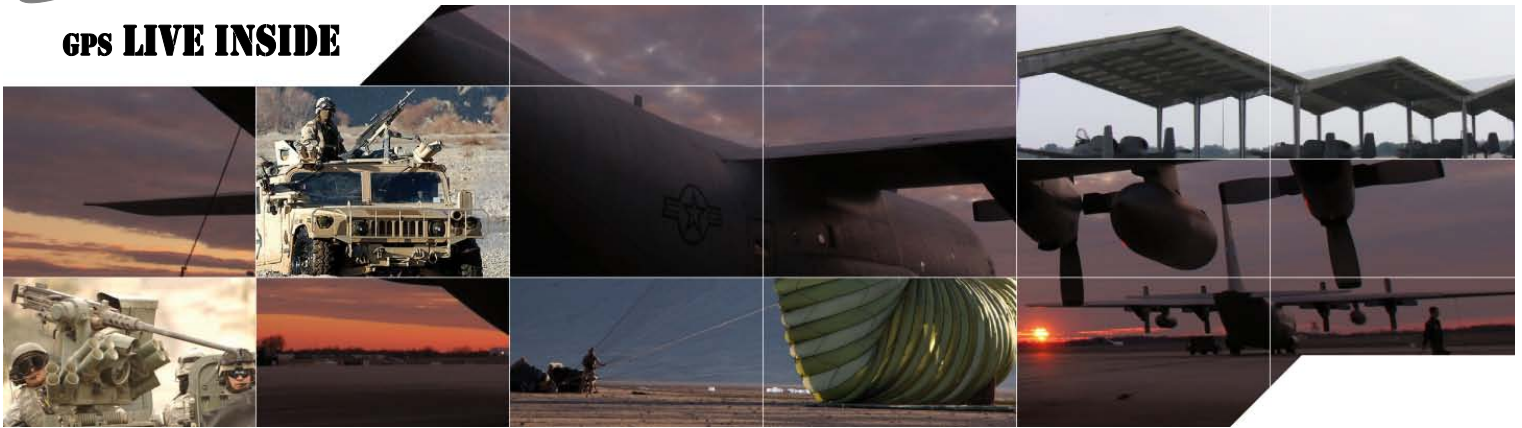


GPS Retransmission White Paper



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Submitted by:
Date:

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Introduction

Global Positioning System (GPS) technology is increasingly being applied in many different military applications beyond navigation. Soldiers use GPS to enhance situational awareness on the battle field with systems such as Land Warrior. GPS applications for airborne soldiers provide guidance to the drop zone in night or inclement weather operations. In the case of Joint Precision Airdrop Systems (JPADS), GPS guidance receivers provide navigation and steering commands to guide the payload to the drop zone. GPS enabled asset tracking may provide current position and status of high value assets, such as VIPs, nuclear weapons, etc. In training applications, GPS technology may be used to track the participating assets, scoring the exercise and enabling a far more instructive de-brief.

In all of the examples above and in many other GPS enabled military applications, it frequently becomes necessary for these GPS receivers to operate in locations where the GPS signals are normally not available. This white paper will discuss the how GPS Retransmission can be a very cost effective solution to the problem of GPS denied environments for *some* GPS enabled applications. Specifically, this paper will concentrate on GPS retransmission systems as they apply to airborne/airlift operation, and specific capabilities and requirements for these systems.

What is GPS Retransmission?

GPS Retransmission, or GPS Repeating, is the art of making the live GPS signals available to handheld or mobile GPS applications at locations where the signals are otherwise not available. Proven applications include the following:

- In the crew compartment of a military vehicle
- In the cargo compartment of a military aircraft
- In the garage or hangar bay of a military maintenance facility
- In the final assembly stage of a military equipment manufacturer

Applications, Benefits, and Added Value

GPS receivers, or specifically the receiver's antennas that are inside of vehicles (aircraft, land vehicles, boats, etc.) or buildings without a Line Of Sight (LOS) view of the GPS satellites, will not reliably provide position information. This limitation can impact many military GPS applications, even if location data inside of the denied environment is not a requirement. For example, the receiver's or system's performance may be impacted in the following ways:

- When the receiver deploys from the vehicle or aircraft, the "time to first fix" (TTFF) can vary significantly based on various conditions (TTFF can be over 5 minutes worst case).
- GPS receiver battery life while operating inside of the vehicle is significantly reduced due to the computationally intensive signal acquisition process.
- Lack of signal availability may preclude verification of system operation prior to deployment.

