High gain, low noise InGaAs APD receiver with fast overload recovery and stable performance through wide temperature range

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ABSTRACT

Optical LIDARs and laser range finders (LRF) require high sensitivity near 1nW while also having fast recovery to overloads as high as 100W peak optical power. Fast overload recovery is required in order to detect subsequent signals after sensing bright targets. In the current work, CMC have created a new family of InGaAs APD LIDAR/LRF receivers, 264-339822-VAR [6], having a higher dynamic range than most commercially available receivers. While maintaining the existing family of receivers' bandwidth and APD gain, a 1.8 x increase in responsivity can now be achieved, while reducing the NEP by 12%. In addition, new improvement to the receiver include reducing overload recovery time to 331ns from a laser pulse of 6W peak optical power allowing close secondary target detection, and achieving NEP as low as 184fW/√Hz at +85°C.

Keywords: LIDAR, eye-safe LRF, LRF, TIA, APD, OPTICAL RECEIVER, FAST RECOVERY, EXTENDED DYNAMIC RANGE, DUAL SLOPE RECEIVER

INTRODUCTION

For APD receivers used in time of flight (ToF) LIDAR and LRF, one of the challenges is to detect high and low signal levels at wide temperature range, with the ability to recover quickly from a signal overload. ToF LIDAR and LRF employ a wide choice of emitters such as pulsed lasers with FWHM in the order of 5-20ns. Pulsed lasers for LIDAR, requiring repetition rates of several kHz, are often 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 flash lamp pumped or DPSS type, but their energy can easily achieve several mJ per pulse, corresponding to several megawatts pulsed peak power.

The integrated APD receiver must be able to operate with these high power lasers with respect to dynamic range, recovery time and damage threshold.

Designing such integrated APD receiver has some challenging factors to be considered. Firstly, to get higher dynamic range, the increase in APD receiver sensitivity should not compromise the device's ability to take high optical input power without saturation. Secondly, the receiver's recovery time is important to detect secondary or nearby targets. Finally, the receiver needs to operate without being easily damaged.

DYNAMIC RANGE AND ATMOSPHERIC BACKSCATTERING

The APD is a critical component. Very few designs are capable of meeting high internal gain, low noise and very fast overload recovery requirements. Many experimental designs have been explored on impact ionization theories, resulting in a 200µm diameter active area low excess noise factor InGaAs APD used in this receiver design [4-5]. In addition to having the advantage of low noise, the APD selected for the 264-339822-VAR receiver family has been optimized for fast overload recovery.

The return target signal ranging from nanowatts requiring a high sensitivity receiver, to milliwatts for close range targets requiring a receiver to tolerate high optical power before saturation. For example, a high saturation level is 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 microwatts. The increased tolerance to saturation point often comes with a trade-off, which is a loss in receiver sensitivity.

The atmospheric light scattering is made up by Rayleight scattering and Mie scattering, but is assumed to be dominated by the Rayleigh scattering effect [2,4]. Typically, optical receivers have a 25dB optical dynamic range. A typical APD-TIA receiver will saturate when exposed to an optical power less than 10µW peak. Increasing the saturation level by two orders of magnitude, by reducing the Z_t (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 [4].

The solution implemented in CMC's 264-339822-000 receiver is a dual transimpedance circuit that senses the backscattering to allow the feedback resistor to switch automatically, without input from the user. The Z_t is modulated directly by the amount of backscattering, detected via the TIA output DC level variation.

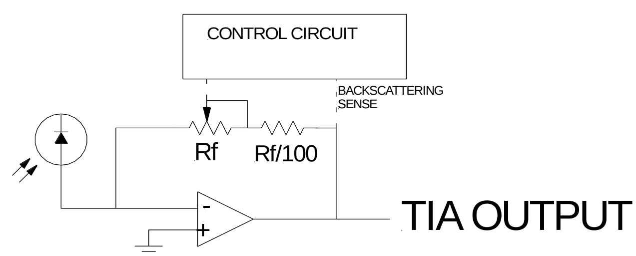

Figure 1 - Continuous Auto switching Circuit

With the auto-switching TIA circuit, the APD receiver is protected from saturation while maintaining the dynamic range and sensitivity.

