DUAL FUNCTION TRANSPONDER
A DATA LINK FOR THE NEXT GENERATION

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ABSTRACT

Future U.S. Navy at-sea and littoral battle group training range instrumentation requires a new, secure, high data rate link This link must be capable of providing the ranges with the capacity to increase the number of players, increase the amount of threat simulation, and allow an improved Global Positioning System (GPS) based position tracking system to be implemented

This paper describes a Dual Function Transponder (DFT) capable of operating on any R-CUBED (Relay, Reporter, Responder) based range as well as any TACTS/ACMI range without modification of either range type. In addition, the DFT provides a new increased data rate capability for use by planned future ranges, enabling a dramatic increase in the number of participants as well as significantly increasing the quantity of data that can be communicated by each player. Miniaturization and programmability are the keys to this development and many of the methods used are described.

KEY WORDS

Training, Range, Instrumentation, Secure Communications, GPS Positioning

INTRODUCTION

Microcom Corporation was tasked by Naval Air Systems Command (NAVAIR - PMA 248) to develop a single datalink transponder that would enhance the Navy's range training capabilities to support training missions. The Navy will conduct their new training strategies on realistic fleet training exercises with emphasis on Littoral (near land) Warfare. This type of warfare will extend the fleet's battle space across shorelines and expand the operational control between land and sea. In this scenario the Navy will fight alongside the Army and Air Force in a joint forces effort.

Two range instrumentation systems exist in the U.S. Navy for tracking participants and collecting data during training exercises. These systems use multiple range measurements between participants to calculate accurate position location. The key element in each range instrumentation system is the data link transponder. Because of the unique range requirements, the Navy has two different instrumentation pods. These technical differences include the following:

<u>TACTS Transponder (Land-based):</u>

(1) Operates at 1.8 GHz and 10 Watts minimum.

(2) Carrier Phase Modulated (PM) by the received ranging tones and Frequency Shift Keying (FSK) data modulation.

(3) Synchronous Architecture - Full duplex mode

<u>R-CUBED Transponder (Sea-based):</u>

(1) Operates at 141 MHZ and 178 Watts minimum.

(2) 4 MHZ Spread Spectrum System - Pulse Position Modulation (PPM)

(3) Asynchronous Interrogate/Respond Architecture

Open ocean weapons and training range instrumentation systems are not well suited to coastal/inland areas.

The new training requirement will have aircraft travel with range instrumentation that allows seamless training exercises between land (Tactical Aircrew Combat Training System - TACTS) and sea (Large Area Tracking Ranges - LATR) combat ranges without pod changes or debriefing. To accomplish this goal, the Navy requires a Dual Function Transponder (DFT) compatible with the existing AN/URY-3 R-CUBED and TACTS/ACMI transponder designs. In addition, the transponders data rates will be increased to support future growth of the training system (increased participants) and increased amounts of sensor and weapons data that must be processed. All debriefings for aircrews would be at both sea-based and land-based sites.

The existing multilateration ranging method of tracking is expected to be replaced by the GPS tracking solution. Eliminating multilateration ranging measurements between players will save air transmission time, decrease transponder processing time, and increase the number of participants that can be tracked by the Master Station

The general operational requirement for datalink encryption is traceable to a Department of Defense (DOD) directive mandating encryption of all "sensitive" range telemetry. All future datalinks developed are required to be encrypted.

