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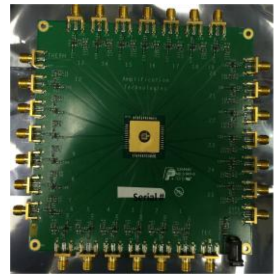
Application Notes: Discrete Amplification Photon Detector 5x5 Array Including Pre-Amplifier Board



General Description

The 5x5 Discrete Amplification Photon Detector (DAPD) array is delivered in a custom hermetically sealed package, which is connected to a printed circuit board with an array of electronic pre-amplifiers. The custom hermetically sealed Covar package contains a two-stage thermoelectric cooler (TEC), a thermistor for temperature control and the 5x5 DAPD photon detector array. The 5x5 DAPD photon detector array has a square optically-sensitive area of 0.5mm by 0.5mm with 25 elements arranged as a 5 columns and 5 rows array. The pitch of the elements is 100 µm, and the fill factor is 81%. Each element is isolated electrically and optically from its adjacent neighbors. The optical window is made of BK7 glass; it is centered on the top side of the Covar package. The DAPD 5x5 Array package is soldered into a 5.5" by 5.5" sized printed circuit board, where a heat sink is attached to the bottom of the custom Covar package.

Each of the 25 detector elements is connected to a separated pre-amplifier channel that terminates on a SMA connector, one for each of the 25 elements of the 5x5array. The array is supplied with an AC power supply for the electronic amplification network. Not supplied, but necessary for operation, are a DC power supply for the DAPD detector array, a 12V DC supply for the liquid cooling fan and circulator, and a temperature controller that uses a negative temperature coefficient (NTC) feedback thermistor.

Inputs and Outputs

Inputs

Total of 4 Connectors:

Function	Connector Type
DAPD-Array DC bias	SMA connector
Pre-Amplifiers electronic network power supply	2.0 x 6.5mm jack high current connector

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Liquid cooler circulator + fan	2.0 x 6.5mm jack high current connector
Thermo-Electric Cooler (TEC) bias	SMA connector

Outputs

Total of 26 SMA connectors:

Function	**Connector Type**
1 to 25 Array elements; marked with an ID number ranging from ID = 1 to ID = 25	25 SMA connectors
Thermistor output	SMA connector

Electronic Connections

Array Structure

The 5x5 DAPD array is a back-illuminated photodetector. The dimensions of optical aperture area are 0.5 x 0.5mm, with 25 elements arranged as a 5 columns and 5 rows array (see Fig. 1). The pitch of the elements is 100 µm, and the fill factor is 81%. The array elements are separated by 10µm wide strip of metal, to effectively open a 90µm x 90µm array element, or pixels, as can be seen in Fig. 1. The light-blue surface shown in Fig. 1 is the metal. The metal contact is shared among all the 25 elements to form a **common cathode**. The dark-blue area shown in Fig.1 is the anti-reflection coated active area of the 25 elements (pixels).

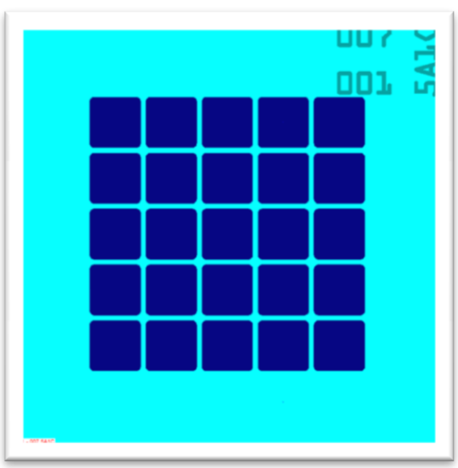

Figure 1: Illuminated (cathode side, aka backside) DAPD 5x5 array aperture and metallization scheme

On the other side of the detector, not shown in Fig. 1, each array element has a separated anode connection. The array elements (pixels) are separated from each other electronically as well as optically, forming an effective active detector element of 90µm x 90µm, in a 100µm x 100µm pitch. The fill factor of this 5x5 array is thus 81%.

Electronic Pre-Amplifier Scheme

The electronic bias and signal-out diagram is designed to bias all the 25 array elements with **the same constant voltage bias**. In addition, it is designed to extract the photon-detection charge pulse using 25 separated pre-amplifiers, one for each array element. The DAPD array bias is thus a negative voltage that is applied to the anodes and the ground is connected to the common cathode, as well as the ground plane of the 25 pre-amplifiers network. The schematic connection diagram is described in Fig. 2. Note that the amplified "signal out" is connected using a capacitor, aka "AC coupling". Thus there is no direct current connection to the anode via the 25 signal out SMA ports. The pre-amplifiers, as well the as the board and the SMA ports, are designed and matched to 50Ω impedance. Thus a 50ΩOhm termination ADC is required to be used at the output.

