FocalPoint

TECHNICAL OVERVIEW · WHITE PAPER

Supercorrelation®

Positioning technologies for a smarter world.

VERSION 2.0

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Proprietary notice

INTRODUCTION

Supercorrelation boosts the performance of radio receivers

Every radio receiver faces the same three problems. It can't integrate weak signals coherently when it's moving. It can't tell a direct signal from its reflections. And it can't distinguish a legitimate signal from a malicious one arriving from the wrong direction.

These are signal-processing problems and they limit performance across the entire RF stack: GNSS, Wi-Fi, cellular, satellite communications, and beyond.

Focal Point Positioning's patented Supercorrelation technology addresses all three at the receiver signal-processing layer. This paper describes the technology and its implementation for GNSS receivers, a product family called 'S-GNSS®'. Readers unfamiliar with the basic functionality of a GNSS receiver should consult Kaplan [1] or van Diggelen [2] first.

A standard GNSS receiver uses antenna/s and correlators to perform correlation, providing input to the navigation engine. Supercorrelation is an additional software function that operates between the correlators and the navigation engine. It provides enhancements to the code tracking functions, boosting the accuracy, sensitivity and reliability of the receiver by removing multipath interference and non-line-of-sight signals.

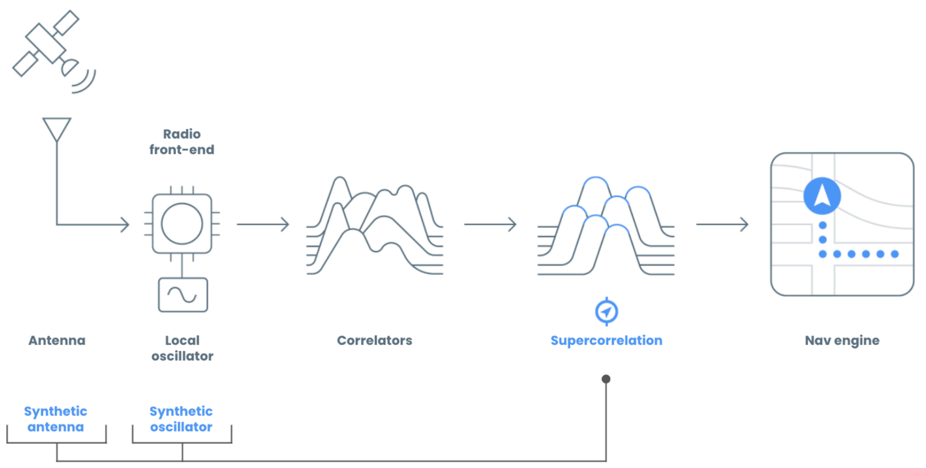


Figure 1 — An S-GNSS® Receiver

Supercorrelation operates between the traditional GNSS correlators and the navigation engine. It effectively creates a high-performance synthetic antenna and synthetic oscillator, processing data from the correlators and removing multipath interference and non-line-of-sight signals. The impact of these corrections is improved sensitivity and accuracy for observables such as pseudorange and Doppler measurements.

BENEFITS

Supercorrelation benefits

Current generation GNSS receivers perform a small amount of coherent integration, typically less than 20 milliseconds, and then incoherently integrate further to boost sensitivity. The reasons for this are historical limitations of data modulation bits, crystal oscillator stability, and receiver motion during the integration period. FocalPoint's Supercorrelation technology overcomes these limitations to enable more than one second of coherent integration. It can do so even while undergoing complex motions and on low-cost hardware.

The benefit is higher sensitivity coupled with unique multipath mitigation capabilities. This provides a high accuracy and high reliability solution for positioning in traditionally difficult environments. It also enables unique angle-of-arrival measurement capabilities only otherwise available from military-grade, export-controlled Controlled Radiation Pattern Antennas (CRPAs).

Multipath mitigation

The major problem with using incoherent integration instead of coherent integration is the increased susceptibility to multipath interference. Incoherent integration destroys the phase information stored within the captured data before combining it, resulting in line-of-sight (LOS) and non-line-of-sight (NLOS) signals accumulating within the same correlation peak, producing a distortion of the desired line-of-sight information. This distortion leads to erroneous pseudorange estimates, which in turn leads to erroneous position estimates.