FAST OVERLOAD RECOVERY

In addition to being able to achieve higher saturation levels, the APD receiver must maintain the ability to detect secondary or nearby targets after encountering highly reflective objects. Even in low transimpendance (low Z_t) mode, return signals as low as 100µW peak will likely overload the receiver, hindering its capacity to detect subsequent signals effectively. Hence, having a fast overload recovery time is critical for the receiver to perform precisely in LRF and LIDAR systems. This fast overload recovery time can only be achieved if both the APD and the TIA circuit have such fast recovery characteristics [4].
With a specifically selected APD for fast recovery time, the next limitation lies in the transimpendance amplifier (TIA). In addition to automatically reduce the transimpedance in the presence of backscattering, the

dual transimpedance circuits presented in Figure 1 can also support fast overload recovery time if the control circuit is fast enough.

Two control circuit options are possible. The first one, implemented in the new 264-339822-000 (referred to as *standard fast overload recovery* in this paper) receiver, has the best performance in terms of recovery time. The other approach, which can be implemented on a custom basis depending on applications, minimizes the output distortions across the -40°C to +85°C temperature range, thus showing stable sensitivity at high temperatures while still maintaining fast overload recovery.

Both fast recovery configurations were tested at low power to show how the output signals are affected by temperature. Results are presented in Figure 2. All waveforms show the output to 20ns, 170nW peak optical power (1570nm), with the APD biased for M=10, (responsivity 1065 kV/W).

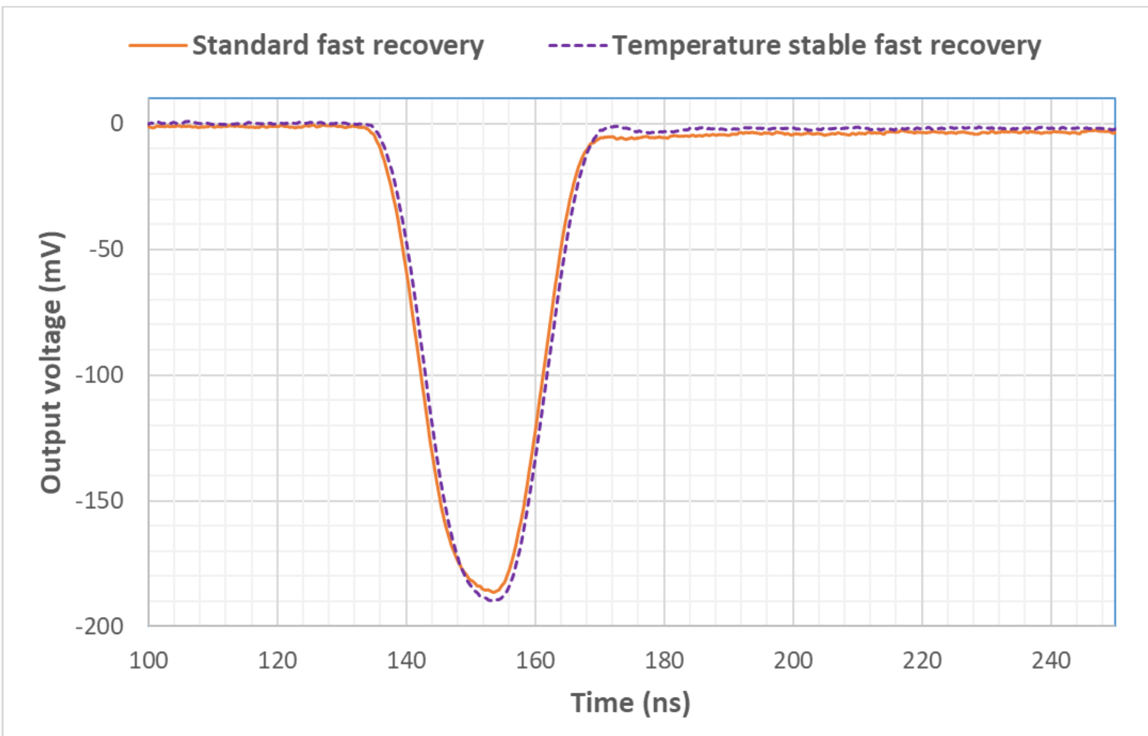

Figure 2 - Output pulse, standard and temperature stable fast recovery circuits, -40°C

In the standard fast recovery circuit, the APD-TIA output changes with temperature, with an overshoot present at high temperatures. However, with the temperature stable fast recovery circuit, the APD-TIA output waveform remains stable throughout the temperature range, without any overshoot up to +85°C, as shown in figure 3.