With a GPS retransmission system installed and providing availability of the GPS signals in the otherwise denied environment, the applications may benefit in the following ways:

- In the cargo compartment of a military aircraft, the GPS retransmission system:
 - Enables acquisition and verification of cargo payload receivers prior to air drop (JPADS)
 - Eliminates TTFF, enabling steering commands immediately upon exiting A/C
 - Enables verification of position, velocity, and elevation of airborne soldier GPS prior to the jump
- In the crew compartment of a typical military vehicle, the GPS retransmission system:
 - Maintains Situational Awareness (SA) with valid location reporting even when inside of the vehicle, rather than reporting of "last known good" location, which would be the location just prior to entering the vehicle
 - Eliminates costly delay in Time To First Position Fix (TTFF) when exiting the vehicle
 - Reduces GPS receiver battery consumption due to computationally intensive reacquisition process
- In the garage or hangar bay of a military maintenance facility and in the final assembly stage of a military equipment manufacturer, the GPS retransmission system:
 - Eliminates requirement to perform maintenance outside of protective shelter, potentially exposing the asset and personnel to hostile fire
 - Allows 100% system functional test, including the application's receive antenna system
 - Maintains "Hot" GPS Ephemeris enabling immediate taxi for A/C on alert status

GPS Retransmission System Architectures

GPS retransmission systems, in their simplest form, include at a minimum the following elements:

- Active Antenna (Active meaning the antenna includes an integrated Low Noise Amplifier)
- Interconnecting Coaxial Cable(s)
- Retransmission Amplifier/Signal Conditioner
- Passive Retransmission Antenna

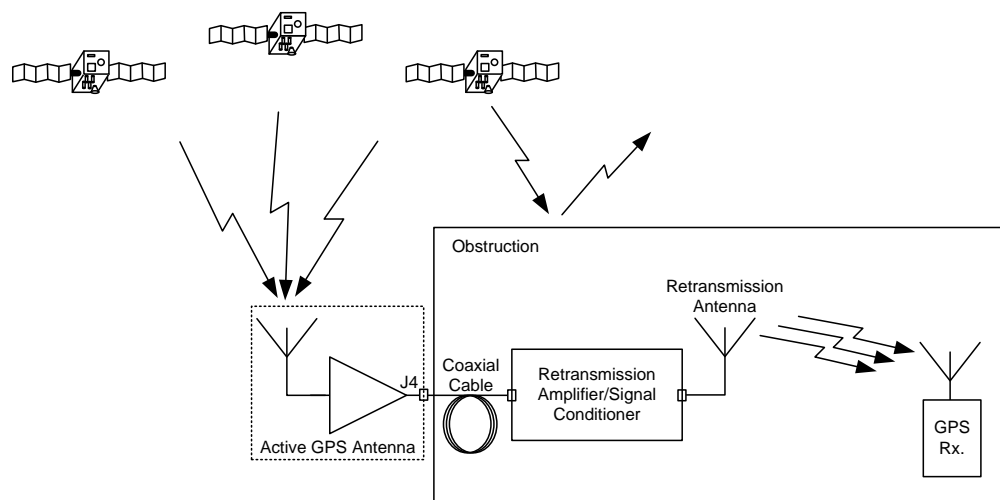


Figure 1. Simple GPS Retransmission System

In this system, the GPS satellite signals are received by the active receive antenna, amplified and conditioned by the retransmission amplifier, and re-broadcast on the GPS frequency(s) by the retransmission antenna. Because the signal delay through the GPS retransmission system is common for each satellite once the signals are received by the exterior antenna, GPS receivers operating in the retransmitted signal environment will generate a location, not at their actual position inside of the hangar, vehicle, or aircraft, but rather they will calculate the position for the system's receive antenna that is located outside in view of the LOS signals. This limitation, however, is not critical for all of the applications described above as the derived location is close enough to accomplish the intended function.

Simple GPS retransmission systems such as the example in Figure 1 are effective in many basic applications, such as a small vehicle garage, or a research lab. However, successful GPS retransmission in the confined, irregularly shaped cargo compartment of a military aircraft or in the crew compartment of a military vehicle presents significant challenges. Limited dynamic range for guaranteed performance of GPS application receivers constrains the retransmitted signal levels in the cargo/passenger compartment. If the retransmitted signal is beyond the dynamic range of the receiver, the GPS receiver may become saturated, resulting in failure to acquire GPS lock on the signals inside or immediately upon exiting of the A/C. An additional consideration must be taken for Selective Availability / Anti-Spoofing Module (SAASM) capable GPS receivers. If the retransmitted signal is too strong inside of the aircraft, this could trigger the Anti-Spoofing capability of the receiver, having an adverse effect on the performance of the receiver. Conversely, the signal may be so low as to preclude signal acquisition and GPS lock by the receiver while still inside the aircraft.