Supercorrelation employs motion compensation of the correlation process itself to separate out the energy from different incoming directions by angle of arrival. This allows the LOS energy to be isolated and a LOS-only correlation peak to be formed, regardless of the number of incoming reflected signals, as shown in Figure 2. This provides improved pseudoranges and Doppler frequencies for available satellites, leading to improvements in position and velocity accuracy and reliability.

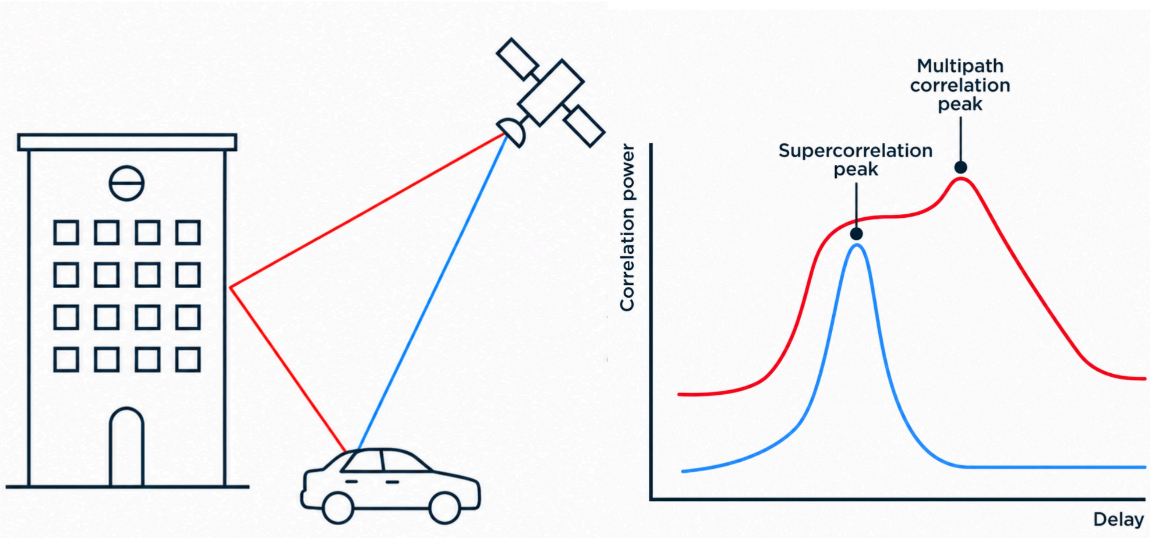


Figure 2 — Multipath Correlation Peak The red line shows a reflected (NLOS) satellite signal and the blue is a direct (LOS) signal. The red correlation peak shows a typical corrupted correlation peak resulting from multipath interference. The blue correlation peak shows the uncorrupted correlation peak tracked by Supercorrelation after rejecting any multipath interference which would otherwise obscure the LOS signal.

Locking on to the line-of-sight signal

Supercorrelation is sensitive to angle of arrival, and can be used to track signals arriving from the known direction of the satellites in the sky. This property can be confirmed by assessing the "true shadows" that can be provided in urban environments by Supercorrelation. As the receiver passes buildings that obscure a given satellite, the C/N0 from Supercorrelation will vary from high values representative of open-sky power, down to just a few dB-Hz, as the S-GNSS receiver correctly tracks into the shadow of the building, as shown in Figure 3.

Often it is observed that traditional trackers will maintain a lock on a reflected signal during such obscurations, reporting incorrect pseudorange, Doppler, and C/N0 measurements within these building shadows. The Supercorrelation outputs will however provide correlation peaks corresponding to the correct pseudorange, Doppler, and C/N0 as the satellite moves in and out of occlusion. Supercorrelation is therefore ideal for shadow matching and 3D-Map-Aiding augmentation systems.

