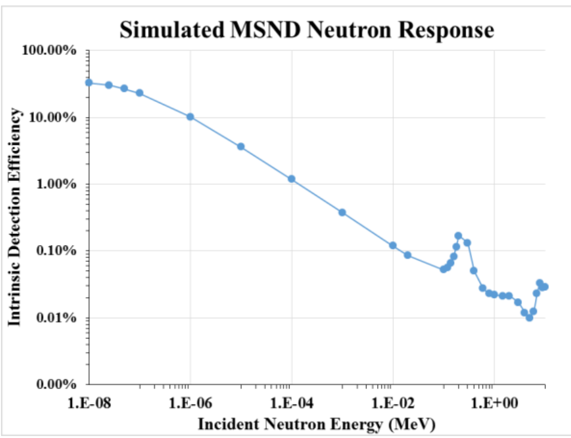
# Microstructured Semiconductor Neutron Detector (MSND®)

***[Updated: June 25, 2021]***

## Description:

The MSND® Tile technology implements $^{6}$Li conversion to yield a thermal neutron detection efficiency of 30%. Optimum HDPE moderator for $^{252}$Cf neutron source at 1-m is 3-4 cm in front and 3-6 cm behind the MSND® sensor.



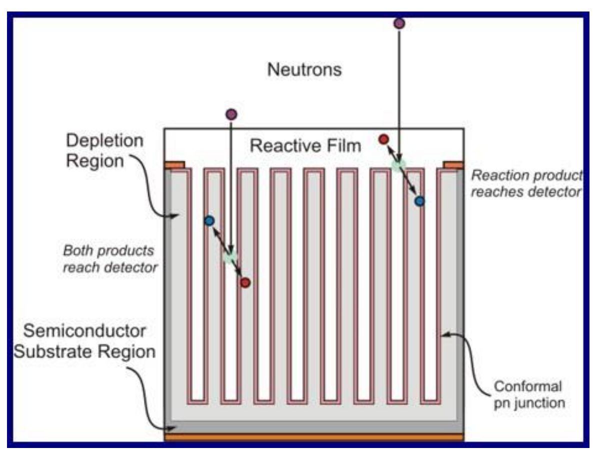


## Features:

- Surface mount ceramic package
- Silver RF integrated shielding
- Thin form factor
- Dimensions: 12.6 x 12.6 x 2.4 mm
- 20-30% thermal neutron efficiency
- Low power
- Low voltage
- Solid State
- 1-cm$^2$ active area

## Solid-State Neutron Detection Applications:

Neutron detector applications include those for homeland security (e.g., border screening), fundamental research (e.g., neutron scattering beamlines), and industrial monitoring (e.g., personnel monitoring, water content in soil). Solid-state neutron detectors provide an alternative to the $^{3}$He-based detectors, maintaining a high thermal-neutron detection efficiency, at a fraction of the volume, mass, voltage, and power required from gas or liquid detectors. Recommend AC coupling to electronic readout circuit.



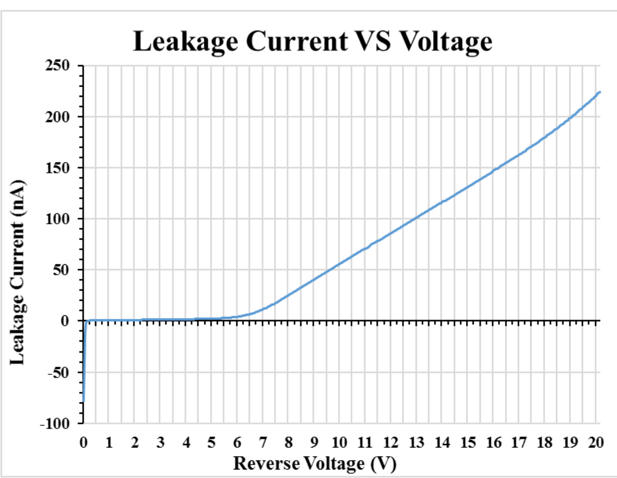
| **ABSOLUTE MAXIMUM RATINGS ($T_a$ = 25°C)** | | | |
|---|---|---|---|
| **PARAMETER** | **SYMBOL** | **VALUE** | **UNIT** |
| Reverse voltage | $V_R$ | 50 | V |
| Operating temperature range | $T_{amb}$ | -40 to 60 | °C |
| Storage Temperature | $T_{stg}$ | -40 to 100 | °C |

