Luna Optoelectronics inc.
Camarillo, California (805) 987-0146 x155

PHOTODIODES: Ubiquitous components in today's arsenal of smart weapons.

Introduction

A decade after the Gulf War, the U.S. is again involved in military campaigns, with "smart" weapons playing a key role. In fact, the political success of this effort has in part depended on the ability to keep collateral damage to an absolute minimum, while effectively targeting specific groups and installations. Thus, it is easy to argue that smart weapons have never been more important. Most smart weapons rely on some type of photonic technology in order to provide target guidance or acquisition. Photodiodes are used as the photodetector of choice in many of these weapons, because they offer numerous important advantages such as compact, lightweight packaging, custom configurations, rugged reliability, and solid-state efficiency. This article reviews several diverse ways in which photodiodes are used to enable smart weapons.

Laser Guided Weapons

The goal of an offensive "smart weapon" is to actively guide the bomb or missile to its designated target. Since all on-board systems are destroyed on impact, it is not economically practical to incorporate complex, expensive components and systems in general purpose bombs and smaller missiles. A popular approach for these types of ordinance is laser guidance. This technique relies on using a laser beam to mark the surface of the target with an intense spot of light. Typically this is performed with a Nd:YAG laser at 1.06 microns. This wavelength offers the advantage of stealth (it is invisible to the eye) while being easily detectable with silicon PIN photodiodes enhanced to operate at this wavelength.

In operation, a laser beam is directed at the target either from the launch platform or by a third party, including covert ground operations personnel. Light reflected from the target enters the front of the missile through the so-called dome. In most cases, the dome optics are molded polycarbonate plastic, to minimize overall cost and weight. These optics also include a bandpass filter to block light outside the laser wavelength. In this way, a high contrast image of the laser spot is focused on to a photodetector assembly, mounted immediately behind the dome. Typically, this photodetector is a quad cell – a photodiode whose active area is partitioned into four discrete quadrants. The output from these four quadrants is amplified using four high-gain transimpedance amplifiers (TIAs) which are often hybridized (integrated into the photodiode assembly) in order to maximize signal-to-noise, and hence range. The position of the image spot on the quad cell is easily determined by the ratio of the signals from these four amplifiers. Of course, the molded optics may introduce aberrations and produce a distorted spot on the photodiode array. However, these effects are easily calibrated out during missile assembly and test.

The launch platform is equipped with a similar system to allow it to track and observe the target before and after destruction. Here, the photodiode quadrant is usually mounted, on a pair of orthogonal gimbal mounts, which provide $\square_X$ and $\square_Y$ adjustment/motion, allowing the platform to "look" at targets at wider angles. Information from this detector allows the bomb or missile to be automatically launched in the correct direction.

This type of system is referred to as "fire and forget"; after launch, signals from the on-board quad detector in the missile are used to adjust directional vanes on the projectile during its flight. There is no further direct communication between the launch platform and the missile. Today, the military uses these systems to guide both passive projectiles and actively propelled missiles.

In a typical battlefield situation, several targets may be simultaneously designated and marked using separate lasers. To avoid confusion and cross-talk, each laser beam emits a coded sequence of pulses. Each missile is pre-programmed to respond to only one of these code sequences.

Wire-Guided Missiles

Another type of ordnance that relies on photodiodes is the wire-guided missile, such as the TOW (Tube Launched Optically Wire-guided) missile. Here the missile remains in direct communication with the launch platform via a long wire, that uncoils during flight. This is not a "fire and forget" system; the launch platform tracks the projectile and supplies corrective trajectory information as required. The launch platform may be a Bradley Vehicle, helicopter, Hummer, or even a simple portable tripod. The idea is to incorporate only the less expensive guidance components in the missile itself, with most of the "smarts" in the launch platform, allowing for repeated use and lower event cost. Unlike laser guidance, no third party target designator is used.

The target is acquired through a bomb-site/telescope type arrangement; the operator sights the target (usually a tank) in the cross-hairs of a telescope. The system computer registers the direction of the target from angular encoders on the telescope gimbals. The missile is launched through a tube, which can be at a large (45°) angle from the telescope, depending on the location of the target. The system computer immediately corrects the trajectory to direct the missile in the general direction of the target.

The system is able to follow the entire flight of the missile by following a xenon lamp located in the tail of the missile. The tracking system actually contains two sub-systems to provide wide field (lower resolution) and narrow field (high resolution) tracking and correction.