This paper will present the electrical and physical capabilities of the DFT. Significant technical differences in the output RF frequency, modulation formats, and output power preclude a shared RF module for the DFT. Power supply and digital functions can be shared between the R-CUBED and TACTS RF modules. This paper describes how the DFT will maintain backward compatibility (i.e. multilateration and data rates) with existing ranges, provide an increased data rate capability for both the AN/URY-3 and TACTS/ACMI transponders, and meet the mechanical requirements for the 5 inch airborne pod and internal package for the F/A-18

THEORY OF OPERATION

R-CUBED OPERATION

Existing ranges compatibility

At present the primary at-sea ranges such as LATR, MSR (Mobile Sea Range), and EATS (Extended Area Tracking System) rely on the R-CUBED transponder to provide the data exchange and position location function. The R-CUBED transponder provides excellent range and has demonstrated high reliability communications for many years. The major disadvantage of the R-CUBED is the data rate, which is insufficient for future requirements. The R-CUBED transponder operates at 141 MHz, which accounts for its extreme range, and uses pulse position modulation. It provides a ranging function that enables any unit to measure its distance from any other unit. The distance information along with altimeter data is then used in a multilateration system to provide the position tracking function. The system utilizes an asynchronous, poll and response, time ordered structure.

Increased data rate

The newest system using R-CUBED transponders is the Large Area Tracking Range system or LATR. LATR no longer relies on multilateration for position, but instead uses Time Space Position Information (TSPI) based on GPS, augmented by an Inertial Guidance system. In addition, the number of participants supported by the LATR system has been increased. This trend is expected to continue and future range systems will be hard pressed to support the increase in data capacity required by these changes. Other requirements envisioned for new training ranges include what is known as Distributed Interactive Simulation or DIS that will allow computer generated threat simulations to be combined with actual participant data to create an interactive virtual environment for training and evaluation purposes. All of these new developments require more data capacity than the current transponders can support.

Increased data rate is one solution provided by the Dual Function Transponder. Increasing the data rate by a factor of four allows many more participants to be updated in the same amount of time.

Extended message lengths

In addition to increasing the date rate, the DFT allows message lengths of over 2000 bits. This is a fourfold increase over the original R-CUBED limitation of 512 bits. Increasing the message length greatly enhances the ability of the DFT to handle computer generated threat data.

Link margin

The DFT operating in the R-CUBED mode has an overabundance of signal to noise advantage because of its high power output and low carrier frequency. The calculated range of this Transponder is over 1000 nautical miles. This calculation assumes a frequency of 141 MHZ, a power output of 53 dBm (200W) and a receiver sensitivity of -98 dBm. The calculation also assumes a 10 dB link margin. The R-CUBED message error rate is specified at 1% with an input of -50 dBm and 10% with an input of -98 dBm. Because of the nature of the spread spectrum modulation used in this Transponder the actual degradation of the error rate occurs very rapidly and appears more like a threshold than a gradual degradation curve. The actual measured 10% error threshold is most often less than -100 dBm. The 1% error rate is maintained down to a level of approximately -95 dBm. The R-CUBED receiver contains circuitry that is designed to maintain a constant false alarm rate in the presence of varying noise levels. A false alarm is defined as a video pulse produced by the CHIRP correlation and caused by noise. The Constant False Alarm Rate (CFAR) function is adjusted at the factory to produce between 100 and 500 false alarms per second. This adjustment is a trade-off between maximum receiver sensitivity and message errors introduced by false alarms. If less receiver sensitivity is required, the CFAR can be reduced so that virtually error free message transmission is guaranteed as long as a link margin of at least 10 dB is maintained

Spread spectrum advantages

One of the great advantages of the R-CUBED mode is the use of a spread spectrum transmission technique. This technique greatly increases the jamming resistance of the signal as well as reducing the possibility of interfering with any other transmission in the same band.

Relay capabilities

The R-CUBED mode supports up to three levels of relay capability. This allows the system to communicate over the horizon or around any line of sight obstruction

TACTS OPERATION

Existing ranges capability

The DFT is completely interoperable with all existing TACTS/ACMI ranges when operated in the 198 Kbps data mode. The TACTS/ACMI mode of operation of the DFT is a TDMA link that assigns each participant a slot (or slots) in which that participant can receive an Uplink message and transmit a Downlink message. An Auto Respond mode allows the participant to transmit a Downlink even though no Uplink was received. Separate Uplink and Downlink RF frequencies are used so that full-duplex transmissions can occur. Two simultaneously active nets are supported, Net A and Net B, with each net having a separate pair of frequencies assigned