Multiple Antenna Systems

The long, narrow dimensions of aircraft cargo compartments taken together with the rapid $1/R^2$ signal propagation losses and limited dynamic range of application GPS receivers typically dictates that multiple retransmission antennas will be required for complete, uniform coverage. The figure below is a simplified example of the GPS signal coverage for a retransmission System in the C-130J aircraft (examples are included for both the short and stretch variants). This figure illustrates the necessity of an adequate number of antennas. Any fewer antennas than shown below would require a higher Effective Radiated Power (ERP), potentially resulting in saturation of the receivers located in the vicinity of a transmit antenna. The saturated receiver would likely result in slow or delayed reacquisition of the LOS signals upon deployment from the aircraft, which would result in lost weather data in the case of the JPADS weather dropsonde or in lost glide range for the JPADS guided parachute systems. Another concern for excessive signal strength is the potential for triggering the Anti-Spoofing functionality of SAASM capable military GPS receivers, which would further degrade the receiver's performance. The higher ERP also extends the range of the re-transmitted signals unnecessarily, which in turn extends the zone of potential interference with other GPS operations outside of the aircraft when aircraft doors are open.

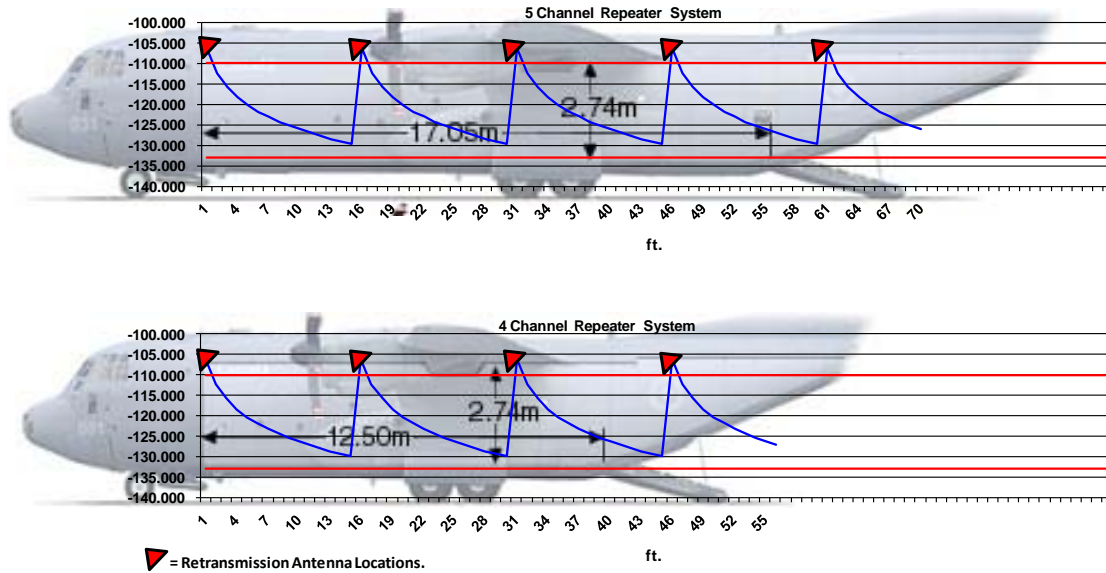


Figure 2. Example of a Multiple Antenna GPS Retransmission System

The antenna system proposed above would provide uniform coverage throughout the cargo compartment, while maintaining a signal level well within the dynamic range of the GPS receivers. In addition to maintaining the desired signal levels, the multiple antenna system also provides diversity in the signal path, preventing blockage of the signal to the application receiver due to obstructions. This is particularly a concern for smaller aircraft, such as the C-27J or the CH-53 (see Figure 3).

One potential issue, however, with multiple antenna retransmission systems is the potential for severe multipath in the GPS receiver's correlators, resulting in significant receiver position error, velocity error, or in the worst case large "dead zones," which are regions between the retransmission antennas where the receivers fail to function in spite of sufficient signal coverage. Special care must be taken in the design of the antenna system so as to eliminate the potential for severe multipath error in the application receivers and to eliminate "dead zones" in the coverage.