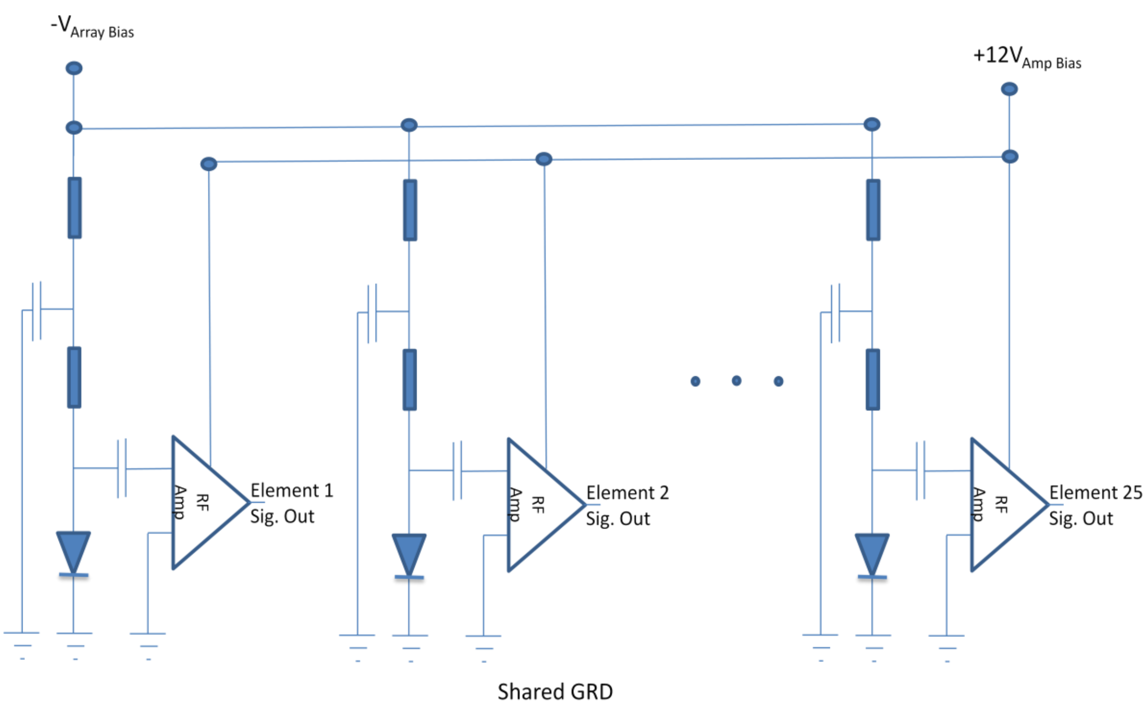

Fig. 2: Schematic connection diagram of the 5x5 array and the 25 electronic pre-amplifiers network

As can be seen in Fig. 2, the DAPD Array negative bias ("-$V_{ArrayBias}$" in Fig.2) is **shared among all the 25 array elements**. That means that all the 25 elements are biased with the same negative voltage. There is no option to individually bias elements at different

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levels. In addition, each array element is coupled to a dedicated RF pre-amplifier. Note that the RF SMA Connector is AC coupled to the element, thus it is not possible to bias the array-element via the SMA connecter of this element. There is only one DAPD-Array bias input, which is the dedicated SMA connected marked as "DAPD Bias", which is connected in parallel to all 25 elements.

The pre-amplifier network layout is such that the electric distance between the array elements is minimized. The variation in signal position in time (jitter) caused by the pre-amplifier circuit board is lower than 100ps.

Testing and Characterization Procedures

Biasing

NOTE: THE 5X5 ARRAY IS EXTREMELY ELECTROSTATIC DISCHARGE (ESD) SENSITIVE. PROPER GROUNDING STRAPS, ANTI-STATIC MATS AND OTHER STANDARD ELECTROSTATIC DISCHARGE PROTECTIVE EQUIPMENT AND METHODS ARE NECESSARY WHEN HANDLING OR TESTING THESE DEVICES.