The Uplink message contains the Pod ID of the addressed participant followed by Control and Information data. The unit responds to the Uplink transmission with a Downlink message containing aircraft and weapons status information. In addition, the system allows for full-duplex 'loopback' of ranging tones from the Uplink to the Downlink. The phase difference between the Uplink transmitted ranging signals and the Downlink received ranging signals is used in a multilateration positioning process

Increased data rate

The future requirements of the TACTS/ACMI ranges are identical to those of the R-CUBED based ranges. These requirements are addressed in the DFT by increasing the data rate from 198 Kbps to 1.2 Mbps. The increased data capacity will allow many more participants in addition to providing the bandwidth to support GPS positioning and increased threat simulation.

Interoperability between high and low rate equipped aircraft

The TDMA structure provided by the DFT will allow both high rate (1.2 Mbps) and low rate (198 Kbps) equipped aircraft to participate in the same exercise. This is accomplished by dividing the 10 ms slots utilized by the low rate aircraft into three 3.3

ms slots which are used by the high rate aircraft. Because of the increased data rate, each high rate slot can contain 1000 more bits of information than provided in the low data rate slots.

AMODSM compatible

Another requirement to be imposed on all existing, as well as future ranges, is a secure data link. In order to comply with this requirement, an AMODSM compatible TAXI interface is provided for all data I/O transfers.

PHYSICAL DESCRIPTION

The mechanical design of the DFT is comprised of two packages. The first package is the AN/URY-3 R-CUBED footprint (9" L x 3.5" W x 3.1" H) with the electrical enhancements incorporated to support the high data rate R-CUBED requirements incorporated. This first package will house the common logic board and power supply for all of the TACTS requirements. The second package will be the TACTS section which only includes the receiver and transmitter functions. All digital interfacing will be provided by I/O connectors on each package. The size of the second box is equivalent to the AN/URY-3. This mechanical configuration will meet the mechanical requirements of the Pod and IPIP configurations.

ELECTRICAL DESCRIPTION

Logic

A transponder capable of adapting to a large base of existing ranges must, by nature, be very flexible. Add to that, the ability to be used by ranges not yet fully defined, and you can understand why "programmable" is a key parameter of the DFT. This feature was accomplished by designing a microprocessor-based logic board with an easily accessible I/O port that can be used to update the firmware and implementing almost all of the remaining logic in Field Programmable Gate Arrays (FPGA). Another overriding concern in the development of the logic board was size. The allowable board dimensions are approximately 8" x 3" including I/O connectors.

Processor

The processor chosen for the DFT is the INTEL 80386SX. This device was chosen because of its wide support and its availability as a MIL qualified part. The INTEL 82370 peripheral controller was chosen to support the 386SX. This device offers a high degree of integration which was required because of the size constraints placed on the logic board. The firmware is interrupt driven and all I/O operations take place via DMA transfers to reduce the load on the processor. The internal timers of the 82370 are used for all time-out functions eliminating any dependence on firmware wait loops. System memory is divided into three major areas, a resident boot-up PROM (1) which is addressed at power up to initialize the processor and is used to write new firmware to EEPROM (2), which holds the operational program, and RAM (3) used for temporary data storage.

FPGA's

With just a few exceptions, all of the remaining logic functions are implemented in two Xilinx programmable logic arrays. The use of these programmable devices allows the system to remain very flexible. These devices are configured each time the unit is powered up or whenever required while in operation. The configuration data is stored in a separate serial PROM. The PROM is an 8-pin DIP that can be easily replaced if minor changes are required in the evolution of an existing range or even if major upgrades are required for a new range system. An external Fail/Safe circuit constantly monitors the configuration of the arrays and the condition of the power supply. If an anomaly is detected the arrays are reconfigured automatically.