In summary, a properly designed multiple antenna retransmission system reduces the necessary radiated power, maintaining it within the dynamic range of the application receivers, while significantly enhancing coverage and performance.

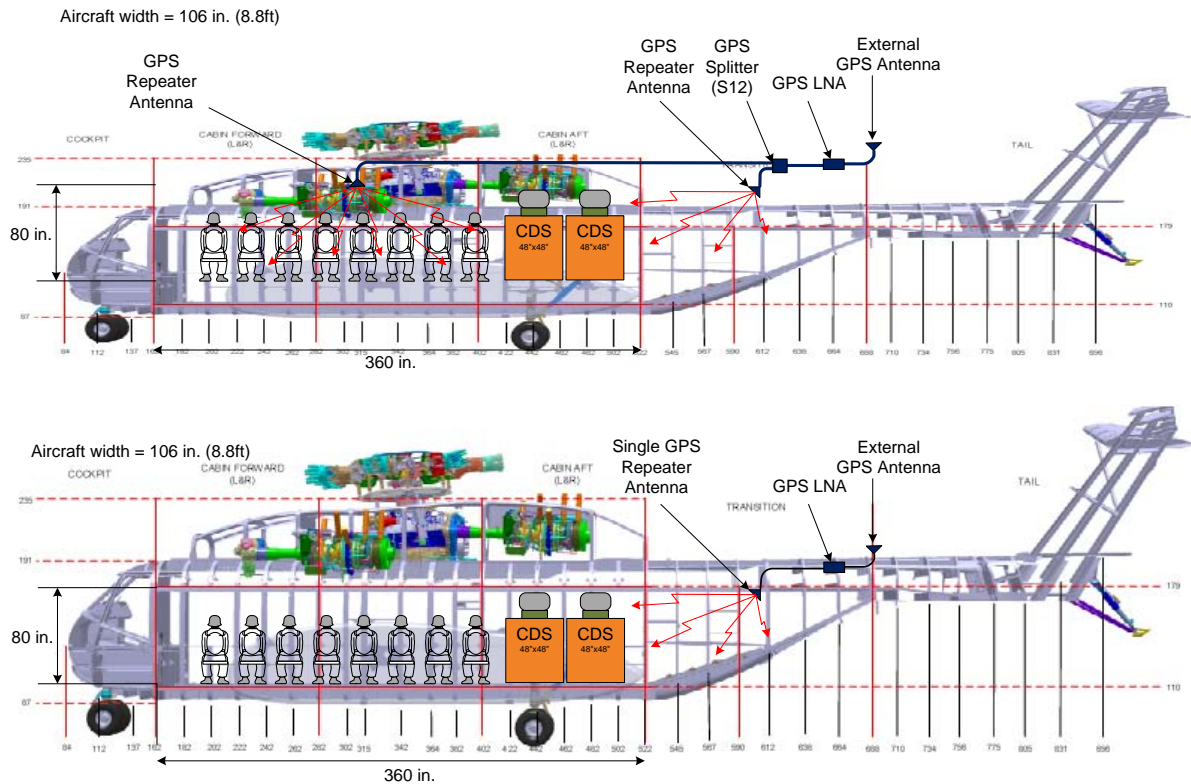


Figure 3. Antenna Diversity with Multiple Antenna GPS Retransmission Systems

GPS Retransmission System Signal Source

All GPS retransmission systems require a source for the live GPS signals that are available outside of the aircraft. This may be realized by an antenna dedicated to the GPS retransmission system on the skin of the aircraft, or the GPS retransmission system may share the GPS receive antenna with the aircraft's navigation system. The latter case, which is the far more likely scenario, requires an additional component that distributes the GPS signal to both systems. The Antenna Electronics Unit (AEU) performs this function in many modern US military aircraft. However, if the aircraft does not include the AEU, a GPS signal splitter is required.

Shared Antenna & GPS Splitter

If a GPS splitter is used, it must be designed so as to not impact the performance of the aircraft's navigation system in any way. For example, the splitter must be amplified to offset the signal losses due to the signal split (e.g. 0dB overall gain from the input to either output is required). Additionally, the splitter must comply with all EMI/EMC requirements for the GPS receiver system (typically MIL-STD-461). Specifically, the splitter's 3rd Order Input Intercept Point (IIP3) must be sufficiently high such that frequency products from other transmitters on the aircraft do not create spurious signals within the splitter that interfere with the GPS bands (L1 and L2). This requirement is typically covered by MIL-STD-461, CS103. Finally, the splitter must be designed to pass the DC voltage from the GPS receiver to the active antenna in order to power the antenna's LNA. This is the simplest implementation in that it requires no additional aircraft wire harness modifications; however, this option does require that the GPS receiver be capable of providing the 45mA for the splitter in addition to the antenna's LNA current. Otherwise, the splitter must include a MIL-STD-704/28V compliant power supply for powering the splitter and for providing the bias voltage to the antenna LNA.