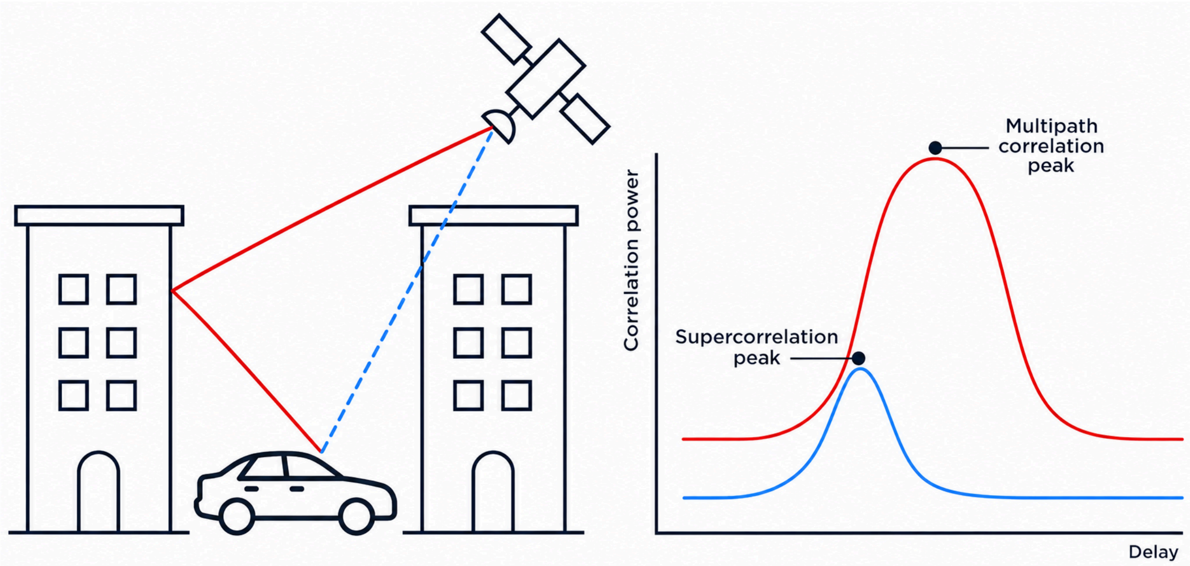


Figure 3 — Locking onto weak LOS

The LOS (blue) signal is relatively weak due to the obstruction, but Supercorrelation enables the receiver to stay locked onto the weak LOS rather than the strong NLOS signal (red). A typical receiver will correlate its replica code with the strong (but inaccurate) NLOS signal (red correlation peak), while a Supercorrelation-enabled receiver is able to correlate with the weaker LOS signal (blue correlation peak).

Spoofer immunity

The ability to reject NLOS signals also enables a Supercorrelation-enabled receiver to be resistant to spoofing. As the spoofer will be unable to send false signals from the correct azimuths and elevations for each satellite, these signals will be filtered out, irrespective of their relative strength. FocalPoint has demonstrated this ability through real-world testing at JammerTest — results available on demand.

Sensitivity boost

Standard GNSS processing typically involves short ~20 ms coherent integration and extended non-coherent integration. Supercorrelation processing enables long coherent integration times. Depending on platform requirements, FocalPoint has demonstrated successful coherent integration periods of between 100 ms and 5 s. These long integrations are possible even while undergoing complicated user motions.

Coherent integration boosts the signal while attenuating the noise, whereas traditional non-coherent integration boosts the signal and the noise by different factors. Supercorrelation therefore provides a boost in sensitivity, even when compared to receivers that are already performing extended non-coherent integration. Supercorrelation typically provides a 6–10 dB reduction in the receiver's noise floor, depending on the receiver settings, enabling the tracking of much weaker signals than is possible in standard GNSS receivers.

Benefits working together

Supercorrelation enables strong reduction in multipath interference, sensitivity only to LOS signal components, and an increase in receiver sensitivity. These benefits all work together to provide more accurate, more reliable pseudorange and Doppler measurements. These in turn result in more accurate PVT estimates in the navigation engine. This is because Supercorrelation rejects NLOS signals when the LOS path is obstructed, whereas standard processing will continue to process NLOS measurements, corrupting the PVT estimates.