I/O capabilities

In addition to the interfaces needed to control the operation of the two transceivers, there are several I/O interfaces used to communicate with external devices. The first is the high speed serial interface compatible with the AMODSM or any other similarly equipped device. The second is the Parallel I/O port used to download new firmware into the unit and to configure certain constants such as the unit ID. The Parallel port is compliant with the standard parallel port of an IBM compatible PC. The third I/O port is a status port used to provide a window into the unit. This window allows a number of internal signals to be monitored while the system is in operation.

POWER SUPPLY

The power supply module interfaces with the +28 VDC aircraft prime power and provides the necessary input prime power conditioning. The power supply generates +24 VDC, +/-8 VDC, and +5 VDC regulated voltages that are shared between the R-CUBED and TACTS sections. The power supply module will meet the requirements of MIL-STD-704. The power supply module has a feature that provides a constant +24 VDC output while switching from no load to full load. This feature has significantly reduced the amount of output storage capacitance required to maintain the output load.

RF ASSEMBLIES

R-CUBED Receiver

The R-CUBED receiver receives the chirped RF, pulse position modulated signal from the host platform/vehicle antenna through the Transmit/Receive (T/R) switch, performs detection and pulse compression, and supplies the compressed pulses to the logic section. A heterodyned architecture was designed in the receiver to accommodate different frequency requirements without changing or redesigning the dispersive delay line requirements. The input sensitivity is -98 dBm and the dynamic range of the receiver is from 0 dBm to -98 dBm. A linear tracking AGC was designed to improve rejection of in-band interference. Spread spectrum modulation is achieved using Surface Acoustical Wave (SAW) devices.

R-CUBED Transmitter

The R-CUBED transmitter generates the chirped RF, pulse position modulated signal for input to a host platform/vehicle antenna through a Transmit/Receive (T/R) Switch. The transmitters center frequency is 141 MHz and the peak RF output power during the chirped RF output pulse is 178 Watts minimum during any duty cycle. The unit's message length is variable and is capable of up to 8 milliseconds. Thermal stability is achieved in the selection of FET RF power amplifiers.

TACTS Receiver/Transmitter

The TACTS range system uses Frequency Shift Keying (FSK) for data transmission and measures the phase shift on three range tones to get range measurements. The TACTS range system operates on one of two uplink/downlink frequency pairs. 1830 MHZ uplink / 1778 downlink and 1840 uplink / 1788 downlink. The two frequency pairs offer flexibility to the ranges in the event of interference. The TACTS transponder operates in a full duplex mode for simultaneous reception and transmission of both range tones and data. The three range tones are phase modulated on the RF carrier. Two FSK data rates are available from the DFT. 198.4 kbps and 1.2 Mbps. In the low data rate mode, the delay variation from reception to retransmission of the ranging tones is critical and should be accurate to within four feet. The range tones are not used and are replaced by GPS in the high data rate mode of operation. The output transmitter power is 40 Watts minimum and the receiver sensitivity is -95 dBm.

CONCLUSION

The Microcom Dual Function Transponder (DFT) is capable of four modes of operation. Two of these modes are R-CUBED based, the other two are TACTS based. This allows the DFT to be completely interoperable with EATS, MSR, LATR, and TACTS/ACMI ranges.

Its purpose is to provide both forward and backward compatibility with current and future range requirements for R-CUBED based ranges as well as TACTS/ACMI based ranges. It will allow an aircraft to be fitted with a single POD and take part in exercises conducted over TACTS-based land ranges and open-ocean LATR or MSR ranges.

The DFT is designed to meet the identical service requirements of the AN/URY-3 R-CUBED unit which is its predecessor and whose functions are essentially contained within the DFT itself. Slight modifications of the present AN/URY-3 circuits are part of the DFT effort, but they are primarily concentrated in the area of the IF circuits and Logic enhancements The rugged Power Supply design presently included in the AN/URY-3 is carried over into the DFT with very few changes.