



SYSTEMS MANAGEMENT RECOMMENDED PRACTICE

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Toughening a PNT System with COTS Inline GPS/GNSS Jamming Protection

RATIONALE

There is a need to strengthen the resilience of all positioning, navigation, and timing (PNT) systems without having to replace the receiver or install an expensive blocking or controlled reception pattern antenna. Commercial off-the-shelf (COTS) inline anti-jam antenna electronics work in conjunction with two or more low-cost fixed reception pattern antennas to toughen any PNT system by minimizing or eliminating the impacts of intentional or unintentional jamming from one or more directions.

FOREWORD

Controlled reception pattern antenna (CRPA) arrays and their supporting antenna electronics (AE) can greatly reduce the range at which receivers are affected by intentional or unintentional interference; however, these systems may not be economically feasible for many PNT systems. A lower cost alternative is a COTS inline anti-jam (AJ) AE working in conjunction with two or more COTS fixed reception pattern antennas (FRPA). These systems do not require a new receiver and can be configured to minimize or eliminate the impacts of intentional or unintentional jamming from one or more directions. They can be used in positioning and timing applications where the receiver is stationary or moving.

Resilience to disruptions caused by global positioning system/global navigation satellite system (GPS/GNSS) interference is essential to maintaining transportation safety and the continuous operation of equipment used by critical infrastructure. This recommended practice provides step-by-step guidance for selecting and installing a COTS inline AJ AE system that will provide category 3 toughening.

NOTICE

This recommended practice is not intended to be a substitute for the manufacturer's guidance or professional installation that complies with local, state, and/or federal laws and regulations.

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Documents
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1. SCOPE

This recommended practice describes how to toughen a new or existing PNT system with the installation of inline GPS/GNSS jamming protection.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 U.S. Department of Homeland Security Publications Library

Available from U.S. Department of Homeland Security, 245 Murray Lane, SW, Suite 2020, Washington, DC 20528, www.dhs.gov/publications.

Best Practices for Improved Robustness of Time and Frequency Sources in Fixed Locations, January 6, 2015.

Improving the Operation and Development of Global Positioning System (GPS) Equipment Used by Critical Infrastructure.

2.1.2 U.S. Department of Transportation Publications

Available from U.S. Department of Transportation, Bureau of Transportation Statistics, 1200 New Jersey Avenue, SE, Washington, D.C. 20590, Tel: 800-823-1351, National Transportation Library Repository and Open Science Access Portal <https://rosap.ntl.bts.gov/contact>.

U.S. Department of Defense, U.S. Department of Transportation, and U.S. Department of Homeland Security (2022). *2021 federal radionavigation plan* (Report No. DOT-VNTSC-OST-R-15-01). U.S. Department of Transportation.

2.1.3 The Institute of Navigation Publications

Available from The Institute of Navigation, 8551 Rixlew Lane, Suite 360 Manassas, VA 20109, Tel: 703-366-2723, www.ion.org.

Akos, D., Chen, Y., De Lorenzo, D., Enge, P., and Lo, S. (2013, January 28–30). *Validation of a controlled reception pattern antenna (CRPA) receiver built from inexpensive general-purpose elements during several live jamming test campaigns* [Conference presentation]. International Technical Meeting of The Institute of Navigation, San Diego, CA.

Chen, Y. (2012, September 17–21). *A study of geometry and commercial off-the-shelf (COTS) antennas for controlled reception pattern antenna (CRPA)* [Conference presentation]. 25th International Technical Meeting of the Satellite Division of The Institute of Navigation, Nashville, TN.

Gupta, I., and Lee, T. (2010, September 21–24). *Combining multiple FRPA for AJ functionality in GPS receivers* [Conference presentation]. 25th International Technical Meeting of the Satellite Division of The Institute of Navigation, Portland, OR.

2.1.4 United States Coast Guard Publications

Available from Navigation Center, United States Coast Guard, U.S. Department of Homeland Security, 7323 Telegraph Road, Alexandria, VA 22315, Tel: (703) 313-5900, <https://www.navcen.uscg.gov/gps-technical-references>.

NAVSTAR Global Positioning System, Joint Program Office (1991). *GPS NAVSTAR global positioning system user's overview* (5th ed.) (YEE-82-009D). Prepared by ARINC Research Corporation.

NAVSTAR GPS user equipment introduction (public release version). (1996). U.S. Coast Guard, U.S. Department of Homeland Security.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 U.S. Government Accountability Office Publications

Available from U. S. Government Accountability Office, 441 G. St., NW, Washington, D.C. 20548, Tel: 202-512-3000, <https://www.gao.gov/>.

GPS Disruptions, DOT Could Improve Efforts to Identify Interference Incidents and Strengthen Resilience.

