A PULSE CODE MODULATED FLIGHT TERMINATION RECEIVER

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ABSTRACT

Flight Termination is a control action that takes place when missiles or targets violate estabished safety criteria. The flight termination receiver, part of a ground to air control loop, is characterised by high system integrity and dedication to recovering and decoding the command signals. The paper describes the factors that have influenced the design and build of a robust Pulse Code Modulation Flight Termination Receiver for use on UK Trial Ranges. This work has been carried out with the support of UK MoD(PE), A ARM 51, on contract number A ARM 13b/224.

KEY WORDS

Flight Termination, Multiple simultaneous command channels, PCM-FSK.

INTRODUCTION

The UK Ministry of Defence (MoD) issued a "Specification for the Development and Supply of Dedicated PCM Flight Termination Command Equipment" in 1982, REF.1. This defined in general terms the required overall system parameters of equipment to replace the existing WREBUS equipment used for the termination of free flying missiles and targets. The requirement called for a radio link within the 400 to 500 MHz band, carrying frequency shift keyed (FSK) pulse code modulated commands. These commands were to have the capability to address up to six airborne vehicles simultaneously and to offer very high safety and reliability features, in a FAIL DESTRUCT mode of operation over a ten minute flight period.

In 1985 Plessey Avionics, now the Electronic Systems Division of GEC Marconi Defence Systems, was awarded a contract to design a PCM Flight Termination System (PCM-FTS) Command signalling system, a PCM FTS Airborne receiver, and a Ground terminal PCM FTS controller unit. Three years later UK MoD produced as part of a Range modernisation programme a "Specification for a flight termination ground transmitter system". REF 2. This called for a ground equipment capable of

operating with airborne receivers built to either the USA's IRIG standard or to the new UK PCM standard. With the addition of new front-end encoding and modulation units, the high power transmitters would serve both IRIG and PCM system requirements.

The need for flight termination on Trial Ranges stems from when free flying missiles and targets violate established safety criteria, depart from operational envelopes, or exceed pre-established range limits. Action must be taken by emergency or design to protect life and property, and must be quick and positive. It is often associated with vehicle destruction by explosive means which destroy aerodynamic stability and rapidly arrest flight, but it can include the deployment of drag devices or the gross disruption of control surfaces.

PCM FTS COMMAND SIGNALS

Design Philosophy

The message format adopted as the UK PCM standard is a compromise between the desirability for simplicity and the need for high integrity and reliability in both the Ground Transmission Controller and the Airborne Receiver. The two main features of the message format are firstly the provision of simultaneous independent control of up to six airborne receivers. Secondly, that the probability of commands being correctly received is maximised, and the probability of commands being misinterpreted is minimised.

In the format, successive frames of data consist of a start SYNC word followed by six PROHIBIT (or FIRE) command words and an end SYNC. Given that there is no requirement to destroy a vehicle, all six command words would read PROHIBIT, and receipt of this command confirms the presence of the radio link and inhibits a built-in automatic FAIL DESTRUCT action. Any vehicle requiring termination has the PROHIBIT word in their own time-slot replaced by a FIRE word, since individual receivers only respond to the commands within its own pre-designated time slot, or channel in the frame. Receipt of a FIRE command produces the necessary termination output. The message sent to the airborne receiver is in the form of a continuous 13.333 k bit serial binary encoded signal that is FSK'd on to the UHF carrier. The NRZ-L code is logic 'I' and 'O' corresponding respectively to a positive and negative frequency shift of 4.67 ± 0.1KHz.

