White Paper

Improved Performance LADAR Receiver

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ABSTRACT

Optical LADARs require high sensitivity near 1 nW while also having fast recovery to overloads as high as 100W. Fast recovery is required in order to detect a secondary target from behind a bright target. In the current work, we have created a new family of LADAR receivers having a higher gain bandwidth product than most commercially available receivers. While maintaining the receiver bandwidth, a 4.8 x increase in responsivity can now be achieved. With cooling of the APD, these new receivers are offering more than a twofold time reduction of the NEP, allowing longer range coverage of the LADAR system. In addition, a new feature is the improvement of the overload recovery to 93ns from an laser pulse of 56mW, allowing close secondary target detection.

Keywords: LADAR, LRF, TIA, APD, OPTICAL RECEIVER, FAST RECOVERY, EXTENDED DYNAMIC RANGE, DUAL SLOPE RECEIVER

1. INTRODUCTION

This work was performed as part of an effort to build an integrated receiver with range gated digital outputs for multi-target detection: LADAR[1] and LRF (Laser Range Finder). These LADAR and LRF devices all use the TOF (Time of Flight and return) to measure the distance to the target. For the source one can find a wide choice of pulsed lasers with FWHM in the order of 5-20ns. Pulsed lasers for LADAR, requiring repetition rates of several kHz, are usually fiber lasers or DPSS lasers with output energy around 100µJ/pulse, corresponding to pulse peak power near 10kW. The LRF lasers have a much lower repetition rate, either flashlamp pumped or DPSS type, but their energy per pulse can easily achieve several mJ per pulse, corresponding to several megawatts pulse peak power. The integrated receiver must be able to operate with these high power lasers with respect to dynamic range, recovery time and damage threshold.

The dynamic range has several features to be considered. The first is the return target signal ranging from nW (nanowatts) requiring a high sensitivity receiver, to mW (milliwatts) for close range targets requiring a high saturation level that often comes with a loss in sensitivity. A high saturation level is also required when considering the atmospheric backscattering signal that could saturate and blind the receiver in the short range portion, because the return atmospheric backscattering reaches several µW (microwatts).

The recovery time is of importance when a coaxial optic is used. The light returned after the T_0 (Laser Initial Firing) from the shared optic leads to a blinding period for the receiver. A coaxial optic design also requires a receiver with damage free operations up to several watts of return signal at T_0. The recovery time is also important to detect a secondary target when in presence of a nearby pair of targets.

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2. ATMOSPHERIC BACKSCATTERING