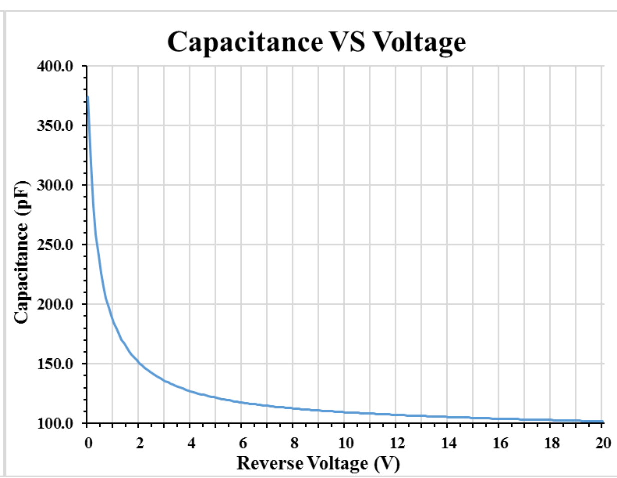
| **BASIC CHARACTERISTICS ($T_a$ = 25°C)** | | | | | | |
|---|---|---|---|---|---|---|
| **PARAMETER** | **TEST CONDITION** | **SYMBOL** | **MIN** | **TYP** | **MAX** | **UNIT** |
| Forward Voltage | $I_F$ = 50mA | $V_F$ | | 1.05 | | V |
| Breakdown Voltage | $I_R$ = 50µA | $V_{(BR)}$ | 28 | 60 | >110 | V |
| Diode Capacitance | $V_R$ = 0V, f = 1MHz, E = 0 | $C_D$ | | 374 | | pF |
| | $V_R$ = 5V, f = 1MHz, E = 0 | $C_D$ | | 121 | | pF |
| Leakage Current | $V_R$ = 3V | $I_L$ | 3 | 8 | 20 | nA |
| Leakage Current | $V_R$ = 5V | $I_L$ | 17 | 31 | 240 | nA |
| Operating Voltage | Recommended | $V_R$ | 1 | 2.5 | 5 | V |
| Est. Average Charge Per Neutron Capture | | $Q_{av}$ | | 80 | | fC |

| **BASIC CHARACTERISTICS ($T_a$ = 55°C)** | | | | | | |
|---|---|---|---|---|---|---|
| **PARAMETER** | **TEST CONDITION** | **SYMBOL** | **MIN** | **TYP** | **MAX** | **UNIT** |
| Leakage Current | $V_R$ = 2V | $I_L$ | 500 | 550 | 600 | nA |
| Leakage Current | $V_R$ = 3V | $I_L$ | 600 | 750 | 850 | nA |

| **BASIC CHARACTERISTICS ($T_a$ = 60°C)** | | | | | | |
|---|---|---|---|---|---|---|
| **PARAMETER** | **TEST CONDITION** | **SYMBOL** | **MIN** | **TYP** | **MAX** | **UNIT** |
| Leakage Current | $V_R$ = 3V | $I_L$ | 1000 | 1150 | 1500 | nA |

**BASIC CHARACTERISTICS ($T_a$ = 25°C)**



## MSND Tile Assembly Notes:

- The MSND Tile is **Moisture Sensitive MSL 5a** according to IPC/JEDEC J-STD-020. Follow IPC/JEDEC J-STD-033B handling and storage protocols.
- Solder-paste stencil mask recommendation in MSND Package Drawing below.
  - Stencil thickness recommendation is 5-mil.
  - Solder paste recommendation is Alpha OM-5100.
  - No-clean solder paste is required.
  - Do not clean the sensors in ultrasonic baths.
  - Do not use water clean solder paste, the MSND Tile is not hermetically sealed.