Command Format

The receiver is designed to accept the carrier frequency and demodulate and decode the serial digital data. In keeping with established PCM techniques the signal is formatted into frames where each frame contains six dedicated PROHIBIT or FIRE channels. For both the single and dual transmitter modes, a command consists of correctly positioned PROHIBIT (FIRE) words with two SYNC words either side of it and a decision in the receiver requires the successful interpretation of three words within the frame.

a Single Transmitter Mode

Each frame which is continuously repeated consists of 248 bits made of up eight 31 bit command words, where the most significant bit is transmitted first. The frame content is, see Fig 1a and 1b

SYNC A - indicating frame start
COMMAND WORDS, 1 to 6, - each receiver recognises its own
SYNC B - indicating frame end

b Dual Transmitter Mode

Each frame consists of 372 bits made up of twelve 31 bit commands. The last eight words are identical with those of a single transmitter format and are preceded by four LOCK words which allow the receiver to acquire and synchronise a clock. Frames are transmitted alternately by each transmitter with a nominal three word non-radiating period between the two. The frame content is, see Fig 2a and 2b

LOCK WORDS - a repeated 4 word preamble
SYNC A)
COMMAND WORDS 1 to 6) as for single transmitter mode
SYNC B)

Command Code Definition

The command codes for LOCK, SYNC A, SYNC B, PROHIBIT and FIRE are selected as a subset from one of four 31 bit GOLD codes, and are chosen to minimise misinterpretation when the signals are correlated with stored replicas. Four different code groups are defined to allow operation at different Trial Ranges and to minimise the changes of cross-correlation. Typically there are twenty different bit positions between the codewords within a command group, so that cross-correlation of the

words when fully overlapped is small. Particular emphasis is placed on reducing any confusion between PROHIBIT and FIRE.

RECEIVER DESCRIPTION

Receiver Function

The Flight Termination Receiver, fig 3, is a miniature fixed tuned UHF receiver/decoder designed to:

a Receive the radio link PCM command signals
b Demodulate and decode the serial digital data
c Effect PROHIBIT and FIRE functions on a selected channel, one of six.
d Provide a suitable output for connection to a flight termination executive equipment
e Provide analogue and digital telemetry outputs for monitoring and test purposes

RF and IF Sub-system

The RF/IF sub-assembly makes extensive use of custom designed LSIs chosen for high performance, reliability and small size. It is a narrow band, fixed tuned, single conversion superhet with the following features:

a Antenna input protection against overload
b RF filtering either side of an RF amplifier stage, via two narrow band SAW filters
c Down conversion to IF via a dual gate MOSFET
d IF filtering either side of IF amplification, via two quartz crystal filters
e Limiter amplification to provide a constant level signal to the FM demodulator over approx 90 db of the input dynamic range
f Demodulation to provide an output voltage proportional to frequency deviation
g AC coupling to an integrate and dump filter and logic level detection

The IF bandwidth is determined by three factors, signal frequency transmission errors (typically 1 part in 10^6), doppler frequency shift and local oscillator errors due to tolerance, temperature and ageing. The total frequency shift is approximately $\pm$ 11KHz, and assuming a bandwidth of 16KHz to recover the signal spectrum the combined bandwidth requirement is 38KHz. For a signal input of -105dbm the receive S/N ratio is 14db which produces a bit error rate of better than 1 in 10^3, and although the gain margin is slightly eroded by clock jitter and errors, the 1 in 10^3 bit error rate is readily achievable.

RF/IF Summary

1	Signal frequency:	fixed in the range 400 to 500 MHz, ± 1ppm.
2	Signal modulation:	Binary FSK with a peak deviation of 4.67KHz ± 0.1KHz
3	Modulation data rate:	13.333KHz, ± 50ppm
4	Signal dynamic range:	-105 to +5dbm
5	Receiver selectivity:	-50db at ± 180KHz, -60db at ± 200KHz
6	IF Bandwidth:	38KHz
7	Spurious rejection:	All spurious and image responses are at least -70db below in-band response.