METHOD

How Supercorrelation works

Supercorrelation uses a complex phasor sequence which is designed to adjust the phases of a chain of GNSS PRN codewords, based on device motion with respect to the LOS. As a result, the S-GNSS receiver integrates strongly with the energy coming from a LOS satellite and attenuates energy coming from all other directions (e.g. multipath and spoofing/jamming). The degree of multipath mitigation provided is a function of both the speed of the receiver through space (relative to the reflecting surfaces in the environment) and the coherent integration time.

The Supercorrelation algorithms also maintain an estimate of the receiver motion during the Supercorrelation period. Supercorrelation can be used without any inertial sensor assistance at all for platforms with simple motion characteristics like cars and trucks, but the sensitivity and computational load are improved if they are available. Even low-quality sensors can be used, such as those in smart-wearable devices.

Some GNSS signals have navigation bits or other data modulated onto the code sequence. In order to coherently integrate these signals for long periods, the data bits need to be removed. This can be done with signal processing, the data bits can be observed and retained in runtime, or an external assistance data stream can be used.

REAL-WORLD RESULTS

S-GNSS® Auto in the urban canyon

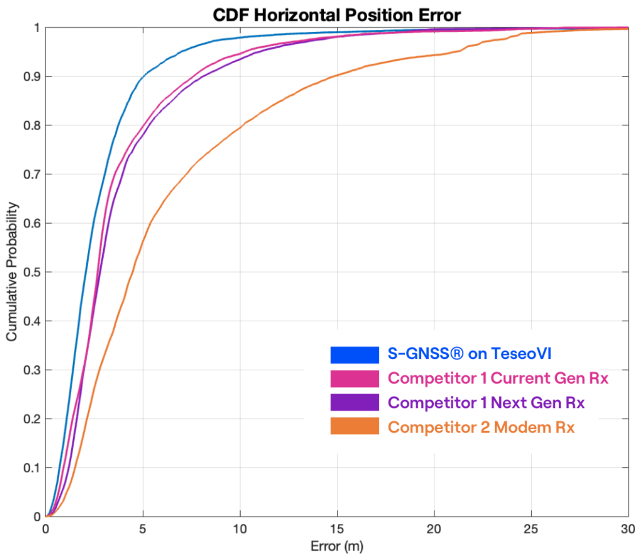
FocalPoint benchmarks Supercorrelation against state-of-the-art competitor receivers in the most demanding environment in the world: the dense urban canyons of the City of London, where reflections off glass-and-steel towers routinely corrupt conventional GNSS.

Figure 4 — S-GNSS® Auto performance map view

The result of Supercorrelation on positioning performance for a car driving in the urban canyons of the City of London. The green line is ground truth from a state-of-the-art IMU, antenna and GNSS receiver. The blue line is the STMicroelectronics TeseoVI receiver with Supercorrelation processing enabled; the pink, purple and orange lines are competitor devices without Supercorrelation. The effect of multipath interference is clear on the competitor solutions, where it cuts through buildings, whereas the S-GNSS receiver ignores the NLOS and keeps the true position more accurately.

REAL-WORLD RESULTS

Quantifying the accuracy gain



Horizontal Position Error: City of London

System	50%	68%	95%
ST TeseoVI + S-GNSS®	2.1 m	2.9 m	7.0 m
Competitor 1 Current Gen Rx	2.8 m	3.8 m	11.0 m
Competitor 1 Next Gen Rx	2.7 m	3.4 m	10.3 m
Competitor 2 Modem Rx	4.5 m	6.8 m	21.2 m

Figure 5 — S-GNSS® Auto performance data

A Cumulative Distribution Function (CDF) of horizontal position error for the City of London competitor benchmark, with a table of key errors at the 50th, 68th and 95th percentiles. The TeseoVI + S-GNSS solution outperforms all three competitor receivers — holding 95% of fixes within 7.0 m where the nearest competitor reaches 10.3 m.

CAPABILITY

SkyScan

Each Supercorrelator is tailored to couple strongly to energy from a given arrival direction through motion compensation. SkyScan is an optimised method of taking the current estimate of the user motion and effectively allowing the receiver to scan the entire sky for incoming energy for each selected satellite PRN. This allows the receiver to not only confirm the availability of LOS energy but to separately measure the pseudorange and frequency associated with any reflected signal from the local environment. The output can be plotted to produce a map of the sky showing each PRN's signal power, as shown in Figure 6.