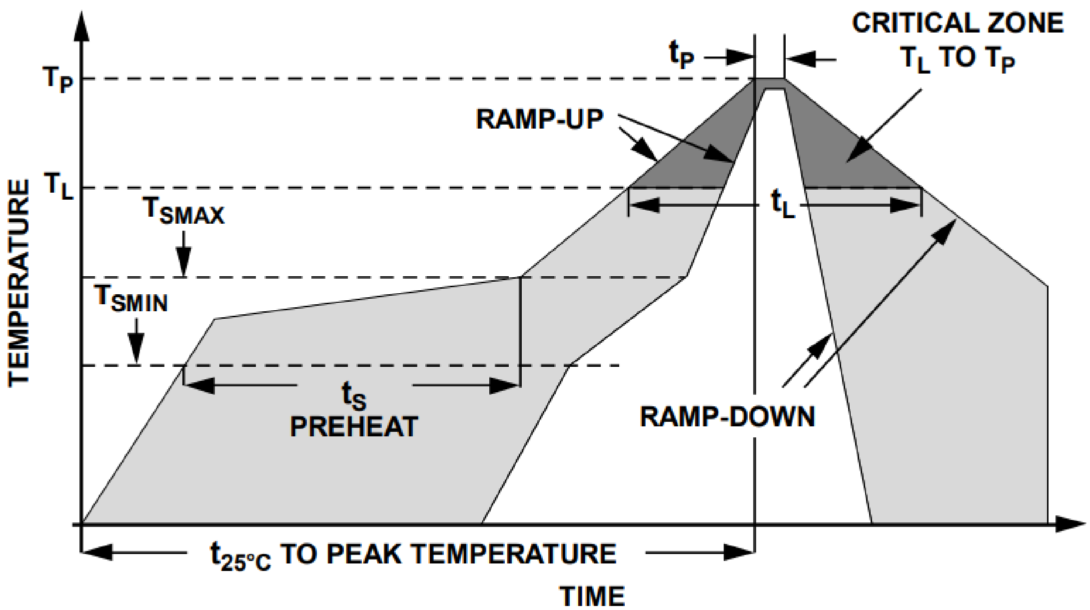



**Figure 1: Recommended solder paste reflow profile for solder paste Alpha OM-5100.**

| | |
|---|---|
| Average Ramp Rate ($T_L$ to $T_P$) | 1°C/second |
| Preheat | |
| Minimum Temperature ($T_{SMIN}$) | 150°C |
| Maximum Temperature ($T_{SMAX}$) | 180°C |
| Time ($T_{SMIN}$ to $T_{SMAX}$), $t_s$ | 150 seconds |
| Ramp-Up Rate ($T_{SMAX}$ to $T_L$) | 1°C/second |
| Time Maintained Above Liquidus ($t_L$) | 70 seconds |
| Liquidus Temperature ($T_L$) | 221°C |
| Peak Temperature ($T_P$) | 240°C |
| Time Within 5°C of Actual Peak Temperature ($t_P$) | 10 seconds |
| Ramp-Down Rate ($T_P$ to $T_L$) | 2.5°C/second |
| Time 25°C ($t_{25°}$) to Peak Temperature | 390 seconds |

## ESD CONSIDERATIONS

Establish and use ESD-safe handling precautions when unpacking and handling ESD-sensitive devices.

- Store ESD sensitive devices in ESD safe containers until ready for use. The moisture-sealed bag is an ESD approved barrier. The best practice is to keep the units in the original moisture sealed bags until ready for assembly.
- Ensure that all workstations and personnel are properly grounded to prevent ESD. Restrict all device handling to ESD protected work areas.

## STORAGE SPECIFICATIONS

The MSND Tile is Moisture Sensitive MSL 5a according to IPC/JEDEC J-STD-020. Follow IPC/JEDEC J-STD-033B handling and storage protocols. This standard classifies proper packaging, storage and handling in order to avoid subsequent thermal and mechanical damage during the solder-reflow attachment phase of PCB assembly. Parts not stored in a moisture sealed container must be dehydrated before assembly to PCB. Recommended dehydration is 12 hrs under 25-in. Hg vacuum at 100C. Also see IPC/JEDEC J-STD-020 notes on dehydration of parts.

## COMPLIANCE DECLARATION DISCLAIMER

RDT believes the environmental and other compliance information given in this document to be correct but cannot guarantee accuracy or completeness. Conformity documents substantiating the specifications and component characteristics are on file. RDT subcontracts subcomponent manufacturing, and the information contained herein is based on data received from vendors and suppliers, which has not been validated by RDT.

