ALTERNATE PNT AND GUIDANCE THROUGH INTEGRATED SENSOR DATALINKS

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ABSTRACT

Ultra Specialist RF (Herley Industries) has developed a novel, low cost programmable datalink-sensor combination which enables high precision tracking, telemetry communications, and control for airborne platforms using line of sight RF. This technology provides a highly reliable and resilient alternative to GPS-based navigation and tracking using relative position through an application of communications waveform and sensor technology with transponder architectures. Ultra views this technology as applicable to any platform requiring Position, Navigation, and Timing (PNT) where GPS may not be available or reliable. This paper will identify the commercial and government applications pushing current technological boundaries. Ultra specializes in providing application-engineered bespoke solutions in the defense, security, critical detection, maritime, C4ISTAR-EW, military and commercial aerospace, nuclear and industrial sensors markets.

INTRODUCTION

Modern aviation and warfare have one very common requirement, that being to know where you are and where everyone else is in relation. With that common requisite, comes the vulnerability to any impediment, intentional or not, to the determination, calculation, or communication of the same. Traditional PNT is provided by some Global Positioning System (GPS) or other method of radio frequency (RF) channel measurements. As most all systems rely on commercial devices and spectrum and well documented protocols, they are subject to interference, jamming, and spoofing using low cost, widely available hardware.

In order to mitigate these sensitivities, Ultra has taken an approach to Alternate PNT of combining well known techniques for reliable positional measurement and tracking and applying multiple pillars of resiliency; those being frequency of operation, processing gain and low probability of intercept through direct sequence spread spectrum, and lastly a relatively low data rate resulting in a high energy per bit. When coupled with conventional tracking and command and control techniques, a highly effective, low size, weight and power (SWAP) system may be employed for highly accurate and reliable PNT.

Due to the military application of this system and in accordance with the International Traffic in Arms Regulation (ITAR), specific details and technical data pertaining to the design and utility of Ultra's system are intentionally excluded from this paper and generalities used as appropriate.

SENSOR AND DATALINK

Ultra has coupled datalink and transponder technology for the purposes of both tracking and communicating with a host platform that had neither capability prior or requires a supplemental faculty for redundancy. Using a traditional transponder approach, an interrogation signal is transmitted from some known location, and the host platform's transponder receives and responds in a deterministic fashion. The sensor receiving the transponder response is a 2-dimensional, multi-channel interferometer which calculates the relative azimuth, elevation, and range.
The relative phase between receive channels is determined by (1).

$$\phi = 2\pi \frac{f}{c} d \sin(\theta) \tag{1}$$

Where:

ϕ is the relative phase difference between channels, c is the speed of light ($3\text{x}10^8 m/s$), f is the signal frequency, d is the distance between channels, and θ is the angle of arrival.

This equation is inverted to calculate θ in both the x and y dimensions based upon the measured phase difference of an incident coherent wavefront. From a waveform and sensor design perspective, the number of receive channels, their spacing, and the signal bandwidth are directly proportional to the signal to noise ratio, phase resolution, and ultimately the precision of the sensor. As such, Ultra's tracking and communications system has been proven to provide less than 250 μrad of resolution per independent measurement using a sensor array aperture which is approximately 400 cm^2.

Range is measured based upon the turnaround time from the coded interrogation transmission pulse to receipt of response. The delay path is well understood through the transponder, and therefore the propagation time plus that delay path gives a reasonable instantaneous calculation of range within between 50-100 cm error depending upon the velocity relative to the sensor. If the platform is moving at a high velocity, performing these calculations uncorrelated and independent of each other many times per second (>10) ensures that any temporary fades or interferences are resolved within a time window which allows for appropriate response and action.

As the signal being transmitted is a coded digital packet, data can be relayed from sensor to transponder and ultimately to the host platform and back. For instance, if the host platform is not under positive control, but rather autonomous, then this system maintains enough throughput to provide positional correction or attitude update information based on the tracking calculations. And likewise, the host platform can transmit relatively low rate telemetry. While not intended as a primary command and control datalink in its current instantiation, there is no significant functional limitation to the utility of the link preventing the data rates or coding from being modified; assuming the associated trade-off of range; all else being equal.

The technique described above and shown in Figure 1 has proven highly effective at providing PNT solutions for contested or GPS-denied or degraded operations as all measurements are relative to the sensor position. In other words, rather than determining the absolute location coordinates based upon some ubiquitous datum, the position is provided relative to an origin, which is often more useful information and easier to calculate. If that known point has valid and trusted coordinates, then all calculations relative to it are equally valid and trusted.

