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Precision Guided Munitions and the Historic Role of GPS

Precision Guided Munitions (PGMs), and other so-called "smart" weapons, have established themselves as a key military technology for the United States and NATO. Combat operations will continue to demand the use of PGMs against targets whose destruction requires a high degree of precision. Precision strikes depend on accurate navigation throughout the entire course of a missile's flight. GPS is a key enabling technology for existing and future military precision navigation applications.

GPS was one of the most important technologies used during the entire Gulf War[1] and not only for PGMs. William J. Perry, then U.S. Under Secretary of Defense for Research and Development, wrote:

> Coalition forces…made effective use of navigation data from global positioning satellites. Many US aircraft, ground vehicles and infantry units were equipped with GPS receivers, which gave them their precise location on the battlefield, as well as the precise time (for synchronization purposes). GPS was important to the Coalition ground forces because it enabled them to locate their units accurately, which otherwise would have been difficult in the desert because of the absence of natural identifying features. GPS was important to Coalition air forces because it allowed them to update the accuracy of their Inertial Navigation Systems (INS) and to improve delivery accuracy of unguided ("dumb") bombs against fixed-coordinate targets. GPS [provided] location accuracies of about 10 meters, more than a tenfold improvement over the navigation systems of previous generations.[2]

Clearly, by the end of the Gulf War, GPS technology and PGMs had gained notoriety as a superior, if not revolutionary technology, and one that had the potential for new and exciting future weapons development. But, what are the events that led up to this stage of evolution? And, how did the U.S. Armed Forces eventually discover the value that a spaced-based technology could provide to the military?

Often, the Paveway laser guided bomb is credited as being the first weapon to fit the general description of a modern PGM. However, Paveway was not the first technology to fit this description. Rather, Paveway was first to gain wide operational acceptance, and, is often regarded as the weapon to usher in the age of precision.[3] The emergence of this promising guidance technology began in the 1960s and marked the first of many technological evolutions.

In the 1960's, the first precision weapon introduced by the US military in Vietnam was the Navy's Bullpup air-to-surface missile. The Bullpup employed a radio command link for guidance and was visually steered to impact by a pilot, or weapons system officer, using a joystick. These early radio guidance systems were unreliable and also proved vulnerable to jamming and enemy countermeasures. The Air Force classified a "second generation" weapon called the AG-62 Walley which earned this distinction through the use of an innovative electro-optical television guidance system. In the late 1960's, a new and promising technology based on semi-active laser guidance was under development by the Air Force and Texas Instruments. The first of these laser guided munitions was the Paveway M-117, which was closely followed by the improved Paveway Mark-84. By 1971, additional enhancements made this laser guided bomb the most versatile and effective air weapon yet fielded.[4]

Many of these early laser guided weapons did not lack accuracy but suffered from vulnerability to weather conditions and in particular low-hanging clouds. Starting in the late 1990's, Raytheon along with the U.S. Air Force worked to integrate GPS guidance into the Paveway III. This new weapon was called the Enhanced Paveway with a capability to penetrate low-hanging cloud cover, and get closer to the target before activating the laser.

1 Michael R. Rip and James M. Hasik, The Precision Revolution GPS and the Future of Aerial Warefare (Annapolis Maryland: Naval Institute Press, 2002), p. 187.
2 Ibid., p. 188.
3 Paul Gillespie, Weapons of Choice The Development of Precision Guided Munitions (Tuscaloosa, AL: The University of Alabama Press, 2006), p. 74.
4 Ibid., p. 114.

Modern high performance PGMs typically employ multiple technologies to improve their robustness and accuracy. For example, the Raytheon Enhanced Paveway III Dual Mode Laser Guided Bomb (DMLGB) combines the strength of laser technology together with GPS and an Inertial Navigation System (INS).[5] The INS transforms raw data into average velocity and distance traveled and does so wholly by internal means. GPS, on the other hand, uses an external reference (satellite signals) for measuring a platform's position and velocity references. The INS has one obvious advantage over GPS – it does not require external signals, and hence, is more resistant to jamming. On the other hand, INS accuracy degrades over time due to the cumulative errors of the inertial sensors.[6] Once seen as competing technologies, GPS receivers and Inertial Navigation Systems are often complementary as demonstrated by Enhanced Paveway III.