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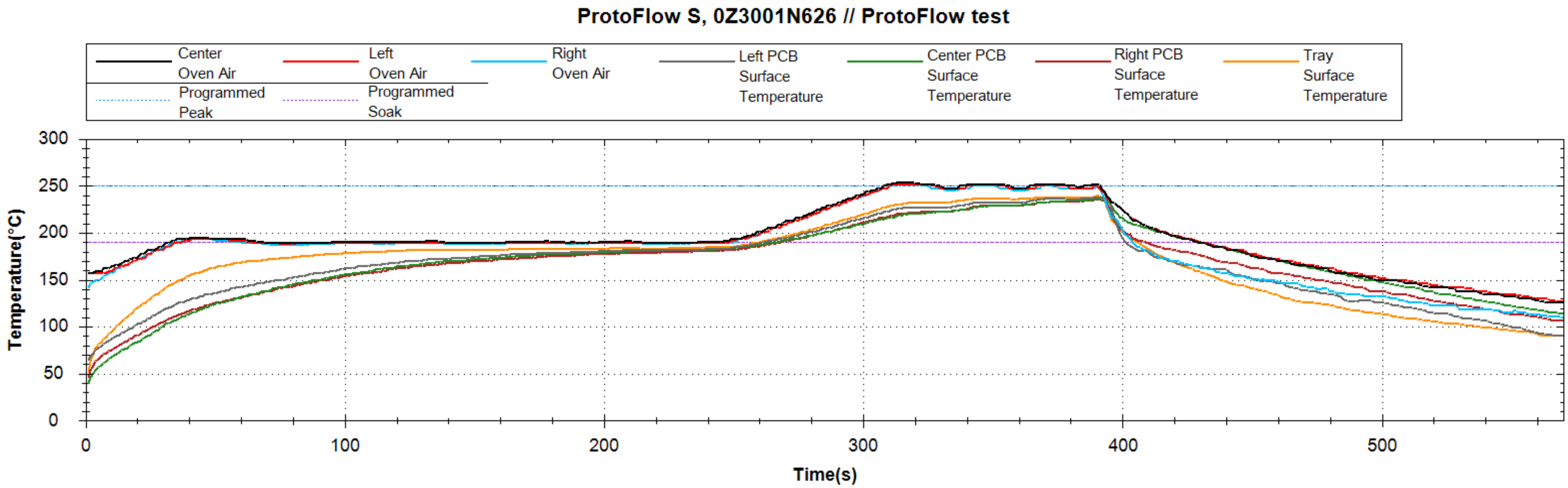
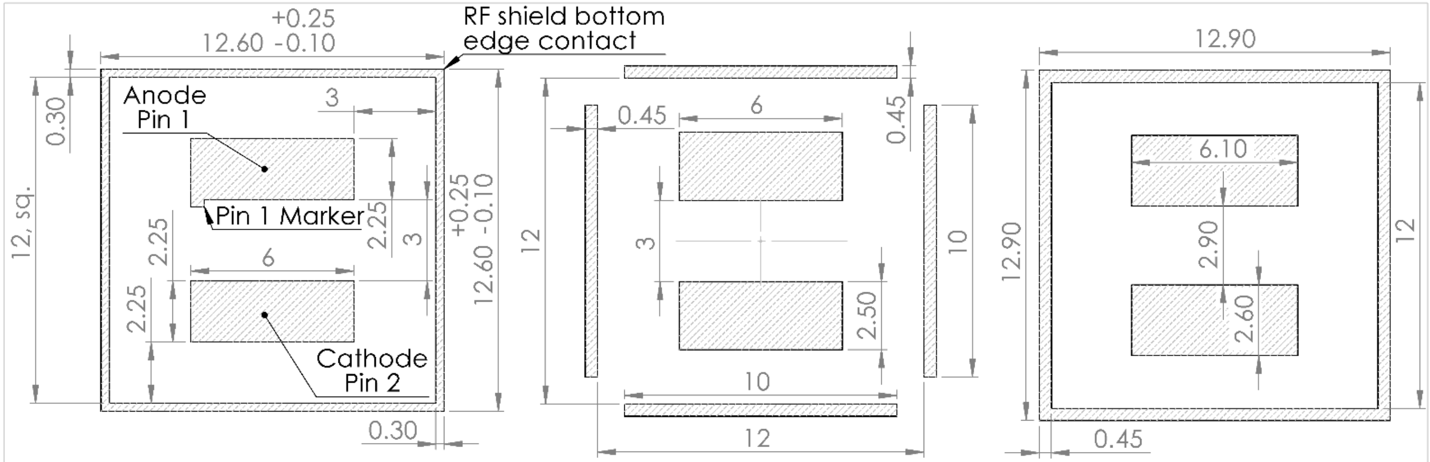


