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Technology Reuse on the Spacelift Ranges

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Range Standardization and Automation Program

The Range Standardization and Automation (RSA) program is designed to completely update both of Air Force Space Command's ranges: the Eastern Range at Cape Canaveral Air Station, Florida, and the Western Range at Vandenberg Air Force Base, California. As part of this modernization, several new technologies are under consideration to improve system performance and reduce operating and maintenance costs. Several of these technologies have the potential to reduce costs to vehicles launched off the ranges, and change the format of tracking data from the range.

The RSA program is planned for three phases. Phase I was awarded by the Space and Missile Systems Center to the Harris Corp. in 1993. It addresses some of the more pressing needs on the ranges such as a new communications system for the Eastern Range and new telemetry processing systems for both ranges. Phase IIA was awarded to Lockheed Martin in 1995 to develop a completely modernized architecture for both ranges, and complete the upgrade of all command, control, and communications systems, and other systems such as weather and optics. Phase IIB, planned for award in 2002, will implement the fixed instrumentation part of the Phase IIA architecture.

It is the on-going Phase IIA effort which provides the opportunity to implement significant changes in the structure and operations of the ranges. Lockheed Martin is proposing use of the Global Positioning System (GPS), and bistatic technology in the Passive Coherent Locator (PCL), as parts of the ranges' tracking capability. Both of these are technologies which have been used in other systems.

Global Positioning System

The ranges need to be able to accurately track all vehicles operating from them, including spacelift, ballistic missiles, cruise missiles, aircraft, and other suborbital vehicles. One of the primary reasons for tracking is range safety. Due to the destructive potential of an errant launch vehicle, all launches are tracked, compared to pre-established safe corridors, and the impact point predicted in the event of an intentional or unintentional flight termination. Due to narrow corridors in some locations, particularly ICBM testing into the Kwajalein Missile Range in the Pacific, tracking needs to be reliable and accurate. Given the high accuracy of ballistic missiles, operational testing of current systems or developmental testing of new systems requires even greater accuracy. Tracking of vehicles launched off the ranges is now done with C-band radar. Due to accuracy needs of range safety, and in some cases of range users testing weapon systems, most vehicles have to fly with a beacon to aid radar tracking. While a well-known, proven technology, C-band beacons and the associated power supply, antennas, and cabling are relatively heavy and expensive. Likewise, the ground radars used for tracking are expensive to maintain and operate, consume large amounts of power, do not have the desired reliability, and are not as accurate as desired in some areas.

Originally intended as a navigation aid for ground forces, GPS applications are rapidly expanding. As GPS receivers become less expensive, smaller, and more capable, it is likely many more uses will be found. It is for these very reasons space launch is in a position to benefit as well. Several system configurations are currently under consideration. Most GPS applications use receivers. The current generation of receivers is small, lightweight, and uses little power. Receivers have an added advantage of being virtually self-contained. Position data from a GPS receiver can be integrated into the telemetry stream, just as the position data from vehicle guidance is today. Due in part to the current use of selective availability (SA), the accuracies of receivers may not be sufficient for all weapon system testing. GPS translators are capable of the extra accuracy needed, as considerably more information is contained in the data transmitted to the ground station. The added processing which can be accomplished in a translator ground station is the source of the higher accuracy. The downside of translators is the size of the market, which is many times smaller. Due to this lower demand, there has not been nearly as much development and the resulting systems are larger, consume more power, and are more expensive.

In addition to the benefits in accuracy, weight, size, and power, a GPS system has the added advantage of extending the range at which high accuracy can be achieved. Where three radars with significant spatial dispersion may be necessary to get high accuracy results with radar, one telemetry dish can provide optimal results with a GPS-equipped vehicle. This is a great advantage when overflying large stretches of ocean where placement of land-based radar is difficult or impossible. Increased accuracy in tracking may make it possible for range safety to widen flight corridors. Wider flight corridors reduce the risk of destroying a launch vehicle which is not perfectly following the planned trajectory, but may still be able to place a payload in orbit. Spatial diversity is also needed for GPS accuracy, but the tracking systems are on orbit. Due to the architecture of the constellation there are always more GPS space vehicles with a view of a launch vehicle than could ever be affordably achieved with radar tracking. Differential GPS, with reference receivers either at all instrumentation sites or just at the Operation Control Centers, is part of the current proposal. Figure 1 shows the technical comparison of the current C-band radar system, GPS receivers, and GPS translators:

