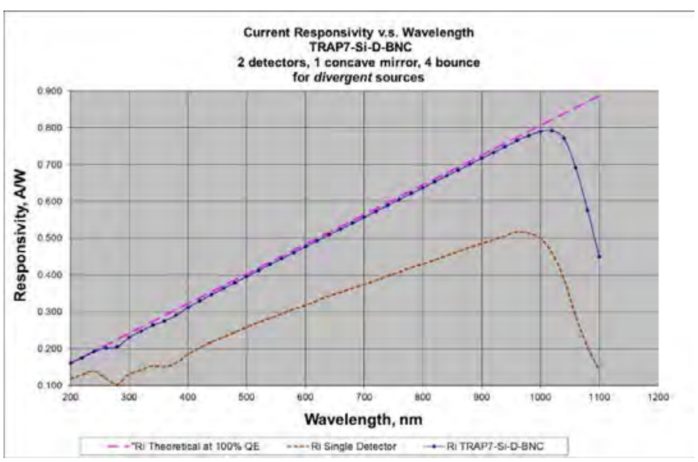

FIG. 1 Current Responsivity (R_i) vs. Wavelength of Model TRAP7-Si-D-BNC Divergent TRAP

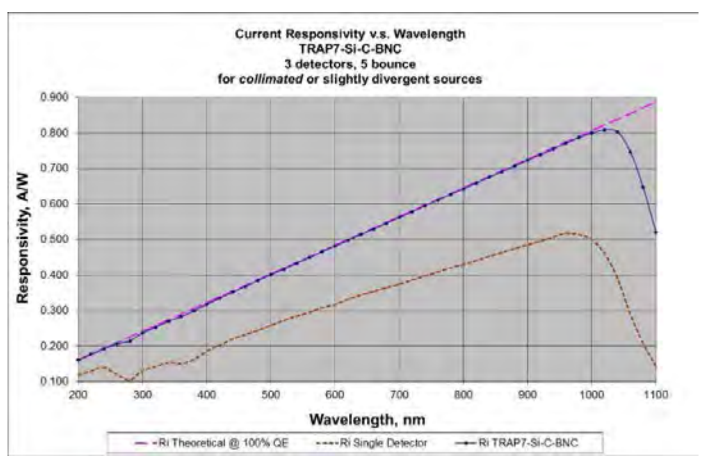

FIG. 2 Current Responsivity (R_i) vs. Wavelength of Model TRAP7-Si-C Collimated TRAP

Notice how close the current responsivity of both types of TRAP detectors is to the 100% QE line, especially in the range from 440 nm to 980 nm. The TRAP7-Si-C-BNC is the closest to 100% QE because of the additional detector and 5 reflections. Hamamatsu provided the Quantum Efficiency data for the typical high QE photodiode, from which these plots were determined.

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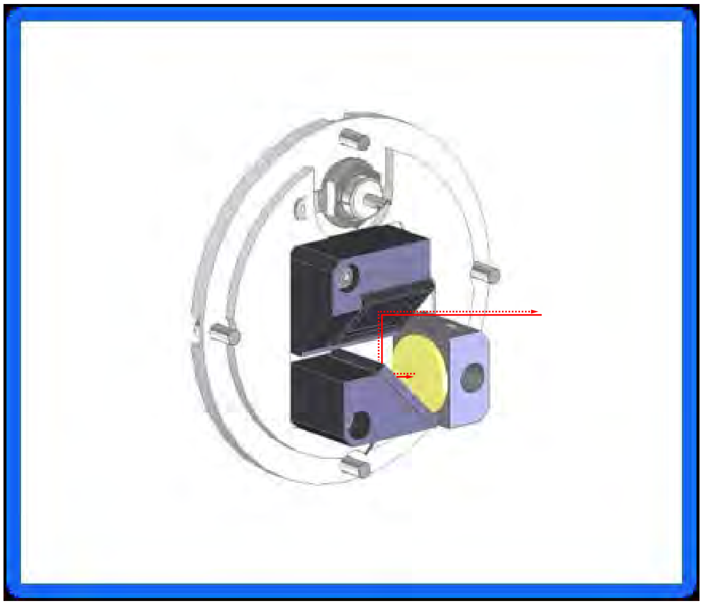
HERE'S A RENDERING THAT SHOWS THE OPTICAL PATH FOR OUR TRAP7-Si-D

The solid red line represents the laser light entering the TRAP, bouncing off detectors 1 and 2, before reflecting off the silvered concave mirror, then back off detectors 2 and 1 as the light (what's left of it!) exits the TRAP.



For a divergent source, like the output of a fiber laser, the concave mirror in this assembly re-collimates the laser light. In our TRAP7-Si-C probe, the mirror is replaced with a 3rd detector and therefore is not the best choice for a divergent source.

OUR TRAP DETECTOR ASSEMBLIES

The photos below show the two different TRAP configurations. The TRAP cover has been removed to view the detector and mirror components.