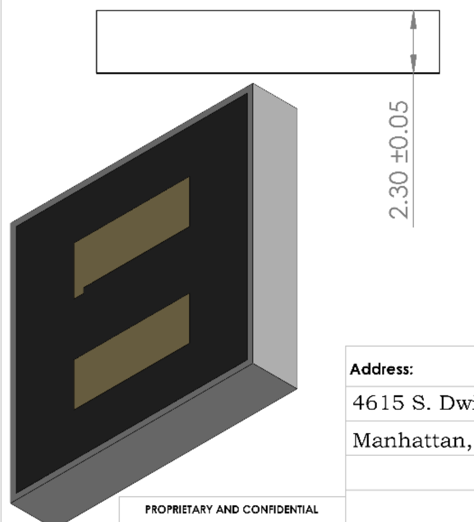

**Figure 2: Example reflow profile in ProtoFlow S oven.**

## AGF-series MSND Package Drawing




**Recommended Solder-Paste Stencil Layout**

**Recommended Footprint Layout**




**Notes**:
- Solder-Paste Stencil mask should have a reduced area for each solder pad and be a 5-mil stencil thickness.
- PCB should have ENIG Finish.
- PCB should have 1-mil Soldermask, with Plugged & Tented Vias under package.

| | | | |
|---|---|---|---|
| **Address:** | UNLESS OTHERWISE SPECIFIED: | DATE | Radiation Detection Technologies, Inc. |
| 4615 S. Dwight Dr. | DIMENSIONS ARE IN: | DRAWN (UPDATED) 3/19/2020 | TITLE: |
| Manhattan, KS 66502 | **Millimeter (mm) and do not include thickness of plating.** | PART #: MSND.S17.CRFS | MSND CDB With RF Shield |
| | Material: **Alumina** | COMMENTS: | |
| **Contact:** Steven Bellinger | | RF Shield is Silver Plated Brass | SIZE **A** DWG. NO. REV 01 |
| **email:** bellinger@radectech.com | | | |
| **Tel: O:**(785) 532-7087 & **C:**(785) 477-1338 | | | SCALE: 5:1 WEIGHT: SHEET 1 OF 1 |

## Example MSND Readout Electronic Design Approach

MSNDs are mounted to ceramic mounting packages (Figure 3) and soldered directly to an electronics PCB circuit. As an example, the RDT Domino board is powered by a 2.9 to 5-volt input and contains pre-amplifying, amplifying, shaping, and pulse discrimination electronics, as well as a TTL-driver for output signal. Output signal from the MSND is amplified and converted to a driven TTL square-wave pulse with a nominal width of 5 to 60 µs, and a magnitude of 5 volts. The minimal footprint of the Domino package makes it ideal for small hand-held detector instruments. The volume reduction can decrease overall detector size or be used to implement neutron moderator or additional sensors.

The Domino V3.0 was initially developed in 2013 as a compact, low-power, microsecond response, neutron detector system with an interconnection capability that allowed the configuration of strips, panels, and z-axis stacks [1-4]. The original V3.0 systems implemented a single 4-$cm^2$ MSND. The Domino system can be divided into two subsystems; the signal processing chain (preamplifier, shaper amplifier, discriminator, output driver); and the support circuitry (biasing, threshold, power conditioning). The manufacturability of the Domino V3.0 suffered in that bias and threshold settings were set by surface-mount resistors, which required manual installation and modifications cumbersome. Differences in MSND characteristics disallow the use of global resistor values.