Figure 1 - Performance Comparison

	Radar (w/beacon)	GPS Receiver	GPS Translator
Accuracy (Real-Time) ¹	100 m; >0.3 m/s	15 m; 0.3 m/s	25 m; 0.3 m/s
Accuracy (Post-Mission) ¹	0.3 m; 0.3 m/s	1 m; 0.003 m/s	2 m; 0.001 m/s
Size ²	90 in ³	10 in ³ (est.)	10 in ³ (est.)
Weight ²	7.5 lb	3 lb (est.)	4.5 lb (est.)
Power ²	23 W	2 W (est.)	17-35 W (est.)

In addition to the potential performance benefits of using GPS for tracking, there are equally convincing potential cost benefits. Figure 2 summarizes vehicle costs per launch and annual range costs. Some near-term investment will be required to achieve the long-term savings. While the costs of implementing GPS on a new vehicle, such as the Evolved Expendable Launch Vehicle (EELV), would not be significantly greater than implementing a radar beacon, there are clearly extra costs involved in converting existing vehicles where the radar integration has already been completed. Current estimates are from approximately \$1.5M for small vehicles such as Pegasus, to approximately \$10M for medium and heavy-lift vehicles³.

Figure 2 - Cost Comparison

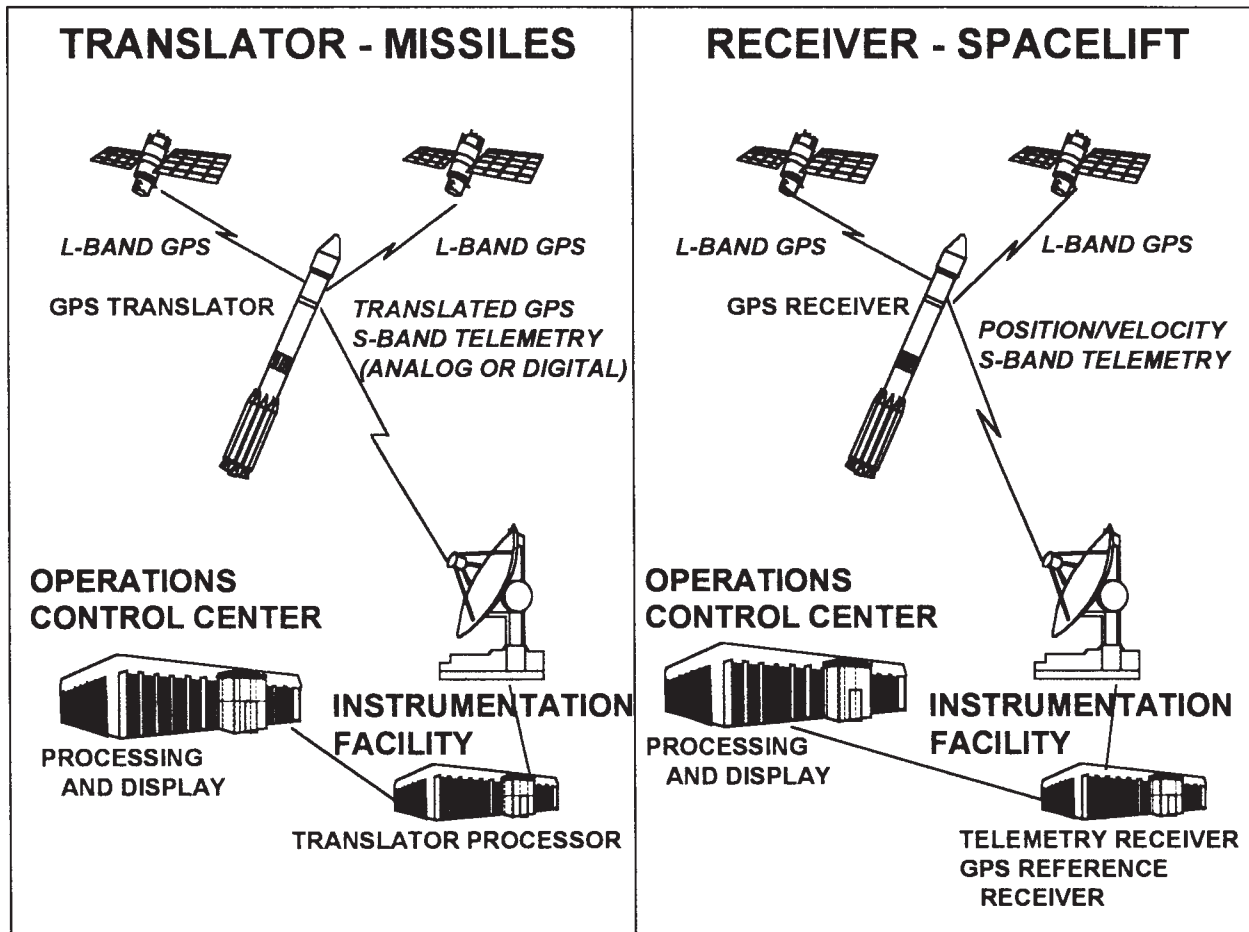
	Radar Beacon ³	GPS Vehicle Kit ³	Annual Radar Cost ⁴	Annual GPS Cost ¹
Small Launch Vehicles	\$10k (avg.)	\$10k (est.)	\$12M (est. for 13 radars which could be replaced by GPS)	\$800k (est. for receivers)
Medium/Large Launch Vehicles	\$65k (avg.)	\$10k (est.)		\$1.3M (est. for translators)