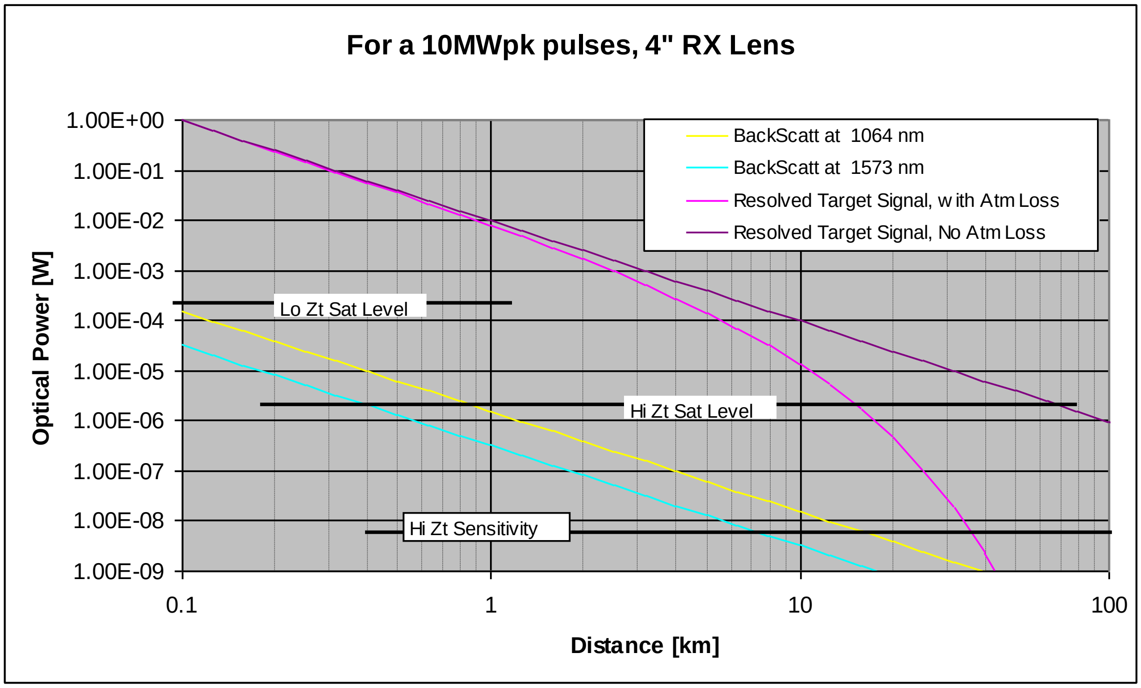

Figure-1: Signal and Backscattering power levels

The atmospheric backscattering is assumed to be dominated by the Raleigh effect[2]. Typically, optical receivers have a 25dB optical dynamic range. The graph in Figure-1 shows that the receiver could easily be saturated by scattering from the first kilometer of ranging. Increasing the saturation level by two orders of magnitude, by reducing the Zt (Transimpedance) by the same amount, would lead to a loss in sensitivity of nearly one order of magnitude if noise is dominated by the feedback resistor noise. It would appear that the solution is to have a SWDR (Switchable Dynamic Range) as in Figure-2.

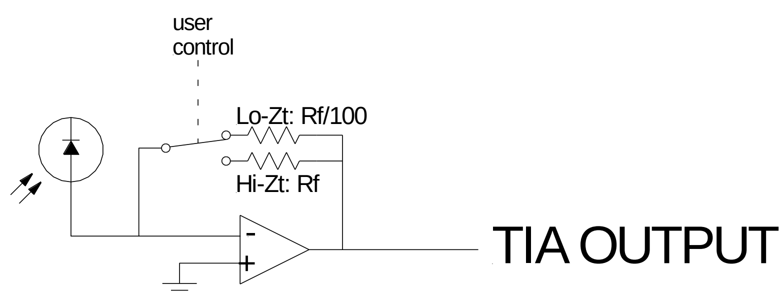

Figure-2: Proven switchable Rf

Such circuits have been widely used over the last 20 years and have demonstrated that the switching can be implemented with negligible performance degradation on the sensitivity when a GASFET, for example, is used as a switch. By switching to Lo-Zt mode, the saturation power level is above the backscattering level, allowing normal operation in the short range area. The switching time is very fast and is limited by the settling time of the amplifier following the switching glitch. Although this solution is practical, it has a few drawbacks. User interaction is required to control the switch. The switching delay would vary from time to time as backscattering is changing, such as when

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the measurement is made from a high speed aircraft. The switching glitch causes a blind time of typically less than 50ns (20 meters) which is undesirable at system level.

The ideal circuit would be an improvement of Figure-2 such that the switching is done in a continuous fashion avoiding switching glitches. It would sense the backscattering to allow the feedback resistor to switch automatically, without input from the user. This is what has been done in Figure-3, where the Zt is modulated directly by the amount of backscattering detected via the TIA output DC level variation.

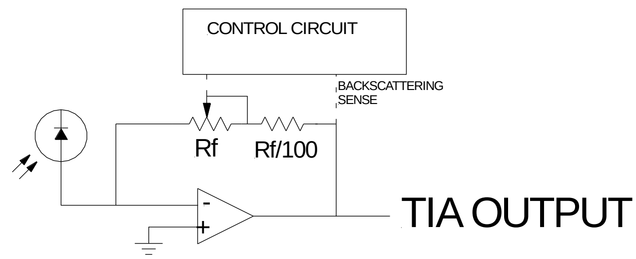

Figure-3: Continuous Auto switching Circuit

For this portion of the circuit, the reaction time could be asymmetrical; a fast turn-on time at the T_0 pulse, followed by a few µs turn-off time in line with the backscattering time reduction. Another aspect is the ability of the receiver to achieve very fast overload recovery time. In the example of Figure-1, backscattering is a concern for only the first km, whereas in the next few kilometers, the target return signal will saturate the amplifier.