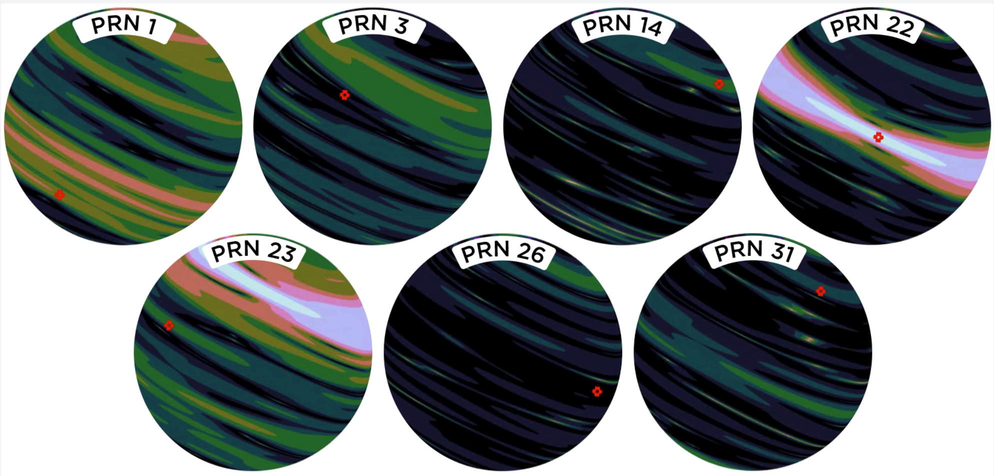


Figure 6 — SkyScan outputs

Example SkyScan outputs for each satellite in use during a moment within an urban canyon. Each disc is an azimuth-elevation plot of the sky, with a red mark showing the position of a given satellite (the PRN number is given in each title). The colours represent the energy detected from all azimuths and elevations. PRN 22 is a strong overhead satellite. PRN 23 exhibits a strong NLOS signal on the north side at moderate elevation, while only a weak signal is detected from the true satellite direction in the West. No line-of-sight energy is detectable at all for PRN 26.

SkyScan applications

SkyScan unlocks new capabilities and strengthens existing ones:

Passive radar

SkyScan data reveals the location of reflective surfaces in the environment and the extra path delay of their reflections — usable as a form of passive radar.

3D map-aiding

3DMA uses building models to predict which signals are blocked. SkyScan enables a far more powerful implementation, feeding measured reflections directly into the position solution [3].

Spoofer localisation

SkyScan data reveals the azimuth and elevation of spoofers, which appear as high-power energy away from the true satellite location.

IN SUMMARY

Summary

Supercorrelation represents a new and significant improvement for GNSS receiver designs. The technology meets three of the most pressing needs in the modern navigation industry through its unique and patented angle-of-arrival sensing capability:

- Increased position and velocity accuracy in dense urban environments through comprehensive multipath mitigation.
- Increased position and velocity accuracy in foliage environments through boosted signal sensitivity.
- Increased resilience to malicious signal attacks.

In addition, the technologies stemming from Supercorrelation — such as SkyScan — unlock unique capabilities and applications that have been hitherto impractical or impossible on consumer-grade GNSS. Supercorrelation is available as a licensable software upgrade to modern GNSS receivers, with flexible deployment opportunities depending upon the customer requirement.

GET IN TOUCH

For further information and to trial Supercorrelation, please get in touch with Focal Point Positioning Ltd:

contact@focalpointpositioning.com **focalpointpositioning.com**

SOURCES

References

[1] Kaplan, E. D. and Hegarty, C. eds., 2017. *Understanding GPS/GNSS: Principles and Applications.* Artech House.

[2] Van Diggelen, F. S. T., 2009. *A-GPS: Assisted GPS, GNSS, and SBAS.* Artech House.