Figure 3 shows a comparison of receiver-based systems, and translator-based systems. Given the need to minimize costs to the spacelift community and the need to provide higher levels of performance to the missile community, the final range architecture will likely include support for receivers and translators.

Clearly there are a number of issues yet to be worked before GPS tracking becomes a reality on the ranges. The greatest technical challenge is developing GPS systems that can withstand the launch environment. While the maximum expected sustained acceleration rates of 5g are not overly difficult, the maximum potential instantaneous acceleration of 50g/s will prove considerably more difficult. Several receiver vendors claim to be able to withstand up to 10 g with current systems for initial acquisition, and recent tests run at White Sands Missile Range have shown sustained operability through 60 g. The GPS Range Joint Program Office is developing a translator specified to sustained acceleration levels of 10 g and instantaneous acceleration of 25 g/s. If track is lost, the probability of regaining track at those accelerations is low. A very likely solution is a vehicle receiver which incorporates an inertial measurement unit to aid in maintaining and regaining track. Given development of a reasonable market, it is entirely possible a receiver manufacturer will develop systems which can withstand sufficient acceleration for spacelift missions without additional investment by the launch or range communities².

The transition of all current vehicles is the greatest challenge. While in the long run GPS will prove beneficial to the range and range users alike, the transition will take considerable effort on the part of the government and the commercial launch industry. The planned transition period, FY2002 - FY2004, will aid the conversion by allowing a launch vehicles to integrate GPS during significant upgrades to other vehicle systems.

