AN INTEGRATED APPROACH TO ROBUST FLIGHT TERMINATION FOR SMALL MISSILE TEST AND TRAINING RANGE USE

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ABSTRACT

This paper will investigate the areas that must be addressed to implement a truly integrated Range instrumentation system on a GPS-based Range, using a patented L-Band commanding scheme. Hardware issues will be highlighted as well the issues to be addressed in changing from an audio tone-frequency modulated command system to a digital system incorporating encryption and spread spectrum. Some thoughts addressing costs and schedule to incorporate this approach into the architecture of Joint Advanced Missile Instrumentation (JAMI) program are also presented, as well as a discussion of the benefits to be accrued over the existing system.

KEY WORDS

GPS, JAMI, Flight Termination, Range Instrumentation, Command Destruct, GPS Telecommand Link, Range Safety

INTRODUCTION

The Juarez Incident of 29 May 1947, when the thrust termination command was insufficient to prevent an errant V2 from impacting and exploding in Mexico, led to the development of the flight termination system used by range safety offices at every test and training range in the United States. Since that time, all ranges have used a system based on high powered UHF transmitters using frequency modulated audio tones to convey flight termination commands to unmanned airborne vehicles. Last year, Global Hawk air vehicle #2, was lost on 29 Mar because it received a flight termination command sent by another range not involved in its operation and test. This loss has stimulated a hard look at the vulnerabilities inherent in this example of early 1950s cutting edge technology.
FLIGHT TERMINATION TODAY

The flight termination system used at today’s test and training ranges is described in a series of Range Commanders Council (RCC) documents and basically consists of a UHF transmitter of relatively high power (to insure receiver capture) operating in the frequency range of 420 MHz to 450 MHz. This FM transmitter sends out a series of audio tones to effect a limited range of commands. These commands are ARM, DESTRUCT, OPTIONAL, TEST and RESET and there are two alternate sets of audio tones for each command. These tones, usually called “IRIG” tones, because of the Inter Range Instrumentation Group (now the RCC) which adopted them in the early ‘50s. Receivers not only receive the UHF-FM signal but also decode these tone sets and output the appropriate command signal to the vehicle. The transmitters and receivers were originally pretuned to both the transmit frequency and the audio tone set frequencies “on the bench” and thus could not be easily or quickly be changed. Today this is somewhat different but nonetheless to change frequencies and tone sets is a carefully controlled procedure and it impacts mission planning and scheduling. Note that only by changing transmit frequency (of which there are typically only two or three options) or audio tone sets (of which there are only two) can a range differentiate among test vehicles. It was this lack of flexibility that doomed Global Hawk.

The advent of manned space travel caused a revisit of this system in the ‘60s. Since the IRIG tone sets were common knowledge and, in fact, had been since they were first transmitted open loop, much less published in IRIG documents, it was thought that there was insufficient protection against an unauthorized flight termination command being received by a manned space launch vehicle. Accordingly the Apollo/Saturn program used audio tones in pairs to form a string of “characters” in what was termed the “high alphabet” Secure Transmission System. These “character” strings were changed for each flight and could not be checked “open loop” before flight, for fear of compromise. This system is still in use today for Space Shuttle and certain DOD Titan and Atlas launches. The National Security Agency (NSA) was (and is) responsible for the generation and maintenance of these strings and they are considered cryptologic codes. Of course, being considered as a cryptologic system means that both the hardware and the software (the codes) must be guarded as cryptologic resources, an expensive and cumbersome process. In its defense, the Secure Transmission System does allow for differentiation among test vehicles, as only a receiver with a matching code will respond to transmitted commands.

CHANGES IN TEST AND TRAINING RANGES

The advent of the Global Positioning System (GPS) has triggered the greatest change in test and training range instrumentation since the post-WWII era. GPS is the first and only successful challenger to radar for Time Space Positioning Information (TSPI), one of the three necessary elements of a range, along with telemetry and control. In fact, a program, the Joint Advanced Missile Instrumentation (JAMI) program was initiated in 1997 to address enhancements in missile instrumentation through the introduction of GPS as an improved and worldwide tracking source. GPS will allow worldwide test and training, eliminating the need for range-specific TSPI and vector scoring instrumentation.