3. IMPROVED RECEIVER RECOVERY TIME

Figure-4 shows that even in LO-Zt mode, the returned signal from targets in the first few km will overload the receiver. To maintain the ability to detect a nearby target pair, the receiver must recover within a few tens of ns. The fast recovery of the receiver can only be achieved if both the APD and TIA have a fast overload characteristic.

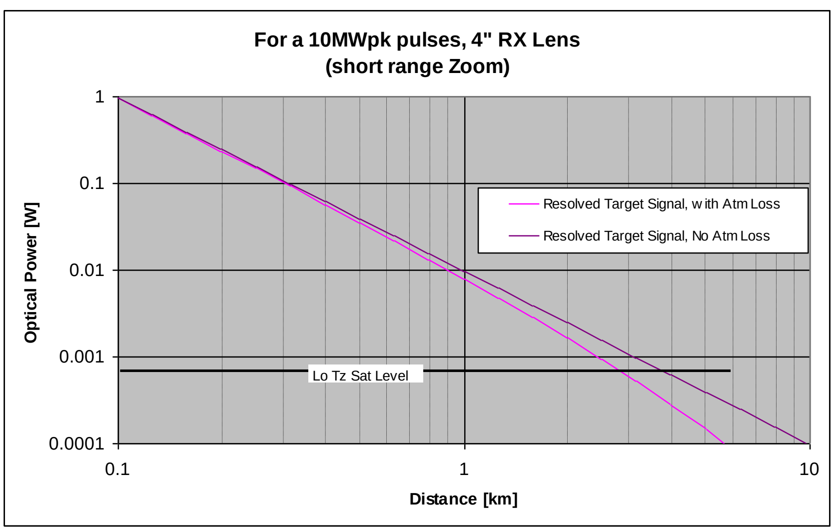

Figure-4: Signal at short range

The same fast recovery time should also be available in Hi-Zt mode when the first target of a nearby pair is highly reflective. We still want to be able to detect the secondary target that may have a fainter signal. The degree of overload and the operating state of Hi-Zt compared to Lo-Zt are leading to similar, but also independent requirements, as shown in Figure-5. Again the solution requires that both the APD and the TIA are capable of very fast overload recovery.

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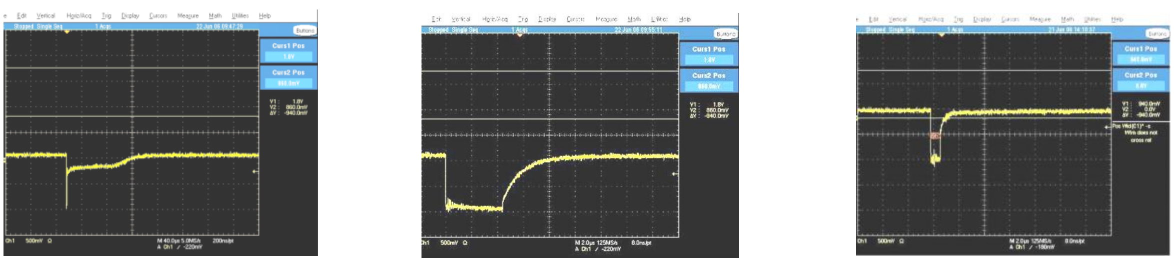
TIA MODE	HV bias	APD	TIA
Lo-Zt	Current limiting protection to prevent APD or TIA damage. Fast recharge of HV as recharge current cannot be discriminated from signal.	Fast recovery to the T_0 pulse of tens of W. The large current flow shall not lead to a field inversion that may take some µs's to recover.	Ability to remove input stored charges from overload pulse and charge to restore bias across APD.
Hi-Zt		No charge trapping (tail current) that may be interpreted as false signal.	

Figure-5: Requirements for path to fast recovery.

3.1 APD IMPROVEMENTS

The HV bias/current limiting alternatives are mature and are not in need of improvement. The APD is a critical component and very few designs are capable of meeting very fast overload recovery requirements. Several design iterations[3] have been needed to get where we are today.



(a) 40us/div ***(b) 2us/div*** ***(c) 2us/div***

Figure-6: APD recovery time evolution @ 332kW/cm^2.