[3] Groves, Zhong, Faragher and Esteves, *Inside GNSS*, 2021. Supercorrelation Plus 3D Mapping-Aided GNSS. insidegnss.com/supercorrelation-plus-3d-mapping-aided-gnss

REFERENCE

Glossary

3D Map-Aiding (3DMA)

A positioning augmentation technique that uses a 3D building model to predict which satellite signals will be blocked or reflected at a given location. Pairs naturally with Supercorrelation's angle-of-arrival sensitivity.

Angle of Arrival (AoA)

The direction from which a radio signal arrives at the receiver, expressed as azimuth and elevation. Supercorrelation provides AoA-sensitive measurements without requiring an antenna array.

C/N0

Carrier-to-noise density ratio (dB-Hz). A measure of received signal quality; higher values indicate stronger, cleaner signals.

Coherent integration

Combining successive samples of a signal while preserving phase, so the signal builds linearly and the noise grows only as the square root. Limited in conventional receivers by oscillator drift and receiver motion.

Controlled Radiation Pattern Antenna (CRPA)

A military-grade antenna array that steers nulls towards interferers and beams towards satellites. Historically the only way to achieve angle-discriminating reception; large, expensive, and ITAR-restricted.

GNSS

Global Navigation Satellite System. Umbrella term covering GPS (USA), Galileo (EU), GLONASS (Russia), BeiDou (China), and regional systems.

Incoherent integration

Combining successive samples after discarding phase (magnitude only). More robust to motion and oscillator drift, but signal and noise grow at similar rates, so sensitivity gains are limited.

Line-of-Sight (LOS)

A direct, unobstructed signal path from satellite to receiver.

Local Oscillator (LO)

The reference clock inside a receiver, used to down-convert and process incoming signals. LO stability fundamentally limits coherent integration time.

Multipath

The arrival of multiple copies of the same signal via different paths — typically the direct LOS plus one or more reflections. Corrupts conventional pseudorange and Doppler estimates.

Non-Line-of-Sight (NLOS)

A signal received only via reflection, with the direct path blocked. Common in urban canyons, under heavy foliage, and indoors.

PRN

Pseudo-Random Noise. The unique code modulated onto each GNSS satellite's signal, allowing a receiver to identify the satellite and measure time-of-flight.

Pseudorange

A satellite-to-receiver distance estimate derived from signal time-of-flight, before correction for receiver clock bias.

REFERENCE

Glossary (continued)

PVT

Position, Velocity, Time. The three core outputs of a GNSS navigation engine.

S-GNSS®

Focal Point Positioning's flagship product for a Supercorrelation-enabled GNSS receiver.

Shadow matching

A positioning technique that uses the pattern of which satellites are visible vs. blocked to constrain receiver position against a 3D map of buildings. Strengthened by Supercorrelation's reliable C/N0 measurements.

SkyScan

A FocalPoint capability that uses a bank of Supercorrelators to map received signal energy across the full sky for each satellite PRN, revealing both LOS energy and any reflected paths.

Spoofing

Transmission of counterfeit GNSS signals designed to mislead a receiver into reporting a false position or time. A growing threat in civil aviation, maritime, automotive and defence applications.

Supercorrelation®

Focal Point Positioning's patented signal-processing technology that enables long coherent integration on moving, low-cost devices, providing angle-of-arrival sensitivity, multipath rejection and a sensitivity boost.

Supercorrelator

A complex phasor sequence used in Supercorrelation processing, tailored to a specific satellite direction and the receiver's motion.

Synthetic antenna

A virtual antenna effect created by Supercorrelation: by motion-compensating the correlation process, a single physical antenna behaves as a steerable directional array, isolating LOS energy from NLOS reflections.

Synthetic oscillator

A virtual oscillator effect created by Supercorrelation: by estimating and compensating for local-oscillator drift within each integration period, a low-cost crystal behaves as if it had the stability of a far more expensive reference.

TCXO / XO / TSX

Temperature-Compensated Crystal Oscillator / Crystal Oscillator / Temperature Sensing Crystal. Lower-cost timing references that Supercorrelation makes viable for high-performance GNSS.

Vector tracking

An advanced GNSS receiver architecture in which the navigation engine feeds back into the signal tracking loops, producing more robust tracking in challenging environments.

FocalPoint

Reliable GNSS, even in the toughest environments.

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