This multiyear Central Test and Evaluation Investment Program (CTEIP) was inaugurated because of the significant cost savings inherent in eliminating radars and their operating and maintenance costs and
substituting the GPS satellite constellation for which no fiscal contribution is required from the test and training ranges. The Air Force Eastern and Western Ranges have been directed to phase out radar as a range safety tracking source over the next few years and replace it with GPS. JAMI has proved pretty conclusively that GPS can be used as a TSPI and a scoring source. The question is, is that all that can be derived from GPS technology?

L-BAND FLIGHT TERMINATION

I believe that the answer is no. As noted above, not only has radar come under review as the TSPI source on test and training ranges but UHF flight termination is also under review. GPS technology can also be applied to flight termination as well as to TSPI. GPS uses satellites that broadcast their ephemeris and a time tag for navigational solutions to be worked out by triangulation. It is this transmission capability using low power, spread spectrum techniques that may be used for command. And, because of the nature of spread spectrum, these command messages can be in the GPS operating band and coexist on a non-interference basis with the GPS satellite transmissions.

Consider a “phantom” 25th GPS satellite in addition to the 24 satellite GPS constellation used for navigation. A receiver on a test vehicle could be easily modified to not only receive whichever of the 24-satellite constellation are in view for a TSPI solution but also to receive transmissions from this “phantom” satellite. These transmissions would be routed to a different part of the airborne receiver and result in a command output rather than a TSPI solution. The required modifications are minimal, in size, weight, complexity and cost.

FTS-GPS INTEGRATION

It must also be pointed out that this “phantom” satellite need not be an orbital vehicle but can be a ground-based pseudosatellite. In the case of small missile test and training ranges, the distances are such that a global command capability isn’t required. It IS possible to create such a range by simple additions to the GPS satellite constellations to receive uploaded commands from the ground and relay them to a test vehicle, either directly or through satellite relay in real time. Preliminary studies indicate the distances traveled by such a signal to not generate significant latency issues. A ground-based pseudosatellite also allows for the capability of incorporating a true GPS pseudosatellite into this L-Band command transmitter. In so doing, the quality of the TSPI solution achieved by the on-board receiver will be improved by the improved Position Dilution Of Precision (PDOP) made possible by having one of the satellites used for the solution located beneath the test vehicle. Additionally, this “pseudosatellite” command transmitter can be the base station for any DGPS corrections. As a matter of fact, the command link could also serve as the DGPS uplink, thus conserving bandwidth to the maximum.

Earlier it was stated that the on board TSPI receiver could also be the command destruct or flight termination receiver. This is inherent in this approach and is a direct result of using a “GPS-like” signal. Not so obvious is the further integration of the airborne instrumentation. Since the TSPI receiver is physically the same as the FTS receiver, there is need for only one power source, one mounting structure and one antenna set. With a small airborne test vehicle, the ability to share antennas can be of great
importance, given the limited “real estate” available for the mounting of antenna systems. If one posits a
test vehicle using GPS for TSPI, this approach for flight termination and using an S-band telemetry
down link, the vehicle would have only two sets of antennas, an L-band for the reception of GPS TSPI
and L-band commands and an S-band set for transmitting telemetry.

RESISTANCE TO COUNTERMEASURES AND INTERFERENCE

When command destruct is mentioned jamming and interference problems are mentioned as well. By
the very nature of this approach, L-band command destruct is at least as resistant to jamming and
interference as is GPS itself. GPS is known as a reasonably robust system due to the fact that it is a
spread spectrum system. Having the signal energy spread over such a wide bandwidth makes the signal
very difficult to jam. Obviously, it can be jammed, of course but there has been a lot of work done on
this at Wright Patterson AFB OH and at Ohio University, under AF sponsorship.

Additionally there has been much work done for the FAA on the near-far problem or the possibility of a
nearby pseudolite transmission blanking out transmissions from on-orbit satellites. This is a crucial issue
in using GPS for Category III aircraft landings. Power management and slight center frequency offsets
and changes in the message format are main thrusts of this research.