The 5x5 DAPD array is a single-photon-sensitive detector array that can also operate as a conventional avalanche array detector. Operating the detector array as a single photon detector is the main application focus, which is addressed in this document. The detector array is comprised of a negative feedback circuit that is integrated with each of the individual 25 array elements. The sensitivity to single photons occurs when the detector is in the so-called Geiger mode operation mode. This is a bias in which the avalanche region of the DAPD is biased above the breakdown voltage. Note, that as with any avalanche photodetector, the operation bias is reversed: the anode potential (voltage) is lower than the cathode potential (voltage).

FORWARD BIASING THIS DEVICE WILL DAMAGE IT.

The DC biasing should be limited to current lower than -20µA.

The following operating procedure is recommended:

It is highly recommended to use a DC bias source with a compliance setting capable of compliance of ± 20µA.

1. Cover the Detector to minimize the ambient light reaching the 5x5 array
2. Connect the TEC, Thermistor, DAPD Bias, and the element(s) under test (e.g. element #15). Do not apply DAPD Bias yet.
3. Set the desired temperature (e.g. -30°C);

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4. Connect the 12V DC Bias using the supplied AC to DC adapter to the Board
5. Connect the 12V DC Bias using the a AC to DC adapter to the cooler and Fan
6. To achieve low array operating temperature of -50°C, external fans are required (not supplied)
7. Wait for and confirm temperature stabilization
8. To apply the DAPD DC bias: start with a low bias of -1VDC, and then gradually increasing the bias to the recommended operation bias, at the desired temperature, based on the test report document.
9. Wait for dark current stabilization. Since the electronic circuit contains capacitors, it takes several seconds for the capacitors to charge up.
10. Observe the dark pulse signal on an oscilloscope and gradually increase the bias to begin the desired measurement

Multi-Photon Pulse Response

The DAPD photon detector response is proportional to the number of photons that arrive. Thus the output charge, which is generated by the detector, is proportional to the number of arriving photons. The linearity range depends on the detector size, the number of amplification channels, and the photon detection efficiency (PDE, see below). Biasing the detector is done in a continuous mode with a constant DC current. Detecting the output pulse is done using any 50Ω analog circuit, such as an analog to digital converter (ADC) or an oscilloscope.

In addition, the linearity, the photon number throughput and the saturation level are related to the recovery time of each of the amplification channels, which is approximately 30ns. In illumination levels below the saturation level, the DAPD is always on, and does not have any dead time. Once all channels of a specific detector element are issuing a response charge, the detector becomes saturated and the linearity is reduced. However, electric field shielding, as well as gain saturation effects, allow for a monotonous signal increase as the number of photons increases above the saturation level. This behavior is shown schematically in Fig. 3. As can be seen in Fig. 3, there are two regions of linearity as a function of the illumination level: A Linear Region (1), up to ~1200photons/pulse, and a Monotonous Region (2), above ~1200 photons/pulse.

Region one, the linear region, ends with what we refer to as the saturation level of the detector, shown as the "knee" of this chart, which is approximately 1200 photons per pulse, in the specific DAPD detector, whose characterization is shown in Fig. 3. The linearity measurement shown in Fig. 3 was performed with a standard DAPD, which has a larger number of amplification channels than the 5x5-array element, and thus a higher saturation level. The saturation level of each the 5x5-array elements is approximately 600 photons per pulse (not shown). Whatever the saturation level, the linearity behavior

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is similar to the one shown in Fig. 3, exhibiting two ranges: the linearity range and the monotonously increasing signal level range.