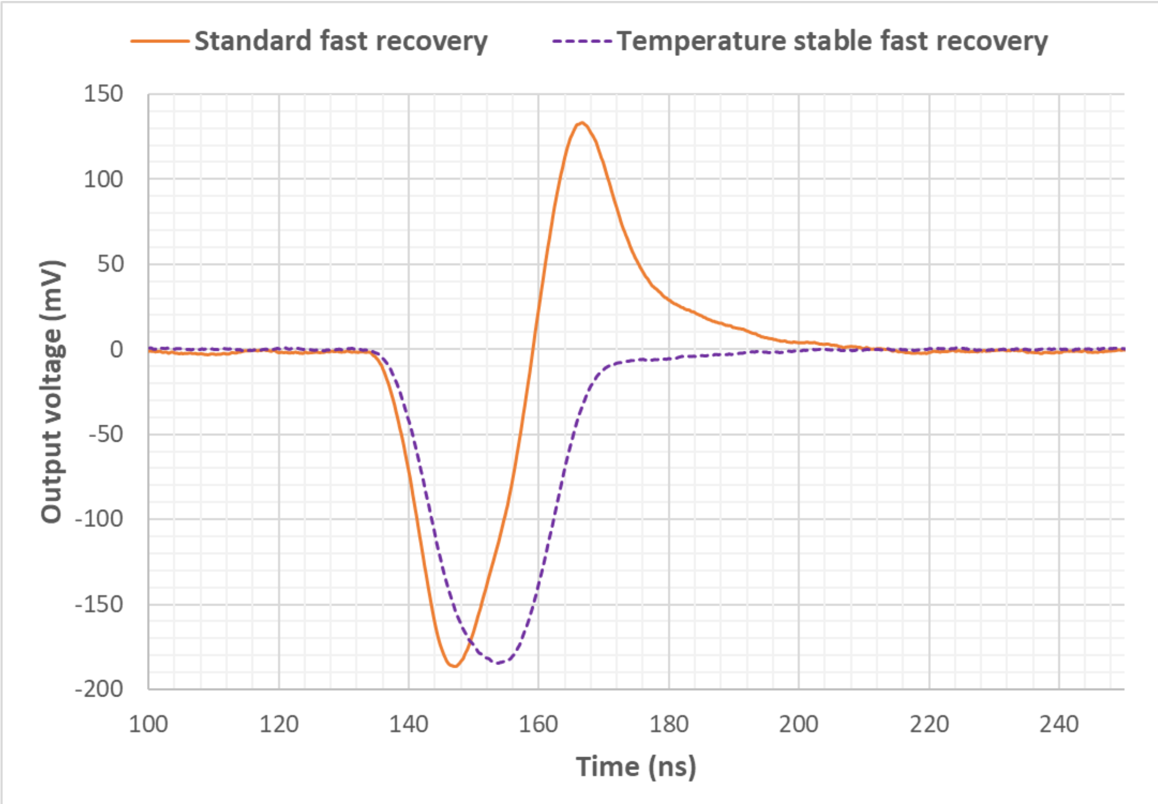

Figure 3 - Output pulse, standard and temperature stable fast recovery circuits, +85°C

The APD-TIA receiver recovery time was tested in three configurations, all with APD biased for M=10 and 125kΩ transimpedance (1065kV/W responsivity):

- No fast recovery circuit
- With the standard fast recovery circuit
- With the temperature stable fast recovery circuit

Recovery time is defined as the delay after which the receiver output has returned to ±200mV from the pre-pulse value.

Figure 4 shows that both fast recovery circuits reduce the saturation period by at least 150ns, and return to 0V much faster compared to a receiver without fast recovery circuit.