There is no disagreement with the requirement for a command signal to get through regardless. This is
the signal strength portion of the reliability issue, the one that drives UHF power to such high levels.
However, it is necessary for such a signal to get through after the position of the test vehicle becomes
unknown, or at least ambiguous. Most Range Safety rules state that in these circumstances, flight will be
terminated. Therefore, any flight termination command signal must be “stronger” than either the TSPI
input signal, which gives the test vehicle its position and velocity vector, or the telemetry downlink,
which informs the range safety officer of the vehicle’s position and velocity vector. Since the
information carried by the command link (a command) is very much less than the information extracted
from a GPS satellite transmission (a 50 bps ephemeris almanac, timing and phasing data) a command
would be decoded under signal strength conditions too low to allow a TSPI solution to be calculated.
Since there is at present some discussion about possible civilian GPS frequencies being proposed at
+3dB above L1, the possibility exists to transmit a command signal at +3dB above the GPS C/A signal
level, further insuring that the command gets through. GPS itself presently operates at two different
signal levels, the L2 P(Y) signal is –3dB down from the L1 C/A signal.

AUTHENTICATION

Notice that ALL other GPS receivers would ignore L-band command transmissions, as they now ignore
all other signals present in the area of L-Band used by GPS. If there were other test vehicles in the air at
the same time and visible to the L-band command transmitter, a difference in either the spreading code
or the command message transmitted would guarantee that ONLY the receiver and vehicle intended for
the command would receive and act upon it. As is the case with unmodified GPS navigation or TSPI
receivers, ALL combination TSPI/Flight Termination receivers EXCEPT the one with the matching
spreading code OR command (or both, for that matter) would ignore the transmitted command message.
Contrary to conventional wisdom, it is authentication that drives the present STS system to encrypted codes. The issue is really NOT that the test vehicle’s command receiver can only decrypt and act on an encrypted command that was transmitted by the “proper” transmitter, but that the test vehicle’s command receiver is able to identify not only the command but which transmitters are sending commands and respond to only those commands sent by the “proper” transmitter. Authentication is well understood today. The US Congress recently approved the use of “digital signatures” as binding on legal documents.

With an L-band commanding system, authentication can be achieved by using a reverse public key-private key system, whereby the command transmitter uses the private key and the on board receiver uses the public key. With such an arrangement, the receiver will be able to authenticate any command received as having been sent by the range command transmitter using the private key. Only the transmitter need be protected as a cryptologic resource. The receiver, with the public key need not be protected in this manner, unlike today’s STS receiver. Additionally, open loop testing of such a system is also possible without compromising the authentication. This is in stark contrast to the existing STS system where any broadcast of commands using “flight codes” is a breach of security and a reason to recode transmitter and receiver with new codes. Also, of course, after a mission is flown with a set of “flight codes” these codes are permanently retired – but the hardware still needs to be protected as cryptologic resources.

**RELIABILITY**

Reliability of such hardware is not really an issue. EWR 127-1 has stated that a GPS unit used for TSPI must be built to a reliability of .9999, equal to the reliability demanded of the flight termination system and higher than the reliability required of a C-Band beacon. These reliability requirements are being met for units designed for use in space launch vehicles. Test and training range requirements are usually not as stringent. This component reliability only addresses part of the problem, of course. The discussion above pertaining to resistance to countermeasures and jamming also relates directly to the reliability of the system to respond with a termination action to a validly sent termination command.

**SELECTABILITY**

One thing that ANY new flight termination system should be able to do is to differentiate among test vehicles such that a command could be sent to a specific test vehicle and be ignored by all other test vehicles. This capability exists in the present FTS, but means either changing frequencies, among those assigned to each range, changing to the alternate IRIG command set or going to the STS high alphabet system and accepting the requirements of protecting cryptologic resources. As pointed out above this is not a particularly flexible system.

L-band flight termination is by its nature a very flexible system. Selectivity can be achieved by “coding” each airborne receiver to respond to a different spreading code “address” or to a different “message.” In GPS terms, this would be analogous to configuring each receiver to recognize a different “satellite” signal or to respond to a different “ephemeris.” It would be simple to adopt a spreading code unique to each test and training range and use a library of command messages to differentiate among test vehicles.
Such an approach would positively prohibit an incident such as the one that terminated *Global Hawk*. A flight termination receiver could be reconfigured on the pad, in real time, as could the command transmitter, and tested open loop to insure compatibility immediately prior to commencing flight or launch. All of this is made possible because an L-band system can make use of all that has been learned over the past 40-plus years about signal propagation and reception and has been applied to GPS.