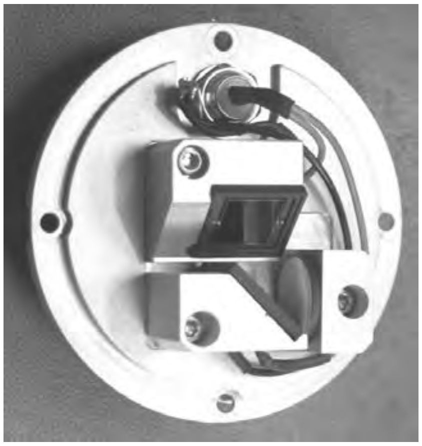


FIG. 3 TRAP7-Si-D-BNC

FIG. 4 TRAP7-Si-C-BNC

OUR CALIBRATION METHOD AND NIST TRACEABILITY

Based on the desire of many of our customers to have NIST traceability, we calibrate each detector against our standard SST-TRAP-D detector (s/n 1001), which was spectrally calibrated at NIST Boulder in 2007. Our calibration is done at a single wavelength, 623.8 nm, using a stable (<0.5% drift), 50 μW, HeNe laser source. Our TRAP Detector standard (s/n 1001) was recently (September 2014), re-tested at NIST to confirm its calibration. The current responsivity, at 632.8 nm, was within 0.5% of the calibration 7 years prior. These detectors are very stable over time!

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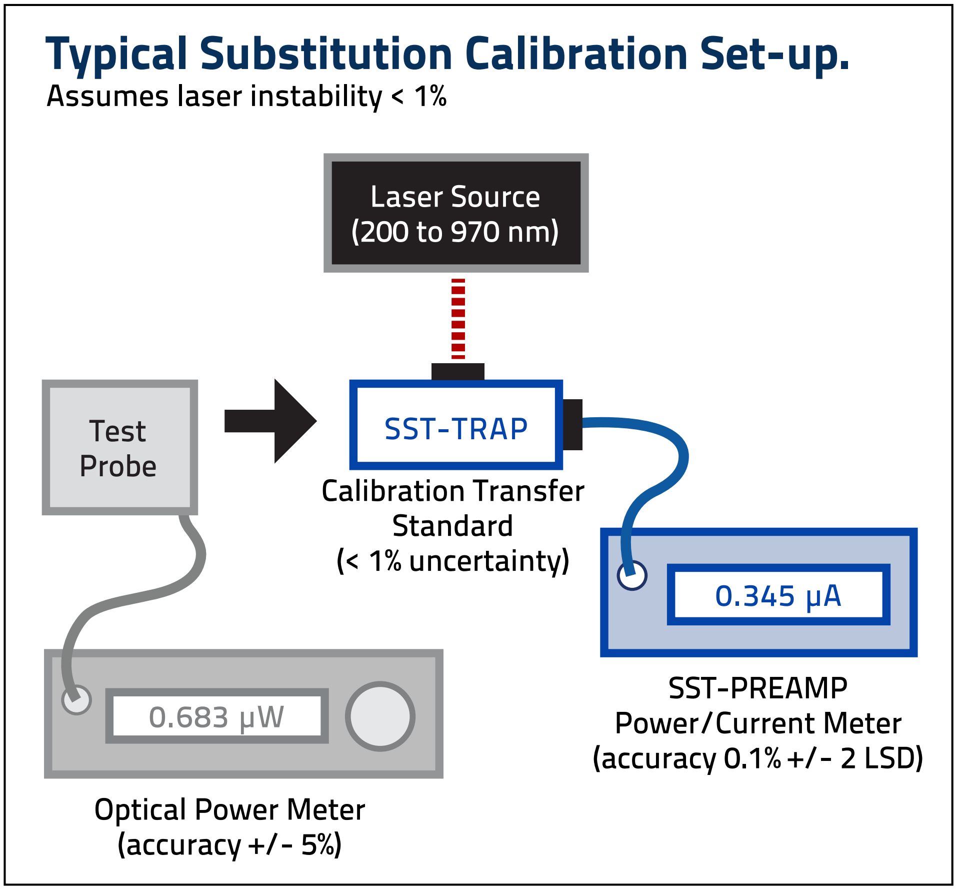
HOW ARE THEY USED TO MAKE ABSOLUTE POWER MEASUREMENTS?

In the diagram below, you can see that the TRAP detector is read out using a precision (0.1 % uncertainty) Current meter, like our TRAP-PREAMP or a Keithley 486 Picoammeter. Now follow these steps:

1. Carefully align your TRAP Detector to your laser source. Note that the beam diameter should be 5 mm or less and centered in the 7 mm diameter aperture
2. Measure the current output and record the number
3. Calculate the laser power by dividing this number by the current responsivity of the TRAP detector at the wavelength of use
4. Now use this power measurement to transfer calibration to the detector under test (DUT)



Our TRAP7 Detectors are an excellent choice to use as a low uncertainty Wavelength Calibration Standard for optical detectors (Si, Ge, InGaAs), optical power meters, and fiber optic power meters in the spectral range from 440 nm to 980 nm.