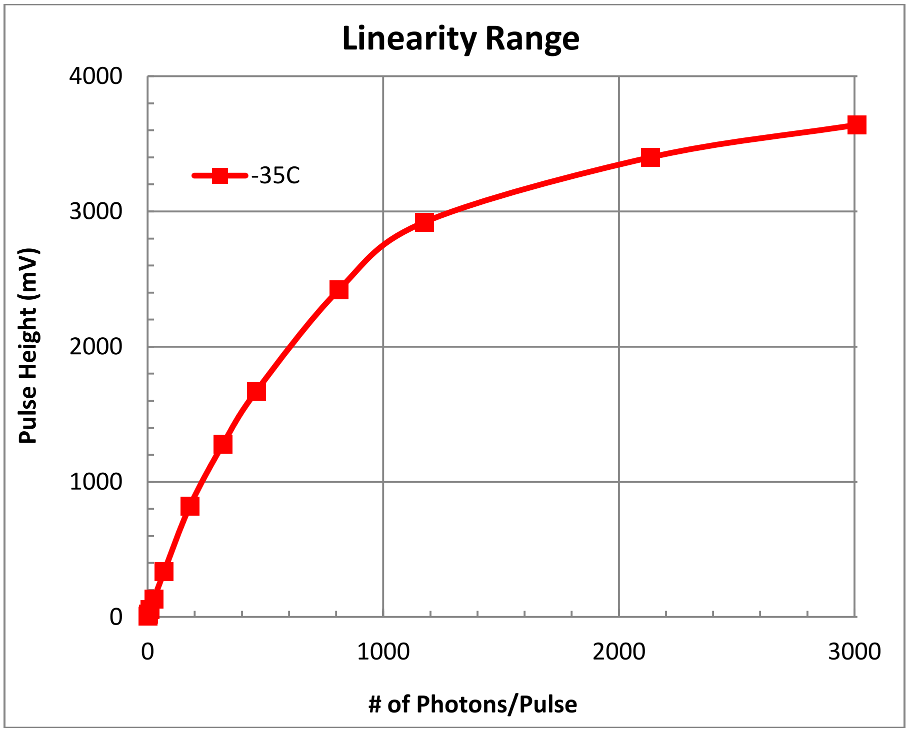

Fig. 3: Typical linearity ranges

Test Report Information

The device has a unique serial identification number that is marked on the PCB. It is sent to the customer with a test report that includes the dependence of the main characteristics for operation as a single photon detector on the bias and operating temperature, which include:

- Dark Count Rate (DCR)
- Photon Detection Efficiency (PDE)
- PDE Temperature Dependence

These measurements are provided as a function of the bias (DCR, PDE) or the temperature.

Dark Count Rate

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As the single photon response pulse is large (e.g. a 5mV pulse), a better measure for the noise generated by a Geiger mode operated photon detector is the dark signal. The term Dark Count Rate (DCR) will be used in this document, even though it is not an accurate term for the DAPD. The reason is that this terminology was first used by conventional avalanche photodetector that are operated under Geiger mode conditions (GM-APD). These GM-APD detectors generate a reading ("a count") regardless of the number of photons. In contrast to GM-APDs, the DAPD will generate a higher-level signal when, say, two thermal-photons are absorbed simultaneously. Nevertheless, the "count" terminology is widely used as a measure of the noise, hence the use in this document. Any level of a dark pulse generated by the DAPD is counted as a "count".

The source of the dark pulses are various thermal / electric field interaction processes, which generate photons that are absorbed in the active area of the detector, and hence generate a response pulse. The higher the (reverse) bias the larger the number of these false pulses per second, because of two main reasons: the generation of photons is higher as the electric field is higher, and the photon detection efficiency improves as the electric field inside the detector is higher.

Photon Detection Efficiency (PDE)

The PDE is the probability that a single-photon that is illuminated on the active area is detected. This measurement is done by carefully calibrating the light source to emit a known number of photons per pulse, e.g. 0.5 photon/pulse (Note that photons are discrete, and obey Poisson distribution: in a given photon there is a probability of 0, 1, 2, etc., photons, based on the Poisson distribution, with a Poisson average of 0.5) . Next, the active area needs to be isolated from any background light, e.g. a dark chamber. The measurement is typically done in a pulse mode, in a way that allows for triggering the response to an anticipated photon. Comparing the average number of detected photons to the emitted ones (average), determines the PDE.

The PDE increases as the bias increases because the internal filed that is build inside the avalanche region helps improve the collection of the photons, as well as the generation of a an output signal. However, higher bias also generates higher dark thermal and other events (such as tunneling), which leads to the existence of an optimal signal to noise ratio bias. In the test report we present this value as the operating bias, and report the PDE, as well as the DCR at that bias, in both a table and two charts.

The user can select to operate at a different bias, optimizing for a given acceptable DCR for example.

WHEN OPERATING THE DAPD 5X5 ARRAY AT BIASES ABOVE THE RECOMMENDED ONE, DO NOT TO EXCEED 20 µA OF DIRECT CURRENT THROUGH THE ARRAY USING THE DAPD BIAS CONNECTOR

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Correlation between Connector (pixel) IDs and Array Location

Each of the 25-SMA connectors is marked with an identification number between 1 and 25. The location and orientation of each corresponding pixel in the 5x5 array is described in Fig. 4. The right-hand side shows a board overlaid with the actual location of each pixel. The left-hand side shows an enlargement of the pixel location representation. Note that Fig. 4 is not to scale.