One other advantage is available to the operational test and evaluation community. For those vehicles that use GPS as a part of its guidance system, a dormant L-band flight termination capability can be built into every production vehicle built. Not, obviously, complete with destruct charges but the RF link would be inherent in every guidance receiver, just as the TSPI source is, by definition, included. All that would be necessary for configuration for operational test of a missile from the stockpile would be to remove the warhead, add a telemetry system, add whatever flight termination mechanism is needed, load the appropriate FTS spreading code into the guidance receiver’s memory and connect whatever circuit needs to be connected from the guidance receiver to the flight termination mechanism. This means a maximum in operational realism and minimum deviation from operational configuration and is not possible with any other FTS system.

**SIZE AND WEIGHT**

This approach to command offers a large reduction in size, weight and infrastructure necessary to instrument a test and training range. The moving of command destruct into L-band will drastically reduce the size and weight devoted to this function, especially on the airborne side, where even with a miniature UHF receiver, there still is the size and weight associated with the antenna system. It has proven rather difficult to get an antenna to function at both L-band and UHF – as the Peacekeeper program found out some years ago. Having the airborne command receiver function embedded into a TSPI GPS receiver/translator, and using the TSPI system’s antenna and power supply would seem to represent the absolute minimum size and weight for a command destruct system. Even with a radar-instrumented range, the size of an L-band FTS would not be any larger or heavier than a UHF FTS and probably be lighter and, given the large GPS industrial base, cheaper.

Instrumenting the test and training range would require the acquisition and installation of a whole new command transmission infrastructure. This is considerably less daunting than it appears to be. The existing high-power, UHF system on today’s ranges, in many cases equipped with steerable antenna mounts, is replaced by a relatively low power L-band transmitter system using an omnidirectional antenna. Not only is there less equipment with less complexity, if only in the antenna system, the L-band equipment draws on the present GPS equipment production base. Pseudosatellites, which the L-band command transmitter greatly resembles, can be ordered from many GPS suppliers and are in the four to five figure price range. Today’s UHF command transmitters are either unique or limited production devices. L-band flight termination replaces them with slightly modified production hardware.

One other issue to be addressed in converting a test and training range to a new system based upon a different frequency range than used previously is the amount of study and experimentation effort in assuring compatibility between the test vehicle and the range instrumentation suite. It is here that a GPS-like L-band flight termination system has a distinct advantage over any other candidate system being integrated into a GPS-based range. Any and all efforts performed to assure compatibility between test
vehicle and the range instrumentation suite for GPS-based TSPI are directly applicable to command system compatibility. There would be little or no extra compatibility effort necessary to integrate L-band flight termination into such a range – and the JAMI program is charged with developing GPS-based range instrumentation.

**FREQUENCY BAND**

In moving command destruct to L-band means adding a new and different usage to this portion of the radio frequency spectrum and approval from the International Telecommunications Union (ITU) in Geneva, must be sought for this purpose. Since this band is presently approved for navigation as well as TSPI purposes (for GPS), it should pose no problem to get this band approved for command destruct. This usage is for the same purpose as TSPI, that is, for test and training range applications, and the signals actually transmitted would not interfere with any approved signals, as they would resemble approved GPS signals in being spread spectrum signals in the same transmitted power range as GPS signals.

Actually, it appears that the UHF frequencies presently approved for this use could be in jeopardy. Both the Eastern and the Western Ranges are moving off of their “protected” frequencies after using them for over 30 years. These frequencies were basically sold out from under them. There is absolutely no guarantee that the present range of 420 to 450 MHz (down from 406 to 450MHz) will be available in the future. There is MUCH more likelihood that a set of spread-spectrum codes and/or a center frequency within the GPS range will be protected and available far into the future.

**CONCLUSION**

There is a definition of the word, *elegant*, which is used in scientific and engineering circles. That definition is, “Characterized by scientific precision, neatness and simplicity.” Integrating L-band flight termination into a GPS-based test and training range is a truly elegant solution to the problem of providing the capability to track and control a test vehicle with a minimum of additional range-required onboard instrumentation. There can be no closer integration than combining TSPI and flight termination in the same “box,” sharing circuitry, power and antennas. The transmitter portion of such a system is no less elegant, possibly serving as a true GPS pseudosatellite for improved tracking accuracy as well as being significantly less complex and costly (especially in reference to the transmitter antenna system). For operational test, there can be no more elegant solution to the instrumentation problem than to use the operational vehicles own guidance GPS receiver as not only the TSPI source but a the flight termination receiver, as well.

**REFERENCES**