These sub-systems are very similar except for f-number and detector size. In each subsystem, the xenon lamp is imaged through a rotating prism on to a two element photodiode assembly with a characteristic chevron shape. The optics form a separate image on each of the photodiode "legs." As the prism rotates, this image moves across the detector producing a modulated signal. This arrangement is used instead of a quad cell, because the optics are designed so that the two legs of the photodetector produce orthogonal information on the trajectory angle, which can be directly converted into pitch and yaw corrective commands for the missile.

The missile is also directed to fly a smart trajectory. Its range is automatically detected using a standard, "time of flight" pulsed laser range finder mounted in the launch platform. (This also uses a photodiode – in this case a high gain avalanche photodiode.) As the missile nears the target (usually a tank) it makes an "up and over" detour so as to the strike the target from above, effecting maximum damage.

Anti-missile Weapons

Smart weapons are also used to protect the launch platform by countering incoming missiles. In particular, a ship presents a large, inviting and slow moving target. Until recently, anti-ship missiles such as the Exocet could strike a ship with devastating effect, as evidenced in the Falklands/Malvinas War between the UK and Argentina. These missiles initially proved hard to counter because of their low trajectory and high speed (up to Mach 2). The task is to accurately direct a defensive missile at the incoming missile and to detonate it in close proximity. A very successful solution has proved to be the RAM (Rolling Airframe Missile) which for security reasons cannot be discussed in anything but general terms here. In this system, photodiodes are used to sense the proximity of the incoming missile, rather than for guidance.

The RAM is a "fire and forget" system; once launched, it relies on internal tracking systems. Initially it tracks the incoming missile using the RF signal used to lock the incoming missile on to the ship. At closer range, it tracks the infrared from the plume of the incoming missile. As its name suggests, the RAM missile rolls (spins) during flight at a high revolution rate. Laser diodes are arranged to emit from the side of the missile. As the RAM passes alongside the incoming missile, the laser light is reflected and collected through optics and a bandpass filter, mounted in the side of the RAM, and then directed onto elaborate arrays of photodiodes. The reflection signal is used as a proximity fuse to detonate the warhead. The success of RAM is due to its ability to discriminate between reflections from the target missile and sunlight, starlight, or reflections off the ocean surface.

Discrimination against ambient light is provided by using laser diode sources and monochromatic (bandpass filter) detection. Discrimination against ocean reflections is provided by the shape of the photodiode array and characteristic profile of the pulsed signal that results from the high speed rotation of the missile.

Since most of the "smarts" are incorporated within this sophisticated missile, RAM represents a higher cost per launch. But, this is really not an issue in this case, given the importance of its role, and the fact that the manufacturer (Raytheon) reports a kill rate higher than 99.99%.

Conclusion

Photonics technology, and the photodiode in particular, has been key in enabling smart weapons that can attack selected targets with great accuracy, avoiding blanket destruction. Now, more than ever, this type of weaponry is critical to the military and political success of modern warfare.

Side-bar: Arc Fault Detection Systems

Photodiodes also play a role in protecting the launch platform from internal failure problems. For example, ships utilize high voltage systems that can arc and create fires. If a fire is not promptly detected and extinguished, it represents a serious risk to personnel – either directly, or by detonating stored ordnance. Because of this risk, the US Navy has recently developed an automated arc fault detection system that relies on silicon photodiodes supplied by Luna Optoelectronics inc.

An electrical arc breakdown generates highly ionized air molecules that emit UV and visible radiation. The arc fault detector gathers this light through an input lens, and passes it through a UV bandpass filter. The UV is then detected using a single element photodiode hybridized with a TIA amplifier. As soon as an electrical arc occurs, this device is triggered and the signal is used to automatically shut down the local electrical system before a fire can be created. The UV filter eliminates false alarms due to changes in ambient light.

Because of its importance to the safety of the ship, this system is also self-testing, by means of integrated LED emitters. Specifically, several LEDs are incorporated within the photodiode hybrid assembly, and are directed at the front window of the detector. During test, light from the LEDs bounces off the inner surface of this window on to the photodiode, which allows a full system test, including automatic electrical shutdown. Visible LEDs can be used because they are located inside the photodiode assembly; their light never passes through the UV bandpass filter.