13	14	16	18	20
11	12	17	19	21
10	9	15	22	23
8	7	4	1	24
6	5	3	2	25

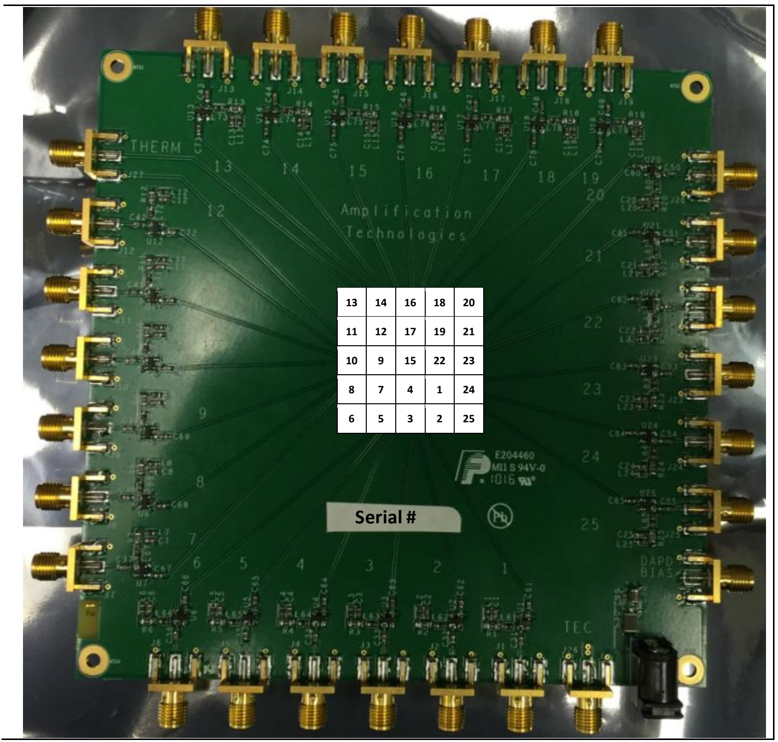

Fig. 4: Correlation between connector (pixel) IDs and array location

Variation of Performance between Array-Elements (Pixels)

The expected variation range between the center pixel, (#15) and the four corner pixels (13, 20, 6 and 25, as can be seen in Fig. 4) is presented in the test report. Since the size of the entire active area of the array is small (0.5mm^2), the variations of various performance parameters across the array are small.

Temperature Dependence of Parameters

The test report includes a chart of the operating bias at temperatures of 25°C, 0°C, and -30°C. The PDE at this operating bias for each temperature measurement is approximately 18%.

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Cooling

ALWAYS USE ACTIVE FEEDBACK COOLING WHEN OPERATING THE 5X5 DAPD ARRAY

Because the printed circuit board, as well as the thermoelectric cooler, generates heat, it is recommended to always use active feedback based temperature control at all times while operating the 5x5 DAPD array. In addition, to avoid heating of the board when not in use, disconnect the electronic pre-amplifiers 12V power supply when not in use.

The Kovar package consist of a two-stage thermoelectric cooler (TEC) and a thermistor. The thermistor is located at the top surface of the cooler, close to the actual 5x5 array, and thus represents the actual temperature of the active array. The TEC and the thermistor have two dedicated marked SMA connectors on the Board. The thermistor is a Negative Temperature Coefficient (NTC) type, with resistance of 2.2kΩ at 20°C. Recommended for use is the *Newport LDT-5500B Precision Thermoelectric Temperature Controller* or equivalent.

The Steinhart-Hart parameters for this thermistor are:

A = 0.775
B = 3.425
C = 0.002

Cooling Operations and Guidance

When the two-stage thermoelectric cooler (TEC) operates in cooling mode, it has a hot surface that needs to be cooled too. It is soldered onto the Kovar package, which is connected to a heat sink radiator. The temperature of the cold side of the TEC is a strong function of the heat sink capabilities of the mechanism that is connected to the hot side of the TEC. The 5x5 DDAPD array board is supplied with a passive radiator type heat sink, which is shown in Fig. 5. This heat sink allows for steady state cooling that sets the DAPD 5x5 array at -30°C. The current should be limited to below 1.0A in these conditions, without additional cooling of the heat sink. The addition of active cooling, using a heat exchange liquid cooler, can reduce the minimum steady state temperature by up to 10°C (liquid exchange). It is recommended to add external fans to help cool the printed circuit board, which helps in reducing the array temperature by reducing the heat flow from the PCB into the array via the wirebonding.

As with all TECs, momentary cooling can occur, which is lower than the steady state reachable temperature, when higher values of current flow through the TEC. **Yet, our recommendation is to limit the current flow through the TEC to 1.0A, and the temperature setting to -40C.**

Additional Information

For additional application information and operation related questions, please contact our technical team via email at contact@amplificationtechnologies.com.

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