2.3 Definitions

BLOCKING ANTENNA: Typically a single element antenna that blocks or attenuates signals from the horizon and receives only signals from higher elevations.

CONTROLLED RECEPTION PATTERN ANTENNA: A phased array antenna made up of multiple GPS antenna elements. When combined with antenna electronics that perform advanced signal processing, interference arriving from specific directions can be suppressed, while GPS signal reception is maintained.

FIXED RECEPTION PATTERN ANTENNA: A single element antenna that provides gain across the sky while providing some suppression of signals from out-of-band frequencies.

GLOBAL NAVIGATION SATELLITE SYSTEM: Refers collectively to the worldwide PNT determination capability available from one or more satellite constellations. Each system employs a constellation of satellites operating in conjunction with a network of ground stations.

GLOBAL POSITIONING SYSTEM: A space-based, dual-use PNT system that is operated for the USG by the USSF. The USG provides two types of GPS service. PPS is available to authorized users and SPS is available to all users.

INTERFERENCE (ELECTROMAGNETIC): Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the performance of user equipment.

JAMMING (ELECTROMAGNETIC): The deliberate radiation, reradiation, or reflection of electromagnetic energy for the purpose of preventing or reducing the effective use of a signal.

MILLISECOND: One thousandth of a second.

MULTIPATH: The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths. When two or more signals arrive simultaneously, wave interference results. The received signal fades if the wave interference is time varying or if one of the terminals is in motion.

NANOSECOND: One billionth of a second.

NAVIGATION: The process of planning, recording, and controlling the movement of a craft or vehicle from one place to another.

NULLING: Suppressing interference from one or more directions, while maintaining GPS signal reception.

OMNIDIRECTIONAL: The ability to receive GPS/GNSS signals equally from any direction.

PNT RESILIENCE: The ability of PNT systems to withstand and recover from GPS/GNSS interference from any source without harmfully degrading or losing PNT information.

POSITIONING: The ability to accurately and precisely determine one's location and orientation two-dimensionally (or three-dimensionally when required), referenced to a standard geodetic system, such as World Geodetic System 1984, or WGS84.

SPOOFING: RF waveforms that mimic true signals in some ways, but deny, degrade, disrupt, or deceive a receiver's operation when they are processed. Spoofing may be unintentional, such as effects from the signals of a GPS repeater, or they may be intentional and even malicious. There are two classes of spoofing:

- Measurement spoofing introduces RF waveforms that cause the target receiver to produce incorrect measurements of time of arrival or frequency of arrival or their rates of change.
- Data spoofing introduces incorrect digital data to the target receiver for its use in processing of signals and the calculation of PNT.

Either type of spoofing can cause a range of effects, from incorrect outputs of PNT to receiver malfunction. The onset of these effects can be instantaneous or delayed, and it is possible for effects to continue even after the spoofing has ended.

TIMING: The ability to acquire and maintain accurate and precise time from a standard (Coordinated Universal Time, or UTC) anywhere in the world and within user-defined timeliness parameters. Timing also includes time transfer.

UNMANNED AIRCRAFT SYSTEM: An aircraft and its associated elements which are operated with no pilot on board.

WORLD GEODETIC SYSTEM 1984: An Earth-centered, Earth-fixed terrestrial reference system and geodetic datum. WGS 84 is based on a consistent set of constants and model parameters that describe the Earth's size, shape, and gravity and geomagnetic fields. WGS 84 is the standard U.S. Department of Defense definition of a global reference system for geospatial information and is the reference system for GPS. It is consistent with ITRS.

2.4 Abbreviations

AE	Antenna electronics
AJ	Anti-jam
C/A	Coarse/acquisition
COTS	Commercial off-the-shelf
CRADA	Cooperative research and development agreement
CRPA	Controlled reception pattern antenna
DoD	Department of Defense
DHS	Department of Homeland Security
DOT	Department of Transportation
EMC	Electromagnetic compatibility
FAA	Federal Aviation Administration
FRP	Federal Radionavigation Plan

FRPA	Fixed radiation pattern antenna or fixed reception pattern antenna
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
INS	Inertial navigation system
ITRS	International Terrestrial Reference System
ms	Millisecond
ns	Nanosecond
NASA	National Aeronautics and Space Administration
NAVSTAR	Navigation signal timing and ranging or navigation satellite timing and ranging
PNT	Positioning, Navigation, and Timing
PPS	Protected Positioning Service
RF	Radio frequency
RHCP	Right-hand circular polarization
SBAS	Space-Based Augmentation System
SBIR	Small Business Innovation Research
SPS	Standard Positioning Service
SWaP	Size, Weight, and Power
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UPS	Uninterruptable power source
USG	United States Government
USSF	United States Space Force
UTC	Coordinated Universal Time
WAAS	Wide Area Augmentation System
WGS	World Geodetic System