AEU & Automatic Signal Level Control

The AEU is the preferred signal source for military aircraft that are so equipped. However, the auxiliary MCR output (J4) of the AEU's fielded in US military aircraft today have a wide range of default gain settings, depending on the implementation in the particular aircraft (e.g. from 17 to 45dB). The AEU gain is very important in establishing the GPS retransmission system's effective radiated power (ERP). As described earlier, precise control of the GPS retransmission system ERP is a key factor in maintaining the signal level within the dynamic range of the application receivers. Furthermore, the AEU specification allows for a very wide range of initial gain accuracy and gain variation over temperature (approximately +/-10dB).

In order to compensate for the wide range of AEU gain settings, initial tolerances, and temperature variations, the GPS retransmission system must have the ability to automatically control the retransmission amplifier's output signal level, thereby precisely controlling the retransmission system's ERP. Thus the GPS retransmission amplifier/signal conditioner must employ an Automated Signal Level Control feature so as to maintain the GPS signal levels in the cargo compartment at the precise levels required for compatibility with all application receivers.

Antenna for Temporary Install Systems

Note that an additional signal source option for temporary roll-on/roll-off systems is an antenna mounted behind the aircraft's windscreen. This configuration is by far the least desirable solution in that the visibility to the overhead GPS satellites is severely limited, sometimes as much as 75%. Limited satellite visibility often results in very poor performance of the application receivers within the aircraft. This option may be used for roll-on/roll-off systems when there is no other choice (i.e. permanent modification of the aircraft is not an option). Permanently installed GPS retransmission, or at least provisions for accessing a permanently installed receive antenna, be it a dedicated receive antenna or a shared one, are strongly preferred in order to ensure GPS retransmission system performance.

Other Implementation Options

Multiple antenna GPS retransmissions systems can be implemented in two different ways:

- A single retransmission amplifier/conditioner with a signal distribution network and multiple antennas, or
- A signal distribution network followed by multiple retransmission amplifiers/conditioners with multiple antennas (the antennas typically integrated with the retransmission amplifiers/ conditioners)

See Figure 4 below.

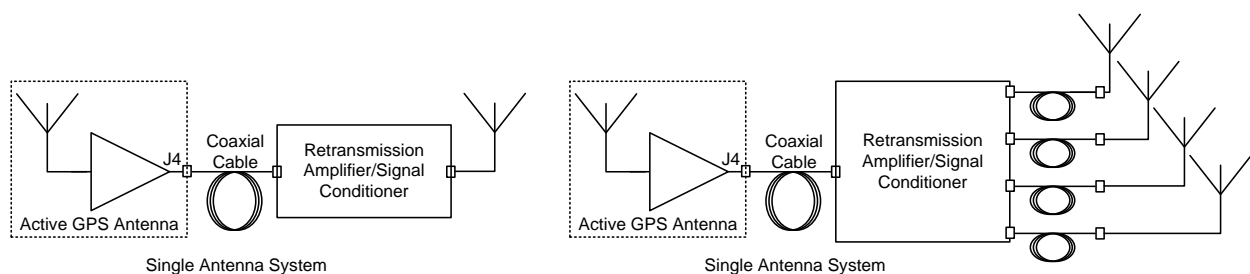


Figure 4. Single Retransmission Amplifier/Conditioner System vs. Multiple Retransmission Amplifier/Conditioner System

The single amplifier/conditioner solution is far more common for the permanent installation systems, but can be used for temporary install systems as well. The single amplifier/conditioner solution allows for one primary LRU which houses the system power supply and other complex system functions such as the automatic signal level control. However, this system can sometimes be a little more difficult to install/remove for temporary install systems.

The multiple retransmission amplifiers/conditioners are typically far simpler to install/remove. However, such systems typically lack the complexity of the single amplifier/conditioner systems (e.g. they typically do not include such functions as the automatic signal level control, requiring manual setting of the system gain during installation).