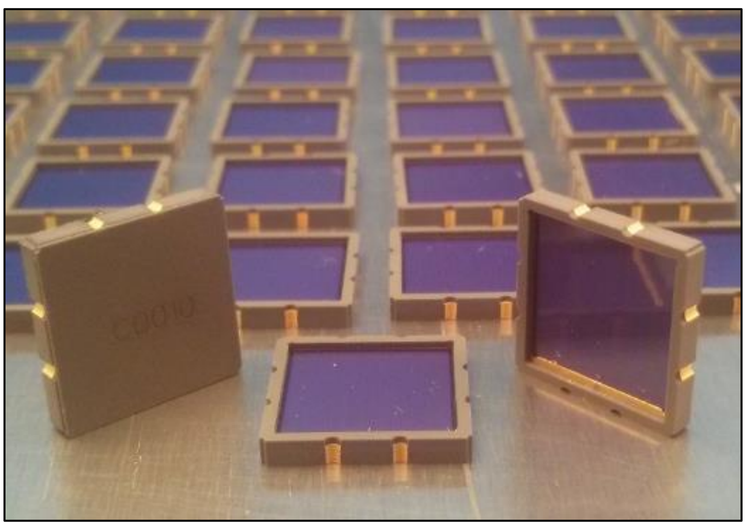


**Figure 3: Shown are rows of ceramic detector boards (CDBs), each housing an MSND. The purpose of the CDBs is to provide electrical connection between the MSND and detector readout electronics.**

## Domino V5.4 Design and Fabrication

As noise from electronics components is often inversely related to power consumption, there was concern reducing the power consumption of Domino V3 technology would degrade the system performance. For this reason, conservative changes were made and implemented into the signal processing subsystem on the Domino V4.0. A new shaper amplifier was used with identical noise and bandwidth specifications, reducing current draw by 90-µA. Lower power amplifiers were also selected in the biasing and threshold circuits, which allowed for the addition of a dual $I^2C$ potentiometer to replace the resistor programming, further reducing current draw by another 88 µA. Finally, a 429-µA reduction was achieved by increasing biasing and load resistor values, and using an alternative voltage regulator, which sacrificed some power-supply rejection capability. An $I^2C$ temperature sensor was added to the V4.0 Domino to allow for automatic bias and threshold adjustments based on ambient operating temperature, which increased the estimated current by 45 µA. Overall, current draw was reduced by 66.6% over the Domino V3.0, with no significant change to the size of the overall sensor package.

The challenge for the Domino V5.0 class of redesigned versions was to reduce the current consumption further without sacrificing detector performance. Calculations and simulations predicted a 5x increase in the noise level, which given the signal gain in the Domino V3.0/4.0, would come close to exceeding the signal produced by a typical neutron event. The Domino V5.1 used an updated components design, which produced a maximum current draw of only 65 µA (7% of Domino V3.0), maintained similar sensor package dimensions, included increased $I^2C$ functionality, and was neutron sensitive. However, the noise performance of the V5.1 was unacceptable. Overall, it was 2.3x noisier than the Domino V3.0 at 8 $fC_{RMS}$ with 390 pF (actual, input referred).

From here, changes were made to the power conditioning circuit. Furthermore, adjusting the shaper time and poles relationships yielded the Domino V5.2 (105 µA) and V5.3 (80 µA) designs, which were simulated and produced. Testing yielded improved noise performance with 2.54 fCRMS input referred measured using a standard 390 pF input capacitance. This represented 74% of the Domino V3.0 noise level.

During the progression through the Domino series, several complicating issues had been convolved into the designs. Classic preamplifier and shaper amplifier systems consume significant power to achieve high performance. The result is that these devices perform well, even with high input capacitance and perform closer to the ideal when implementing pole-zero cancellation, integration, and filtering. The Domino electronics are “non-ideal” due to their low-power requirements, and parameters such as the limited slew-rate and bandwidth have a significant impact on the preamplifier response and shaper performance. The Domino V3.0 had only one shaper pole because of the dominant effect of the internal amplifier poles. As the Domino designs progressed, electronics topologies evolved, producing the V4.0, V5.0, and V5.1 topologies. The topologies can have as many as 7 poles and 4 zeros in the transfer function, all of which impact the system response. In addition, the preamplifier has five noise sources and the shaper amplifier has six noise sources, and nearly all contribute to the overall performance.