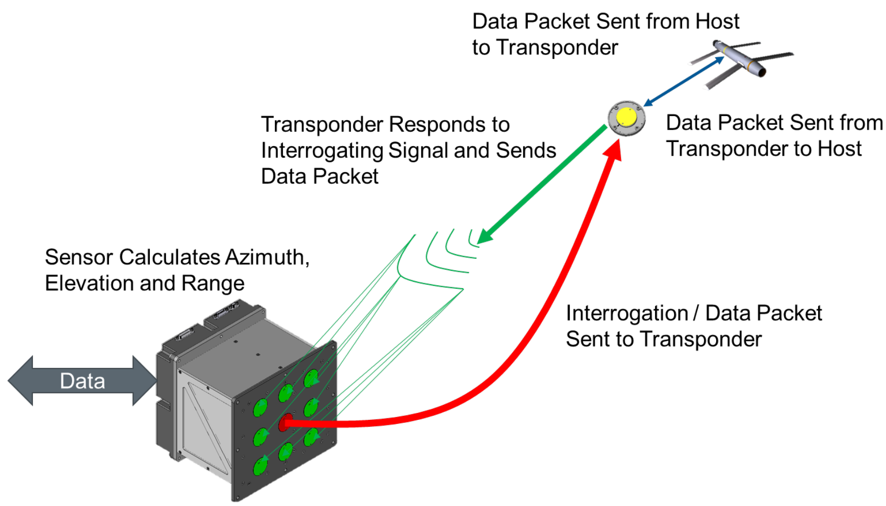

Figure 1 Ultra Alternate PNT Solution for Tracking and Communications

THREE PILLARS OF RESILIENCE

The combined techniques of transponder, interferometer, and datalink independent of each other is not innovative, however combining them for the purposes of Alternate PNT and guidance is. However, whenever RF is involved in the operation of any system, the limitations of physics and the opportunity of bad actors to interfere or otherwise degrade the channel will always be present. The approach taken by Ultra in the design of their Alternate PNT solution addresses those limitations with resilience at its core. Beyond the use of relative position calculations, there are three important factors of the RF design of the system which provide value beyond that of traditional PNT.

Frequency of Operation

Conventional GPS operates in the L-Band (1575.42 MHz L1, 1227.6 MHz L2, and 1176.45 L5) which certainly has advantages and disadvantages. The advantages, in short, are that signals below 2 GHz do not require highly complex RF hardware such as antennas and amplifiers and are not highly impacted by weather and ionospheric propagation. As GPS signals are provided by Medium Earth Orbit (MEO) satellites, reliable propagation to the ground through the atmospheric layers and any weather conditions is often on the edge of sensitivity. Ground units (receivers) require at least four (4) satellites with radio line of sight (RLOS) to provide a proper position measurement. Therefore, any significant interference to that signal, in-band can degrade the ability for any receiver to resolve the, already relatively low signal from the noise or interference.

By operating in the Ku-band (12-18 GHz) and being a terrestrial (not satellite-based) system, the Ultra Alternate PNT tracking and communications system avoids many of the challenges identified prior. This does not imply that it performs the same function, however it is purpose-built to allow for positive tracking and communications with a platform using relative measurements from the sensor location.

The Ku-band is far less cluttered than L-band in that there is very little commercial utilization at this time. The primary exception being that the lower Ku-band is used for satellite services, such as television broadcast. With the availability of spectrum outside of that used for such purposes, the amount of power able to be transmitted over a very wide bandwidth lends itself to highly spread signals. Additionally, Ku transmissions are traditionally highly directional and polarized. This implies that the receiver and transmitters require some angular alignment, such as having to have a satellite dish pointing to the correct point in the sky. This serves as a limitation due to the losses associated with off-axis alignment between transmitter and receiver so in instances where the sensor or host platform may be changing direction or orientation, there is risk of loss if not properly accounted for in design. This directionality subsequently makes it very difficult for a non-coherent sensor and/or interference source to detect and then impact the communications substantively, especially when one or both ends of the link may be moving as that would require non-cooperative, active tracking as well.