GPS Guidance Kits

GPS Precision Guided Munitions comprise a GPS receiver integrated with a guidance kit. The guidance kit consists of a specialized antenna and associated RF components needed to connect the antenna to the GPS receiver. These guidance kits must be extremely robust to handle high g-force associated with a gun launch, often 20,000 g's or more. Increasingly, guidance kits are being fitted to "dumb," or unguided bombs, which steer them to the target post launch. This market is continuing to expand with development of "smart" howitzer and mortar rounds. Advances in antenna technology are also making GPS more applicable to a wider variety of munitions.

XM 982 Nosecone with Dualband L1-L2 GPS Antenna Array

First, specialized passive antennas are capable of providing a fixed-shape antenna beam. For example, a fixed beam, forward-null antenna may focus less energy in the direction of a missile's flight path, or possibly, a reduced level of energy below the missile's flight path. This design strategy assumes that most jammers will be co-located with the targets they are intended to defend. A fixed null in the jammer direction could provide as much as 15 dB signal suppression. Active beam-forming antennas may steer even less signal in the direction of strong in-band (jamming) signals. Effectively, a null-steering antenna could provide 30 dB or more attenuation of the unwanted signal. In the case of multiple jamming signals, the adaptive beam forming process becomes more complex, and requires either additional antenna elements or a reduction in suppression performance. Of course, any benefits gained from adaptive beam forming must be balanced against reductions in satellite signal reception due to the dynamically changing antenna radiation pattern.

ERGM LRIP with Two-element GPS Patch Antenna Array

Given this complicated operating environment, selection of the appropriate antenna is an essential part of the overall system performance optimization. Examples of modern precision guided munitions using GPS for guidance include:

XM 982

- Raytheon's Extended Range Guided Munition (ERGM) and XM982
- AGM-88 HARM (High Speed Antiradiation Missile) supersonic air-to-surface tactical missile
- Enhanced Paveway II

These special GPS antennas may be conformal or embedded antennas. An example is the 2011TF L1/L2 GPS antenna. This antenna was designed and optimized for both supersonic flight and extreme environmental conditions. The 2011TF GPS antenna features dual o-rings to seal the antenna from the elements. The ra-

5 Raytheon Corp. Marketing Data Sheet, "Enhanced Paveway II Dual Mode GPS/Laser Guided Bombs", 2009

6 Naser El-Sheimy, "Less Is More–The Potential of Partial IMUs for Land Vehicle Navigation," Inside GNSS (Spring 2008), p. 17.

AGM-88 HARM (High Speed Antiradiation Missile) Air-to-Surface Tactical Missile

dome is constructed of high grade polymer resin for UV and abrasion resistance, and resistance to all deicing fluids, jet fuels, and standard cleaning solvents.

This antenna has been used by warfighters in combat operations around the world with successful deployment on guidance units for Paveway 2,000 pound bombs. The Paveway II picture shows an array of two GPS antennas (circled in yellow) to provide continuous GPS coverage during weapon flyout through impact.

PCTEL 2011TF L1/ L2 GPS Munition Antenna

PGM technology has firmly established itself as a key part of the future evolution of weapons platforms. The public recognition of the value of PGMs, and their place in modern warfare, may have only begun in the 1990's, but the foundation for this technology has been building for many decades. Guidance Kits, and their components including the antenna structure, are an essential part of this technological evolution. This is especially important as they are both retrofitted to existing weapons platforms, or designed-in to new platforms, with the challenging and often conflicting requirements for smaller, lighter, more rugged, and lower cost.

Two GPS antennas (circled in yellow) to provide continuous GPS coverage during weapon flyout through impact.

PCTEL, Inc. is a leading supplier of specialized military antenna systems. PCTEL's antennas are equipped with features enabling them to achieve a high level of performance under challenging environmental and operational conditions. Munitions Guidance Antennas used for purposes such as controlling missiles are highly ruggedized; portable SATCOM antennas are miniaturized for laptop and portable radio communications; precision aviation antennas are GPS and GEO augmented; airborne antennas have standardized mechanical features for integration into airframe platforms; and SATCOM and asset tracking antennas have specific mechanical features and configurations for embedding into electronic and mechanical enclosures. Customization of these antennas allows them to function under extreme conditions such as severe vibrations on an aircraft or missile, and severe weather conditions including sandstorms, while still facilitating reliable, high-speed communication and data transmission.

2011TF GPS Antenna Array (circled) during Weapon Release

F-117 dropping Paveway Precision Guided Munition