3. OVERVIEW OF FRPA, CRPA, AND MULTIPLE FRPAs FOR GPS/GNSS RECEIVERS

In September 1996, the public release version of the book NAVSTAR GPS User Equipment Introduction stated that “there are three basic types of GPS antennas, a passive Fixed Radiation Pattern Antenna (FRPA), a FRPA with an integrated preamplifier, and a Controlled Radiation Pattern Antenna (CRPA). The requirement to drive a long cable run, with its associated signal loss between the antenna and the GPS receiver resulted in a FRPA with an integrated amplifier.” Up until 2008, CRPAs had been shown to be the only effective means of protecting GPS receivers against multiple wideband jammers; however, that changed when the U. S. Air Force funded a Small Business Innovation Research (SBIR) to design, develop, simulate, implement, and test combining FRPAs into a CRPA array for GPS anti-jam improvements on UAV platforms.

FRPA gain patterns are permanent; they are determined by the design of the receiving element. CRPA gain patterns are variable and controlled in real time by the AE. A CRPA has two components: an antenna array and the AE. The antenna array is composed of antenna elements spaced at approximately half wavelength separation, at the operational wavelength. It is essential for optimum operation of the CRPA that all the antenna elements in the array have omnidirectional performance with constant gain characteristics over as large a sector as possible.

The AE controls the array's radiation pattern by adjusting the gains and phase from each antenna element to create a null and then steer it in a pseudorandom fashion across the nominal gain pattern to minimize the total measured power. The AE ignores the RF energy from the GPS/GNSS satellites because their power level is lower than the background noise. CRPA systems are typically capable of generating and steering multiple nulls, which allows them to counteract the threat from multiple jammers. There are CRPA systems capable of nulling and beam steering; however, they are outside of the scope of this recommended practice.

A multiple FRPAs system functions just like a CRPA system; however, the AE uses multiple identical FRPAs, each with an integrated amplifier instead of a single multiple-element fixed array. Figure 1 is an illustration from the GPS NAVSTAR Global Positioning System User's Overview. On the left it shows a CRPA system nulling a single high-power jammer and, on the right, it shows a FRPA being jammed. A two FRPAs system similar to the one shown in Figure 2 will null a single high-power jammer just as the CRPA system does in Figure 1. The AE shown in Figure 2 requires less than 1 W of power, weighs less than 6 ounces, and occupies less than 6 in³ of space.

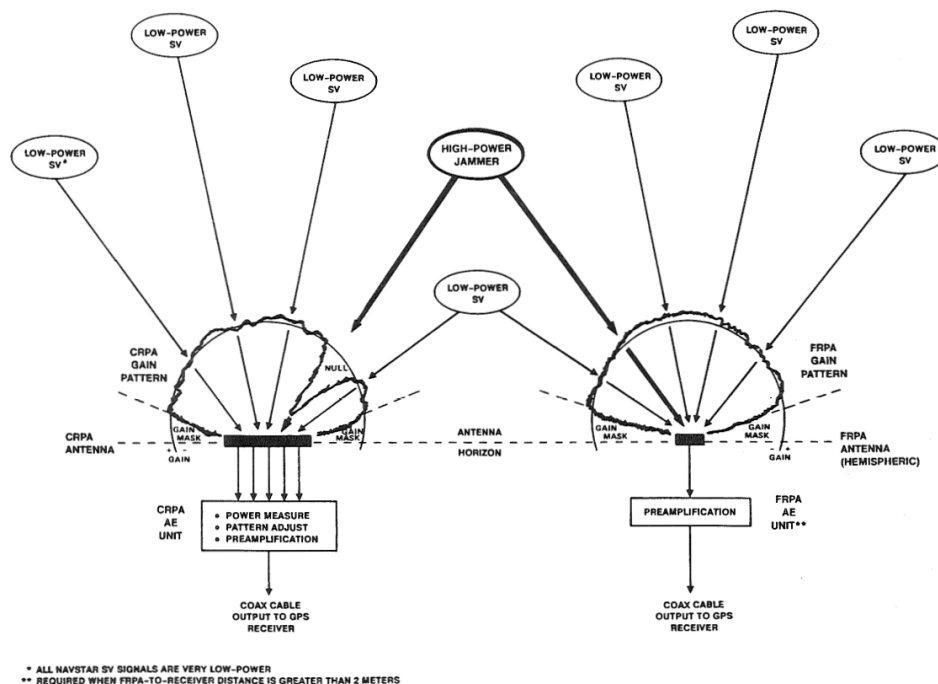


Figure 1 - CRPA and FRPA vs. high-power jammer
 Source: NAVSTAR Global Positioning System, Joint Program Office (1991).
 GPS NAVSTAR global positioning system user's overview (5th ed.)
 (YEE-82-009D). Prepared by ARINC Research Corporation.