Lastly, the cost and complexity to design and manufacture Ku-band hardware is significantly higher than L-band due to the precision and low rate of commercial utility. With the higher carrier frequencies, the associated wavelengths get proportionally smaller, and by extension so does the difficulty in producing and maintaining the sensitive RF microelectronics. i.e. L-band wavelengths are 30-15 cm where Ku are 2.5 to 1.67 cm. As a result, the efficiency is much lower as design tolerances become equally proportional in their constraints and subsequently cost prohibitive, particularly as signal bandwidth is also increased.

Spread Spectrum

The tracking and communications system developed by Ultra employs basic direct sequence spread spectrum (DSSS) methods for spreading a relatively low data rate with a pseudorandom code and realizes approximately 33 dB of process gain per equation (2).

$$G_p = 10\ \log_{10}(F_s/F_d) \tag{2}$$

Where:

- G_p is the process gain in dB.
- F_s is the spreading frequency or rate in Hz.
- F_d is the source data rate in Hz.

Now there are certainly many more factors to processing gain and successful communications, such as coding and error corrections, however for the purposes of comparison and simplicity, this paper will focus on first principals. Being a terrestrial system, either air to air, ground to air, or ground to ground, the limitation for range is driven by the line of sight and transmit power. Assuming a nominal ground to air configuration where the sensor is at or slightly above ground height and the host platform between 10,000-15,000 m above ground level, the nominal horizon limit is approximately 450 km. For comparison, GPS satellites are in orbit approximately 20,200 km from Earth with a transmit power of 44.8 W (+46.5 dBm) and yields approximately 181 dB of free space path loss (not accounting for atmospheric absorption and weather). This means that the signals reaching the ground are already at -135 dB at best. Thankfully, GPS signals have up to 43 dB of processing gain through spreading a very low rate (50 bps) signal over 1-10 MHz, depending upon which signal and robust coding. It usually also includes positive gain antennas and highly efficient RF front end receivers to account for the dispersion and loss. As a system, GPS certainly performs its role admirably and efficiently however, the relatively narrow spreading (max. 10.23 MHz) and high dispersion over space, subjects it to being overcome by interference by a manageable radiated power over a relatively narrow bandwidth.

With a transmission power of between 0.5-5.0 W (+27-37 dBm) per pulse and assuming equivalent gains and sensitivity, the Ultra gain proven by spreading the signal far more than 10 MHz provides a process gain advantage of approximately 12 dB (or 1600%) over traditional GPS. The unique pseudorandom code assigned to each platform also allows for a high number of transponders to be simultaneous tracked and communicated.

Energy Per Bit (or Symbol)

Lastly, is the fact that the data being transmitted between the sensor and transponder is at a relatively low rate compared to that of the spreading signal. The modulation being utilized is Minimum Shift Keying (MSK) which maximizes the energy per bit or symbol over a wide bandwidth meaning that there needs to be enough interference energy at the receiver for long enough duration over the entire bandwidth to overcome the decoding of any given bit. For instance, if the data rate is 25 kbps, in an MSK system, each symbol would be 40 μs long. This would necessitate an interferer to put enough energy on the receiver to overcome the processing and RF gain stages described earlier. Now consider that that 25 kbps signal is spread over bandwidths thousands of times wider than the source. There is now a significant challenge to degrade the link for any extended time. As stated, each measurement is completely independent, and there hasn't been any consideration for error correction which would make increase the complexity of the interferer exponentially. With the consideration of the prior two "pillars", it can be determined that the effort required to disrupt or significantly degrade the tracking and datalink components of the Ultra Alternate PNT without prior knowledge of the location, coding, direction, orientation, and polarization of either end of the system would be quite daunting.

CONCLUSIONS

As described in this paper, the utility of a system which allows for highly accurate and reliable tracking of a platform without the need for any reliance on GPS, over a potentially very long range, while also being able to communicate, is only bounded by the willingness and creativity of platforms with which to integrate. The value to the unmanned vehicle domain has certainly been the most obvious. When co-located with a ground control station for an unmanned air vehicle (UAV), this system provides a position track which can supplement the existing PNT solution either as a validation tool, or fail over while also supporting secondary command and control and telemetry communications. As a validation tool, the host or ground station can compare the GPS and the relative measurements to ensure that the GPS data is reliable. Similarly, a sensor can be employed on an airborne platform and maintain positive tracking and communications with any number of hosts below and point of origin essentially acting as a handover node for more effective command and control far beyond traditional tracking line of sight. These capabilities, plus extremely high reliability and survivability in contested or congested RF environments are provided by the innovative Ultra Alternate PNT solution.