Figure 3 - GPS Translator/Receiver Comparison



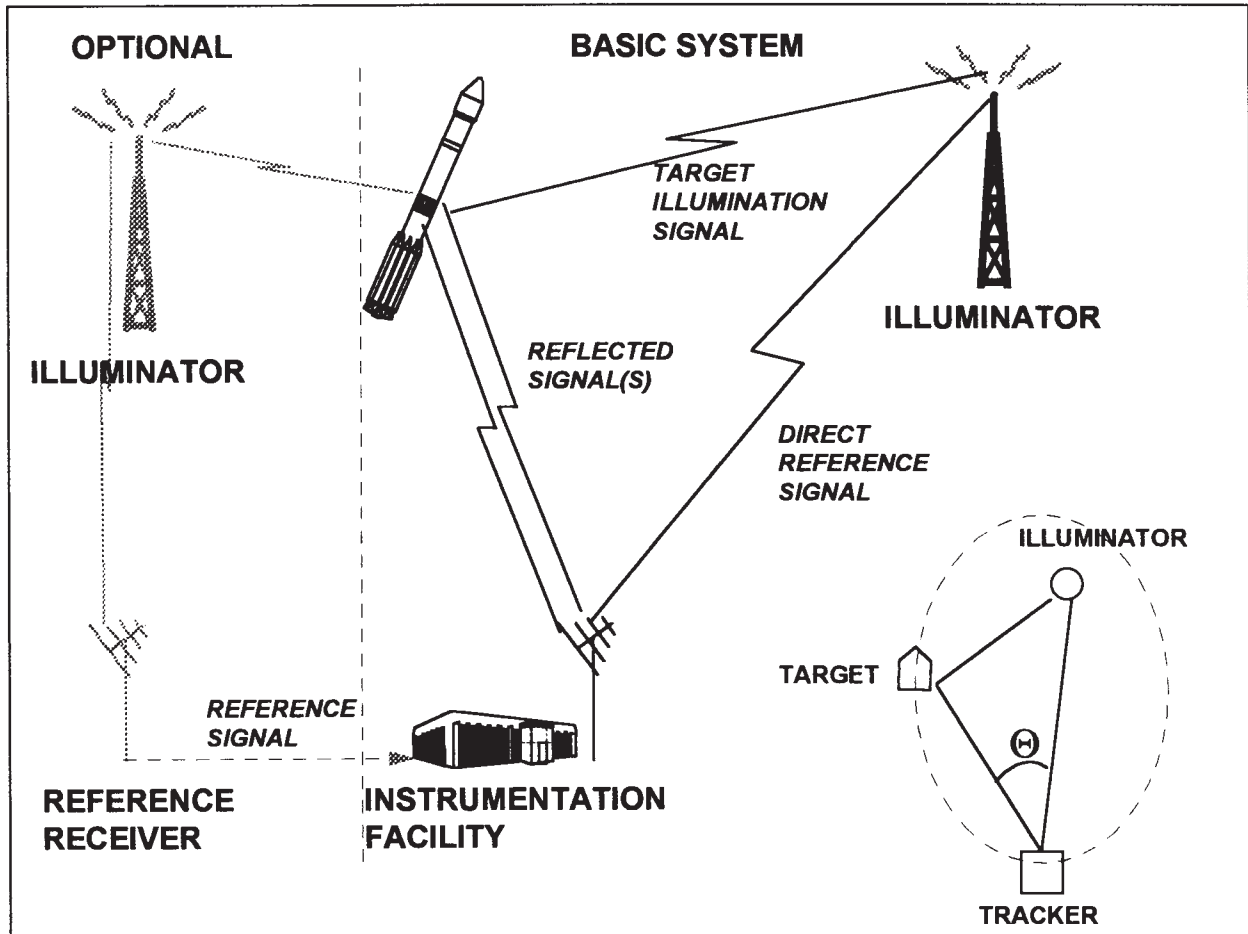
Passive Coherent Locator

The Passive Coherent Locator (PCL) system is an application of bistatic radar technology. Bistatic technology has been used in a number of demonstrations over the past decade, and is currently being evaluated for use in range tracking systems. Lockheed Martin has developed several systems, as has the Air Force's Rome Lab. As with GPS, there are a number of possible system configurations, with varying cost and technical benefits. The basic concept takes advantage of ambient radio frequency (RF) energy and tracking Doppler shifts between direct receipt of one or more RF signals and received signals which are reflected off the target vehicle. Variations on the theme include the frequency range utilized, the amount of automation in the system, the antenna configuration, the number of illuminators used, and the algorithms used to process the returns.

One potential system configuration consists of the system shown in Figure 4. From a single illumination source, the tracking station receives direct signals as well as signals reflected off a target. Processing of these two signals yields a Doppler shift, which identifies the range of the target to a number of possible points which describe an ellipse. Measurement of the angle to the target versus the angle to the illuminator places the target at one point on that ellipse, resulting in an identified point in space. Clearly there will be other returns from any given illuminator, and tracking can only be effectively carried out by consistently identifying the location of

the target, or targets, to be tracked. Amplitude of the return, Doppler shift, and trajectory are all useful in correlating returns to specific target tracks.