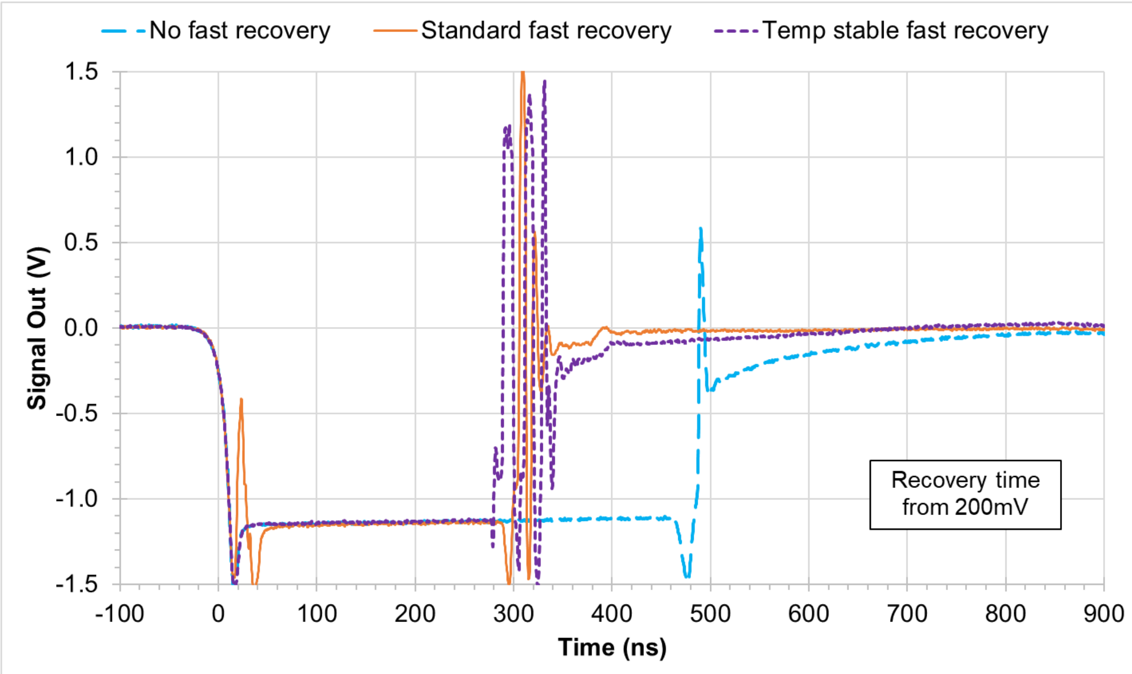

Figure 4: Overload recovery signal after 20 kW/cm2 pulses, 20 ns FWHM

Figure 5 shows the recovery time for the three configurations to a 20kW/cm^2 (6W peak power on the APD active area), 20ns optical pulse width, using a 1064nm laser.