Figure-6 outlines the evolution of the APD recovery time. The photos of Figure-6 where all taken in Hi-Zt mode where Rf=68kΩ. Figure-6a is one where the internal field was inverted preventing rapid charge collection, leading to high photocurrents for several microseconds. In Figure-6b, there was a partial field inversion and possibly an imperfect grading in the epitaxy of the APD. Figure-6c was a good device; however, today's APD's are capable of even faster recovery and in order to take advantage of these faster APD's, the TIA recovery time needs to be improved.

3.2 TIA RECOVERY IMPROVEMENT

Now the next bottleneck for faster recovery time lies in the TIA. Going back to Figure-3, the proposed approach is to have the control circuit fast enough so that during the overload, the Lo-Zt can be turned on completely. After that the switch returns rapidly to a partial ON state depending on the amount of backscattering. The question is; could the switching be fast enough to obtain a dual slope transfer function as shown in Figure-7? A more important criterion is the circuit stability as Zt is varied between LO and HI values, where the bandwidth has to be maintained with target pulses free of resonance.

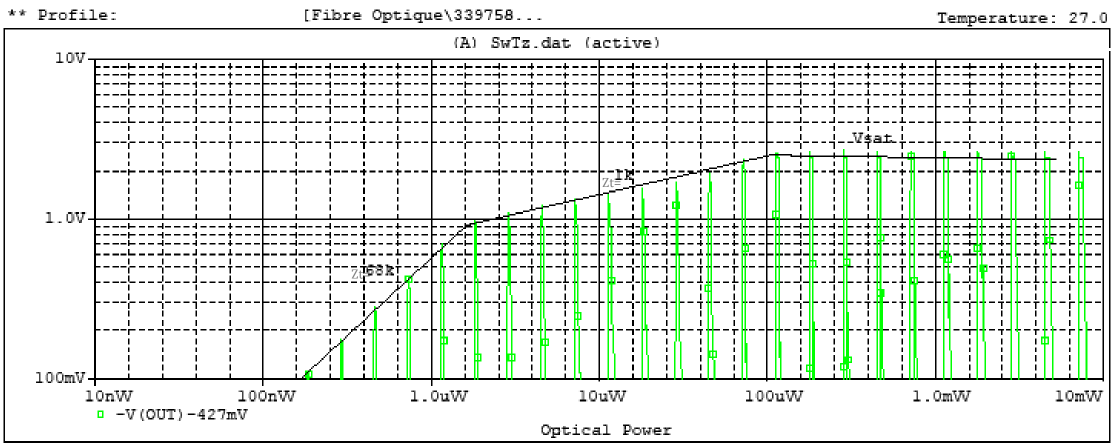


Figure-7: Dual Slope Receiver

3.3 TIA HI-Zt IMPROVEMENT

The receiver sensitivity is primarily dominated by the 200µm APD noise and the Johnson noise from the feedback resistor. The APD noise becomes dominant at elevated temperatures and may be controlled with the use of a TEC (Thermo-Electric Cooler). State of the art receivers with 50MHz bandwidth have an internal transimpedance of 68kΩ. Previous development work to cost reduce the TIA gain stage led to a large increase in the GBWP (Gain BandWidth Product) and that internal gain had to be reduced to maintain compatibility with existing products. We believe that the new GBWP would make it possible to maintain the BW to 50MHz by increasing the Zt to 330kΩ. With the noise contribution from the feedback resistor calculated in Eq-1, using k as the Boltzman constant and T as the temperature in Kelvin, we get

$$In(R = 68k\Omega) = \sqrt{\frac{4kT}{R}} = 0.492 \text{ pA}/\sqrt{\text{Hz}} \quad @ \, 25°\text{C} \qquad (1)$$

which at higher Zt would become

$$In(R = 330k\Omega) = \sqrt{\frac{4kT}{R}} = 0.223 \text{ pA}/\sqrt{\text{Hz}} \quad @ \, 25°\text{C} \qquad (2)$$

allowing a NEP reduction by a ratio of 2.2.

4. EXPERIMENTAL DATA

4.1 IMPROVED RECOVERY TIME

The APD TIA receiver with the dual slope configuration was tested at multiple overload power up to 100W (332kW/cm^2) on the 200um APD. Figure-8 summarizes the improvement obtained in recovery time with the new APD TIA combination compared to the previous fast overload recovery circuit. The receiver was also tested at various optical background powers and maintained the overload recovery time improvements.