Figure 4 - Nominal PCL System



Advantages can be gained by using multiple illuminators or multiple receiving antennas. Just as multiple radars will add to the accuracy of a radar tracking solution, multiple illuminators can add to the accuracy of a PCL tracking solution. The angle measurement will always have some uncertainty, and multiple solutions from different angles will narrow the intersecting areas. This diminished area corresponds to the increased accuracy of the tracking solution. A multiple-illuminator solution will also provide a more robust system where one or more illuminators may not provide sufficient RF energy on the target or to the tracking station. Since the angle to the target must be measured in relation to the angle to the illuminator, use of a single antenna requires pre-surveyed and characterized illuminators. A single antenna may also require some movement in azimuth and/or elevation to maintain view of the target, which adds antenna position into the tracking processing. Multiple element antennas, such as the circular array of dipoles used in several Air Force Rome Lab systems, allow the tracking station to characterize

the current RF environment without any extensive pre-mission surveying. Location of illuminators is determined in real time using the known beam angle of each of the elements of the antenna. This also eliminates the need to physically move the antenna during a mission as track could be handed off from one element to another.

One disadvantage of a single receiving station is the limited range available. When a target is no longer reflecting a signal from an illuminator which is also received directly by the tracking station, the illuminator can no longer be used in the solution. In some cases, that range can be extended by using a reference receiver. As shown in the "Optional" section in Figure 4, the reference receiver is located where it can receive direct RF from a pre-surveyed illuminator. The reference receiver must be able to transmit an adequate representation of that RF signal to the tracking station. Since the illuminator in this case is a known quantity, the reference station need only provide a frequency reference for the Doppler shift processing. The tracker can then use the reflections of that illuminator off the target, along with the known location of the illuminator, in determining the position of the target.

Passive Coherent Locating offers a number of technical benefits to the ranges and to range users. Using ambient RF eliminates the need for large transmitters. The wide beamwidth of the antennas minimizes the need to move antennas while tracking, and may eliminate the need for moving antennas altogether. A single system can track several objects. This capability may be useful for debris tracking, although further development is necessary to track the large number of objects resulting from a launch vehicle termination. Since bistatic technology tracks in Doppler space and each piece of debris is likely to have a unique Doppler signature, discrimination of separate pieces should be enhanced. There is no need for any additional equipment on board the vehicles to be tracked, so there is no power or weight penalty on any launch vehicle. Finally, PCL can provide some imaging capability. Current systems use illuminators from HF to L-band, and the imaging capability will increase as frequency does. Proper frequency selection can result in ignoring small objects which are of no interest, or can result in identification of relatively fine details where needed.