The analysis of the response produced a V5.4 variant of the Domino topology (see Figure 4 and Domino V5.4 specification document), which is compatible with both the 5.2 and 5.3 preamplifier and shaper devices and also includes the shielded CDB package. This variant further refines the pole locations and shaping time while adding an additional pole to the shaper response. The V5.4 topology implements N=2 using discrete poles, but also incorporating the amplifier poles into the shaping response, see Figure 5. When simulated, this configuration was predicted to have 1.72 $fC_{RMS}$ input referred noise with a 400 pF detector capacitance. Bench measurements performed on the prototype yielded 1.61 $fC_{RMS}$ with 390 pF detector capacitance. Thus, the Domino V5.4 reports 47% of the noise levels of the Domino V3.0. One potential cost of the new configuration is that the full-width half max (FWHM) pulse width out of the shaper increased to 50 µs.

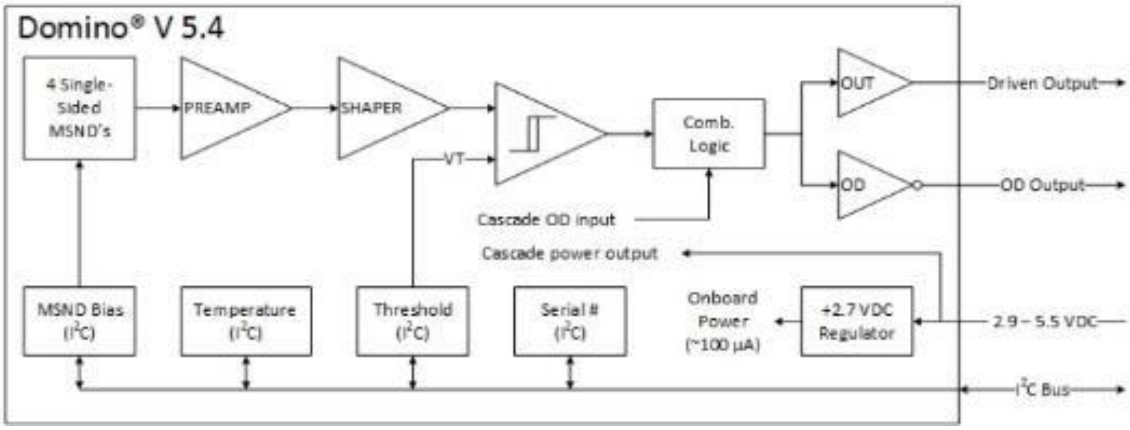



**Figure 4: A functional block diagram for the Domino V5.4, composed of MSND preamplifier/shaper/discriminator chain and I²C temperature sensor. The discriminator outputs to a 50-ohm driver. Detector bias and discriminator threshold are set using non-volatile digital potentiometers on an I²C bus.**