Permanent vs. Temporary Install

Currently available GPS retransmission systems include both permanently installed as well as temporarily installed systems. For example, GPS Source is currently providing either the entire system or components for permanently installed systems for the C-17 and the MV-22 aircraft. Both GPS Source and PSI have systems for temporary install on the C-130 and C-17. GPS Source also has available GPS retransmission systems that are easily configurable for installation on a large range of aircraft, including all variants of the following aircraft: C-17, C-130, V-22, H-53, H-46/47, H-60, CN-212 CASA, C-23 Sherpa, C-27J, etc. The following are a few of the advantages and disadvantages for temporary install vs. permanently installed systems.

Advantages for Temporary Installed Systems:

- Typically far less expensive to develop and procure
- Procurement and fielding can be much quicker than a permanently installed system
- Can be used on multiple aircraft platforms without customer integration; however, the system will not be optimized for any specific aircraft

Disadvantages for Temporary Installed Systems:

- Temporary install GPS retransmission systems can require significant removal and installation time. This prohibits a quick transition from a primary aircraft to a spare in the event of primary aircraft failure.
- These systems experience frequent failure or loss of system components due to the continuous handling during installation and removal (e.g. coaxial cables, power cables, connectors, etc.).
- They frequently fail to perform to specification due to improper installation.
- Typically, they require non-standard logistical support.
- Due to the requirement that they support multiple aircraft and/or aircraft configurations, temporary install GPS retransmission systems are not optimized for any specific aircraft configuration, resulting in compromised performance.
- Due to the fact that US military aircraft have non-standard A/C 28VDC outlets, the temporary install systems must have power cables supporting each aircraft platform for which the system is intended to operate, or the system must be designed to operate from a common military battery system, such as the BA5509.
- If the host aircraft is not equipped with an AEU, the temporary install system must either include a signal splitter which must be inserted between the aircraft's GPS antenna and navigation system, or the GPS retransmission system's antenna must be placed behind the aircraft's cockpit windscreen. As described previously, locating the receive antenna behind the windscreen severely limits satellite visibility and reduces the performance of the retransmission system.

Advantages for Permanently Installed Systems:

- A significant increase in mission readiness is recognized.
- System design and installation are optimized for best possible performance (e.g. 100% GPS Retransmission System coverage under worst case cargo conditions).
- Aircraft is pre-configured for PADS & special operations missions.
- The system has fully verified and validated compatibility with all other aircraft systems as well as PADS & special ops mission equipment.
- There is improved safety of flight.

Performance Requirement & Expectations

Certain levels of performance and quality are to be expected in a state of the art GPS retransmission system. The following are the minimum performance criteria that should apply for a permanently installed solution where the system is optimized for installation on the particular aircraft. Many of these requirements should also apply to temporarily installed systems; however, certain aspects of performance may be compromised for system and installation simplicity.

100% Coverage

100% GPS signal coverage of the cargo compartment can be accomplished given the proper antenna system design and installation. The necessity for installers to tweak and adjust the retransmission system antennas in order to achieve signal coverage for specific payload locations is a waste of valuable time and a distraction from the mission at hand. Permanent install systems and higher quality temporary systems (if designed and installed correctly), should provide 100% coverage of the cargo compartment.

Additionally, it is common for the JPADS mission planners and Special Operations Mission Commanders sitting on the flight deck of large cargo aircraft to utilize a GPS receiver and moving map display during the course of a JPADS mission so as to maintain situational awareness and mission progress. Consequently, GPS retransmission systems intended for larger aircraft, whether for permanent or temporary install, should include an option of GPS signal coverage of the flight deck, even if only localized coverage in the area of the flight engineer/mission planner station.

100% Compatibility

The GPS retransmit subsystem must transmit a usable signal to all areas of the cargo compartment for commercial and military GPS receivers such that dropsondes, AGUs, and other devices receive the real-time GPS signal prior to deployment from the aircraft. One-hundred percent compatibility is a reasonable requirement for GPS retransmission systems. If designed correctly, GPS retransmission systems should be 100% compatible with any military or civilian GPS receiver brought onto the aircraft.

Signal Level

Regardless of the GPS signal source, GPS retransmission systems should be designed to ensure the compatibility requirement described above is met. The systems should provide and maintain a precise GPS signal level. The precise GPS signal should be available within the designated coverage area and within the normal operating range of GPS receivers.

Continuous or Near Continuous Lock

Although a brief loss of GPS lock (e.g. not more than 5 to 8 seconds) can be expected during the transition from a retransmitted GPS signal to the LOS signals outside of the aircraft, primarily due to the sudden shift of 50ns to 200ns in satellite signal code phase delay, a prolonged loss of GPS signal availability by the application receiver should not be observed. The GPS retransmission system design cannot do anything to address the loss of GPS signal when the application receiver is “tumbling” upon exit; however, if the system is designed correctly, nearly all GPS receiver applications should re-acquire very quickly and begin providing valid navigation data to the application within seconds of deployment.