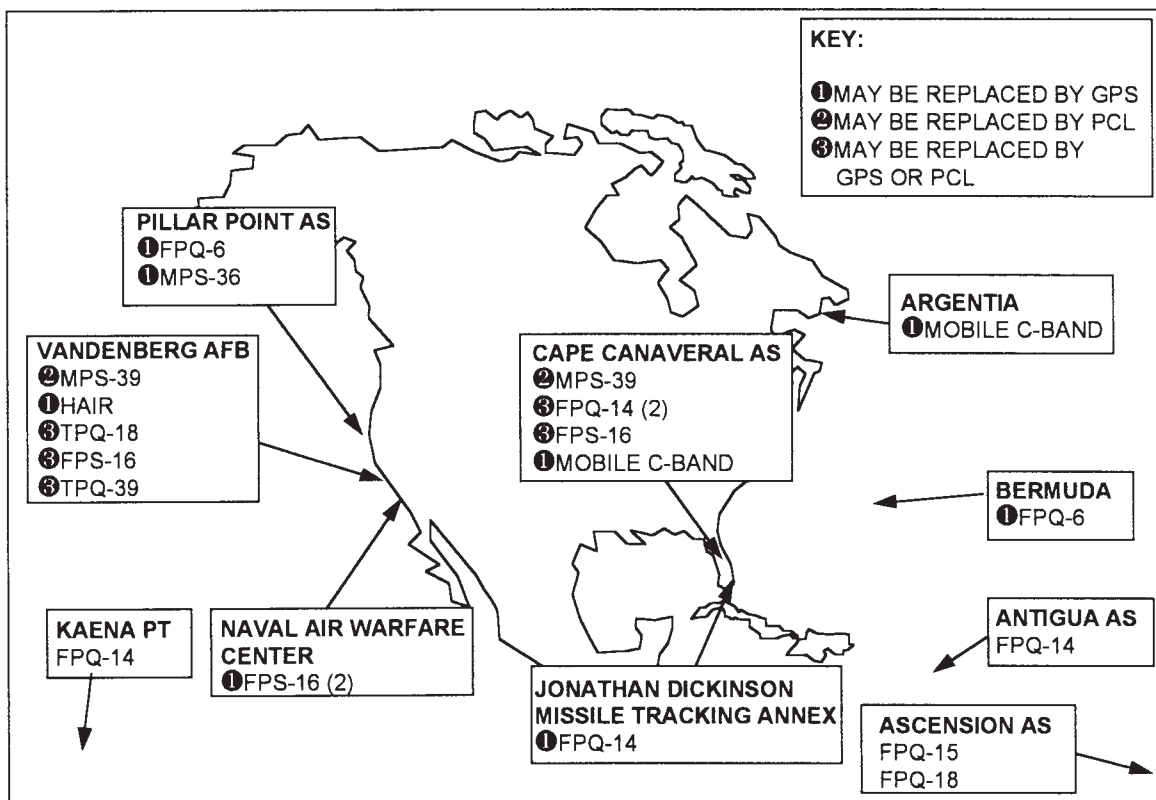
While great opportunities exist with bistatic technology, there are several areas requiring more work. Since PCL tracks in Doppler, only moving vehicles can be tracked. The ranges need to be able to track from first motion, so additional effort is needed to provide a system which can track at very low velocities. The multiple-target capabilities may provide significantly better debris tracking, but the association of returns of several illuminators off each target is the most difficult challenge remaining. Current bistatic systems require up to 10 seconds to determine an initial track, and the latency thereafter is around 1 second. These times can be reduced significantly, but with some increase in clutter. Latency times of 1 millisecond are probably the lower limit of an operationally useful system. Finally, tracking accuracies do not meet all range requirements for tracking. PCL can not replace tracking systems such as radars or GPS for all tracking requirements, but can provide a useful secondary source of data where there are many objects to be tracked or where ground clutter or plume attenuation may affect telemetry.

The cost benefits of PCL are compelling. As almost all of the system hardware is off-the-shelf, costs of a PCL system are in the \$300k - \$400k range. Software development would be the most significant cost area. The elimination of large precision tracking antennas and high-power transmitters would result in a significant reduction in range acquisition and operating costs. Depending on the final GPS implementation and a number of other issues, PCL could make it possible to eliminate anywhere from 2 to 6 radars. The resulting savings could be as high as

\$5M dollars a year in operations, maintenance, and support.

Summary

The two initiatives discussed both pertain to tracking capabilities on the ranges. These tracking capabilities are among the most important, and among the most expensive. Based on costs collected on the uprange radars on the Eastern Range, each radar costs close to \$1M per year to operate, maintain, and support. Both GPS and PCL could provide tracking capability for considerably less, reducing costs to the Air Force and to each range user. Figure 5 depicts the current range radars and identifies those which could be eliminated by either GPS or PCL. The radar at Bermuda is owned by NASA, so it may only be eliminated from Eastern Range use rather than physically eliminated. The radars at the Naval Air Warfare Center are owned by the Navy, and may only be eliminated from Western Range use rather than physically eliminated. The radars at Kaena Point, Antigua, and Ascension are used for other functions, and will remain for the foreseeable future.



As defense and other government budgets decline, better use must be made of the available funds. Reusing technology developed for other purposes is certainly more cost-effective than developing new technologies for every new program. The cost savings are magnified when

those new technologies result in systems which are significantly less expensive to acquire, operate, maintain, and support. While all of the technologies described in this paper are still in the proposal stage, ongoing analysis and demonstration may prove the viability for incorporation into the ranges.

1. Global Positioning System (GPS) Trade Study, 18 Aug 96, Lockheed Martin Tactical Systems Company
2. E-mail correspondence with Mr. David Villapando, Aerospace Corporation
3. SMC/CWR briefing, "GPS as a Metric Tracking Source", 5 Feb 97
4. CSR memo, "Cost of Radars, RSA Team Action Item 61212-05", 31 Jan 97