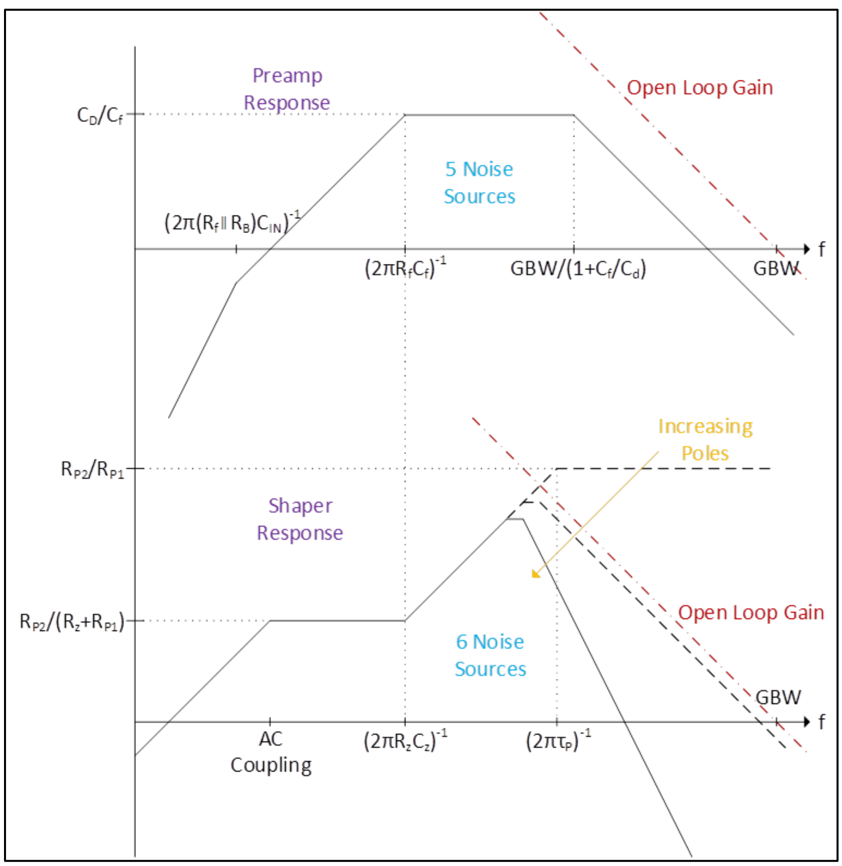



**Figure 5: Plotted is the Domino V5.4 topology transfer function. By increasing the number of electronic poles, the system noise is reduced thereby increasing overall performance.**

## Example of Designing a Charge Sensitive Amplifier (CSA) Circuit

An informative tutorial on developing a CSA circuits for Si diodes can be found in these internet links:
https://physicsopenlab.org/2017/09/27/charge-sensitive-preamplifier/
https://www.hamamatsu.com/resources/pdf/ssd/charge_amp_kacc9001e.pdf
https://www.ti.com/lit/an/sboa061/sboa061.pdf?ts=1624445138990
https://www.analog.com/en/technical-articles/optimizing-precision-photodiode-sensor-circuit-design.html#

An example of a preamplifier circuit that would work with the MSND Tile is given in Figure 6. The rest of the readout electronics circuitry as shown in Figure 4 can be developed straight-forwardly with basic circuit component selection. See referenced internet sites for guidance and examples.

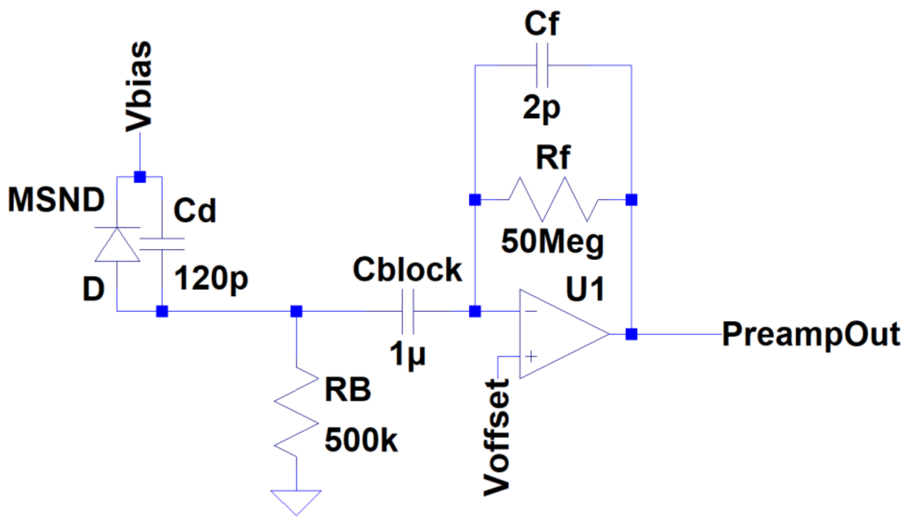



**Figure 6: Example MSND Tile preamplifier circuit design.**

## References:


[1] A. Soto *et al.*, "A semiconductor-based neutron detection system for planetary exploration," *Nucl Instrum Methods Phys Res Sect A,* vol. 966, 2020.

[2] T. Ochs *et al.*, "Wearable Detector Device Utilizing Microstructured Semiconductor Neutron Detector Technology," *Radiation Physics and Chemistry,* 2017.

[3] R. G. Fronk *et al.*, "High-efficiency microstructured semiconductor neutron detectors for direct 3He replacement," *Nuc. Instrum. and Meth.,* vol. A779, pp. 25-32, 2015.

[4] R. F. Fronk *et al.*, "Improved low power, modular thermal neutron counter based on microstructured semiconductor neutron detectors (MSND)," in *IEEE Nucl. Sci. Sym.*, Oct. 29-Nov. 5 2016.