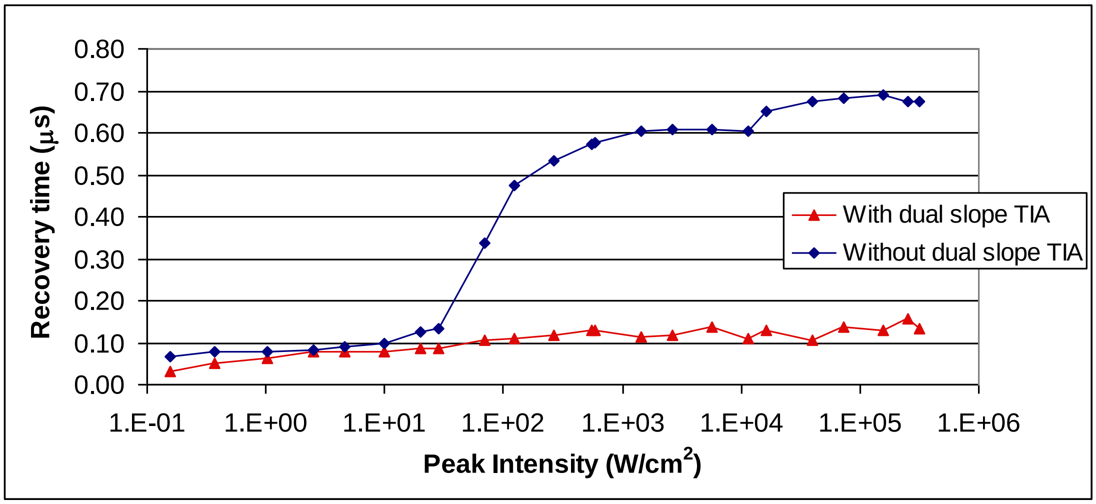


Figure-8: Overload recovery time to 200 mV with 320 kW/cm^2 pulses, 4 ns FWHM

Figure-9 shows the difference with and without the improvements when a 100W optical overload pulse hits the 200µm APD.

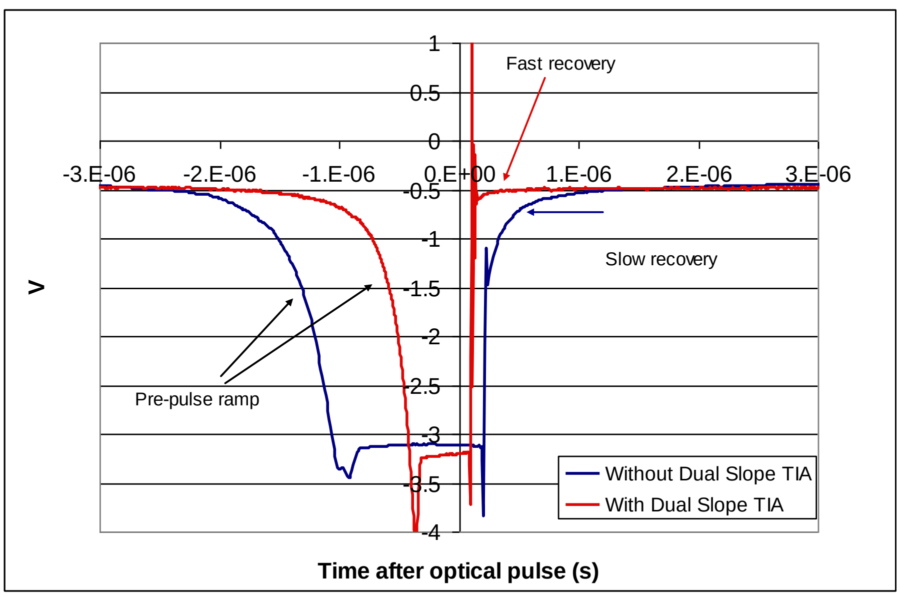


Figure-9: Overload recovery signal with 320 kW/cm^2 pulses, 4 ns FWHM

The saturation in the pre-pulse area occurs later (at a higher power) with the new circuit which is a condition similar to a high backscattering background where the amplifier should not be saturated. The receiver was tested successfully with a background of a few tens of microwatts. At T=0 is when the 4nS FWHM laser pulse reaches 100W on the 200µm active area. The new circuit induces a positive after pulse and returns to the baseline level much faster than the previous state-of-the-art APD receivers

4.2 IMPROVED Zt

The circuit was tested with the higher transimpedance (330kΩ) where responsivity was increased from 613 kV/W to 3016 kV/W while maintaining the bandwidth well over the 50 MHz target. This higher responsivity allows the received signals to be of higher amplitude at the output and to reduce the sensitivity to surrounding noise sources.