Extensive BIT and Fault Isolation

All modern avionics equipment, whether they are permanently or temporarily installed, should feature a robust Built-In-Test (BIT) and Fault Isolation capability. In the GPS retransmission system, the BIT/FI capability should provide for system operational status and enable maintainers to isolate system faults to the individual system elements (so much as possible). Thus, the BIT/FI capability should meet the following requirements:

- BIT, together with associated support equipment, shall be designed so as to enable Fault Isolation to the system individual item level so much as possible, quickly and efficiently
- BIT shall detect functional degradation of overall system performance
- Any failure of BIT circuitry shall not cause failure or degradation of other GPS RS functions
- BIT functionality shall validate the functionality of the GPS RS functionality at power on and periodically during operation
- BIT shall be designed to minimize false BIT annunciations
- BIT shall make maximum use of system functional circuits

BIT Adequacy

- Percentage of Fault Detection (BIT-D): >95%
- Percentage of Fault Isolation (BIT-I): >90%
- Percentage of False Indications (BIT-FI): <5%

Signal Quality

The GPS retransmission system should be designed so as to maintain the GPS retransmitted signal quality. The Signal-to-Noise ratio of the retransmitted signal should not be degraded more than 3dB with respect to the LOS signal quality available outside of the aircraft.

Signal Accuracy

The GPS retransmission system should maintain adequate GPS signal accuracy with respect to position and velocity inside of the aircraft. Quality GPS receivers, while operating with the retransmitted signal, should maintain a position accuracy of 50m 2DRMS relative to the location of the receive antenna on the aircraft. Quality GPS receivers, while operating with the retransmitted signal, should maintain a velocity error of less than +/-20 knots with respect to the aircrafts true ground speed.

Oscillation Prevention

Due to the fact that GPS retransmission systems receive and retransmit on the same frequency, employing significant gain in the process, the potential for the system to oscillate is a real concern, particularly in smaller aircraft.

When a GPS retransmission system is installed incorrectly (i.e. insufficient isolation between transmit and receive antennas), or a system has experienced some kind of failure (e.g. a failure resulting in excessive system gain and transmit power), an oscillation can occur that results in a spurious emission transmitted by the system at a signal level sufficient to jam not only the GPS receivers operating within the aircraft (including the aircraft's own navigation system), but other GPS operations for miles around. Consequently, it is imperative that the modern GPS retransmission systems employ some method of detecting an oscillation condition and inhibiting system operation in order to avoid this scenario.

Quality

Designed and to the following minimum MIL-STDs:

- Electrical Power Service Conditions MIL-STD-704
- EMI/EMC MIL-STD-461
- Environmental Conditions MIL-STD-810
- Human Factors & Personnel Safety MIL-STD-1472
- General Safety MIL-STD-882
- Software Development Process Quality RTCA DO-178B, MIL-STD-498
- Construction
 - Materials, Processes, Parts MIL-E-5400, MIL-STD-1568, MIL-STD-1587
 - Finish & Color AFSC DH2-2 DN 2A2, MIL-E-5400
 - Soldering IPC/EIA J-STD-001, Class 3, IPC-A-610, Class 3
 - PWB Design: IPC-2221, IPC-2222
Fabrication: IPC-6011, IPC-6012, Class 3
 - Interconnecting Wiring MIL-HDBK-454

Verification & Validation

Verification and validation of the GPS receiver system design is imperative to ensure that the system meets the quality and performance requirements identified in the previous paragraphs (verification), and that the system can perform the intended mission (validation).

Modern electromagnetic computer models are an excellent tool for performing systems verification against requirements for coverage and signal level.

Electromagnetic Computer Model Simulations

To verify compliance with the requirement for 100% coverage, GPS Source has completed analytical models that calculate signal coverage in the empty cargo compartment, and verify those models by completing more detailed cargo compartment electromagnetic computer simulations for worst case cargo configurations (see Figure 5). This model demonstrates the far more complex nature of the electromagnetic environment inside of the aircraft cargo compartment due to multipath reflections. However, it also illustrates the usefulness of completing a simple signal level map calculation in the preliminary systems design (see Figure 2). Note that signal levels with the cargo envelop are consistent with the original simplified model.