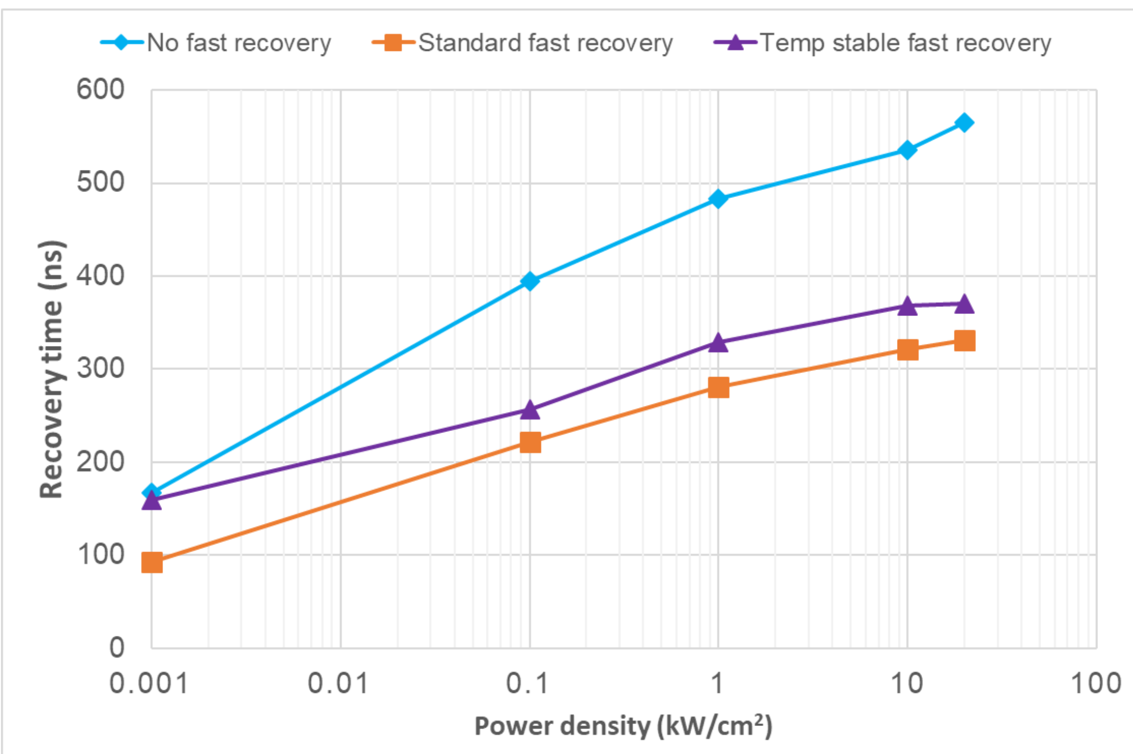

Figure 5 - Recovery time to 200mV for 20ns pulses

Compared to a circuit without dual transimpedance, the standard fast recovery circuit reduces the recovery time by 40% to 45%, as shown in figure 5, from 0.1 to 20kW/cm^2. The temperature stable fast recovery circuit reduces the recovery time by 30% to 35%, , on the same power range.

IMPROVEMENT ON TRANSIMPEDANCE AMPLIFIER AND NEP

The total noise from an APD receiver is a combination of the APD chip and the electronic circuitry. As the noise from the selected APD is fixed, the TIA input noise and the Johnson noise from the feedback resistor can be reduced with improvement on circuit design.

Most commercially available InGaAs APD receivers with 50MHz bandwidth have an internal transimpedance (Z_t) of 68kΩ.

APD-TIA modules from CMC can achieve a minimum bandwidth of 50MHz, while increasing the Z_t to 125kΩ. This increase in responsivity will not result in a NEP penalty, since the Johnson (thermal) noise contribution from the transimpedance resistor will be reduced, as shown in Equation 1.

With the noise contribution from the feedback resistor calculated in Eq-1, using *k* as the Boltzmann constant and T as the temperature in Kelvin, we get

$$\mathrm{In} = \sqrt{\frac{4kT}{R}} \qquad (1)$$

Where k = 1.38 x 10^{-23} J/K, and T = 298K

For transimpedance values of 68kΩ and 125kΩ, the Johnson noise currents at 25°C are:

I_n(R = 68kΩ) = 0.492pA/√Hz,
I_n(R = 125kΩ) = 0.363pA/√Hz,

allowing a Johnson noise reduction by a ratio of 1.35.

Typical performances with 68kΩ and 125kΩ are summarized in Table 1.

Table 1 : Performance comparison, 68kΩ vs 125kΩ transimpedance

Transimpedance	Bandwidth (MHz)	Responsivity (kV/W)	NEP (fW/√Hz)	Responsivity increase (%)	NEP improvement (%)
68kΩ	88	580	115	84	12
125kΩ	62	1065	102		

Both results measurements done at +25°C case temperature, with output noise integrated over a 1MHz to 71MHz bandwidth.

Increasing the transimpedance to 125kΩ yields a NEP reduction of 12%. See Table 2 in experimental data section for NEP measurement for various configurations mentioned above.

The recovery time and output stability results presented are primarily dominated by the TIA components, as the APD's used in CMC's optoelectronic receivers recover much faster than the amplifier.

However, the APD performance has a major effect on NEP, especially at high temperatures. A very low excess noise APD will yield better sensitivity, for the same operating conditions.

Table 2 summarizes the NEP for the standard and temperature stable fast recovery configurations, both measured with a typical APD and a low excess noise APD. For all measurements, APD is biased for M=10 (1065 kV/W responsivity).

Table 2 : NEP measurement for fast overload recovery circuit configurations

APD type	Recovery circuit	NEP (fW/√Hz)	
		+25°C	+85°C
Typical	Standard	119	395
	Temperature stable	115	233
Low excess noise	Standard	102	250
	Temperature stable	102	184

The temperature stable fast recovery circuit provides NEP improvement with both types of APD's, but the effect is more pronounced with the typical APD's.

CONCLUSION

The experimental data highlights the fast overload recovery performance of the new 264-339822-VAR family of CMC InGaAs APD-TIA receivers, as well as the improvements that can be achieved by using a higher transimpedance and a temperature stable fast recovery circuit.

The NEP at ambient can be reduced by up to 12% by increasing the transimpedance from 68kΩ to 125kΩ (1.8x). Furthermore, a temperature stable fast recovery circuit could reduce the NEP between 26% and 40% compared to the standard fast recovery circuit, at temperature of up to +85°C.

Forthcoming work will consist of integrating the temperature, fast recovery circuit into next generation APD receivers.

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