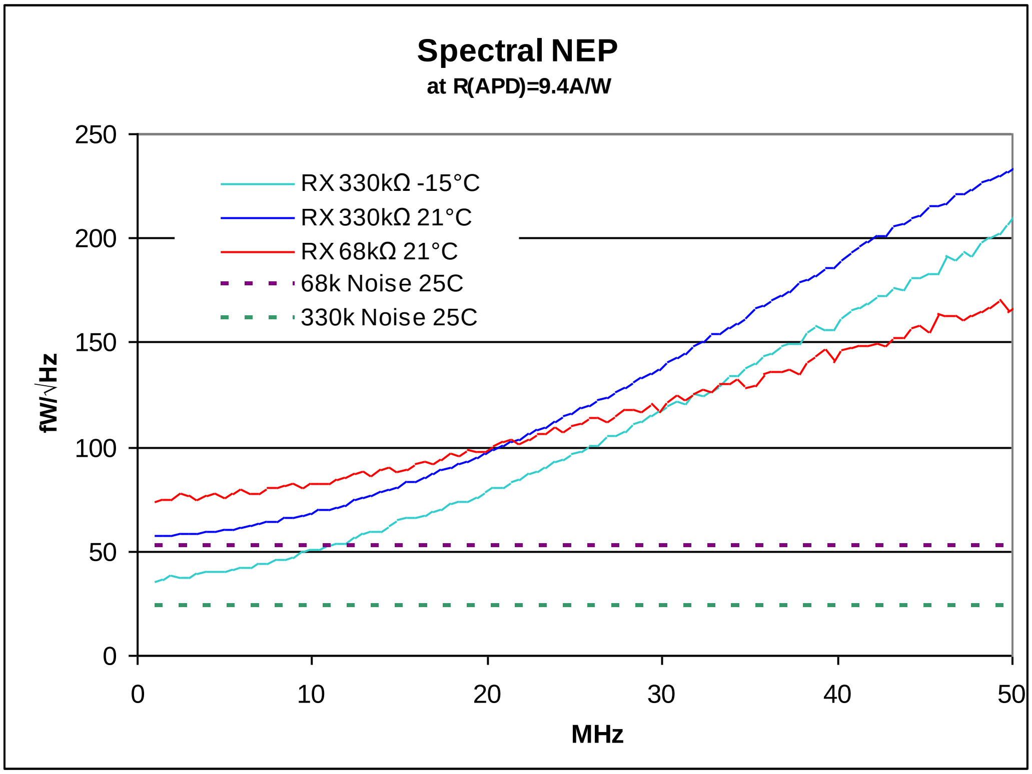


Figure-10: Spectral NEP comparison with 68kΩ and 330kΩ feedback resistors.

In Figure-10, the expected spectral NEP reduction was obtained at low frequencies but was lost at the higher frequencies. It can be observed that the spectral NEP rises with the frequency. This rise is created by the preamplifier input noise voltage components and is more pronounced when Zt is at 330kΩ. The preamplifier has 2 gain stages, and the gain distribution was not re-optimized for the 330kΩ version.

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5. CONCLUSION

The current work has demonstrated significant improvement in the overload recovery time remaining below 200ns up to 100W overload on a 200um APD. The same circuit also provides a higher saturation optical power for atmospheric backscattering, which is currently typical with today's high power laser in LADARs. We also demonstrated the increase in the GBWP with the new family of TIA's, allowing higher bandwidth or transimpedance. These new faster recovery receivers can now be incorporated into CMC's full LADAR/LRF signal receiving products with the additional stages of TPT (time programmable threshold), TPG (time programmable gain), and digital outputs with low FAR (False Alarm Rate).

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