Ground and Flight Tests

Design verification and validation testing of the GPS retransmission systems on the host aircraft are critical and should be required in order to ensure that the GPS Retransmission System is tested for following:

- Complete compatibility with all elements of the application system. For example, in the case of JPADS, the testing should ensure compatibility with the GPS-guided parachute system (the AGUs), the CF29 Mission Planning Laptop and Software, the UHF datalink receiver, and the weather dropsonde.
- EMI/EMC Safety Of Flight
- GPS signal assessment throughout the cargo compartment and if required, on the flight deck. Signal assessment is evaluated in terms of Signal Level (or Strength), Signal Quality, Signal Accuracy, and Signal Coverage, with at least two configurations of the cargo compartment: empty, and a worst case cargo configuration or occupancy
- Interoperability with other A/C avionics systems
- System control, fault isolation, and troubleshooting
- An airdrop or free fall airborne jump test, where GPS signal lock by the application receiver is evaluated during the pre-deployment, throughout the deployment, and for the first few moments of the descent under canopy.

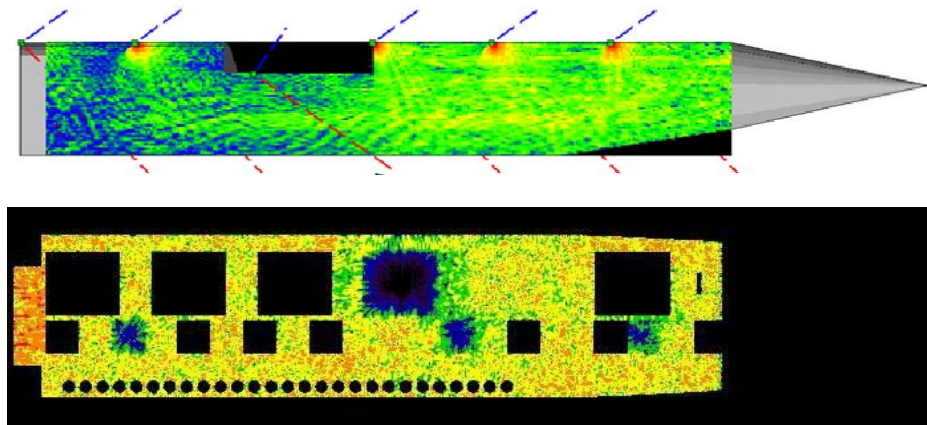


Figure 5. Electromagnetic Cargo Compartment Simulations (C-17 example)

(Top: Side View, Empty Compartment; Bot: Top Down View, Alternating Height & Material, DR & CDS)

NTIA / IRAC Background

The US Federal Government Agency that administers policy relating to the use of the GPS bands is the National Telecommunications and Information Administration (NTIA), an organization within the Department of Commerce. The committee within the NTIA that establishes this policy is the Interdepartment Radio Advisory Committee (IRAC). In October of 2005, GPS Source presented recommendations for a regulatory regime and provided supporting technical analysis that assisted the NTIA/IRAC in establishing policy regarding devices that retransmit the GPS signals. GPS Source, working with other Federal Government Agencies, including Spectrum Management from the Department of the US Army, as well as the USAF Space Systems Battle Labs and other industry colleagues, was successful in securing a regulatory regime for authorization to operate GPS retransmission systems for fixed indoor locations and for mobile armored vehicles. At present, the IRAC policy, as established in the NTIA handbook (NTIA Procedures and Principles for the Assignment and Coordination of Frequencies), expressly forbids the operation of GPS retransmission systems inside of US military aircraft over US territory. GPS Source proposes working with the US Defense Department and the IRAC to resolve this conflict and establish provisions within the NTIA Handbook to cover GPS Retransmission in US military aircraft.

Links:

GPS Source Presentation to IRAC:

http://www.ntia.doc.gov/osmhome/irac/GPS_Source_%20IRAC_Presentation_10-28-05.ppt

GPS Source Technical Presentation to IRAC:

[http://www.ntia.doc.gov/osmhome/irac/GPS_Source_Re-Radiator_Kit_Tech_Ana_10-30-05_\(2\).ppt](http://www.ntia.doc.gov/osmhome/irac/GPS_Source_Re-Radiator_Kit_Tech_Ana_10-30-05_(2).ppt)

NTIA Procedures and Principles for the Assignment and Coordination of

Frequencies, see paragraphs 8.3.28 and 8.3.29

<http://www.ntia.doc.gov/osmhome/redbook/8.pdf>

GPS Source Contact Information

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