Command Decoder

The command decoder an ASIC gate array recognises and implements the flight termination commands contained in the date stream from the RF/IF sub-assembly. Because the received commands are pre-determined codes the processing is one of correlating the receiver data with stored reference codes. The ASIC contains the functions of codeword detector, code store, clock generator, FIRE gate and telemetry timer. Further it can be programmed to accept the "pre-set at manufacture" inputs which select the mode of operation (Fail Destruct in UK), unit address (one of six), command code group (one of four) and Fail Destruct time (0.2 sec to 8.0 secs). The heart of the array is the codeword detector that interprets incoming data by comparison with stored replicas of SYNC A, SYNC B, PROHIBIT and FIRE. The detection criteria is that the SYNCs are recognised at the correct spacing together with a PROHIBIT or FIRE in the correct unit address, and the acceptance threshold requires at least 27 bits from each of the 31 bit words to be correct. When a FIRE command is decoded the FIRE switch closes producing a short between the FIRE output and FIRE or return. The FIRE response time is 38 m.sec for single transmitter operation and 87 m.secs for the dual transmitter mode. If PROHIBIT is decoded the logic resets the Fail Destruct timer, but if this command is not received within the Fail Destruct time then the logic commands a FIRE function. Additionally either loss of DC power, within 50 m.sec of the DC supply falling to below 20v, or loss of the command link will produce a FIRE output.

The Fire Switch

The FIRE switch is a power FET, with an 'ON' resistance of 0.25 Ω, capable of switching a 6.5 AMP detonator current, via such safety and arming systems as may be fitted. It has up to four inputs according to which Fail mode is pre-set at manufacture, and in the Fail Destruct mode a FIRE output is produced when either a FIRE

command from the decoder or a Power fail signal is present. In the Fail Inert mode a FIRE output is produced only by a FIRE signal from the command decoder.

Telemetry

The receiver provides six outputs for test and telemetry (TLM) purposes.

a	Signal Strength TLM:	an analogue 0.8v to 4.5v, nominal, signal indicating signal strength over the -105dbm to +5dbm range
b	FIRE TLM:	a digital monitor of the reception of a FIRE command, logic 1, equals FIRE
c	PROHIBIT TLM:	a digital monitor of the reception of a PROHIBIT command, logic 1 equals PROHIBIT
d	TLM A:	a digital monitor of the Fail Destruct timer, logic 1 equals Fail Destruct
e	TLM B:	a digital monitor of the FIRE switch state, logic 1 equals FIRE switch ON
f	RECEIVED DATA:	a digital monitor of the received data stream, logic 1 equals Fo + 4.67KHz, logic 0 equals Fo - 4.67KHz

All of the digital telemetry outputs are at TTL levels.

Mechanical and Environmental Aspects

The external dimensions of the receiver are 79mm x 59mm x 11mm, it weighs 240 gms (360 gms including 1 metre of cableform), and operates in an environment that is more stringent than previously asked of flight termination receivers. The environmental specification is as follows:

Operating temperature:	-40°C to +85°C for two hours
Survival temperature (unpowered):	-55°C to +100°C for sixteen hours
Operating vibration levels:	$0.6g^2$/Hz, 50Hz to 4500Hz for sixty secs
Air carry vibration levels:	$0.1g^2$/Hz, 50Hz to 4500Hz for two hours
Operating shock level:	100g for eight m.sec
Survival shock level:	500g for one m.sec
Acceleration:	100g linear in any direction
Atmospheric pressure:	45 millibars (equivalent to 70,000 ft altitude)
Humidity:	95% at +40°C

The receiver has been fully tested over its specified environment and the mechanical design ensures that the ground running life and shelf life are respectively at least 1000 hours and 5 years when stored at an ambient temperature of between 0°C and 30°C. After the 5 year shelf life units should be revalidated at yearly intervals.

SUMMARY

The PCM FTS receiver has been designed and developed to meet the requirements of a modern Trials Range and the system concept and command signal structure has led to a versatile and robust miniature receiver. Advanced technology, packaging techniques and construction methods have been employed throughout, from RF to IF to digital processing. Emphasis has been placed to safety and reliability aspects and the combined programme of analysis and testing of the receiver demonstrates that all of the objectives have been achieved.

ACKNOWLEDGEMENT

The author wishes to freely acknowledge the work undertaken by personnel within UK MoD and GEC-Marconi who specified the requirement, proposed solutions and undertook the design and development of the PCM FTS receiver. In particular, acknowledgement is made to the Communications Group at GMDS-ESD led by Mr G Robinson, to Mr B Booden who headed the original design and development team, and to Mr N Moon who has taken the receiver through qualification, reliability testing, extensive environmental testing to pre-production manufacture.

REFERENCES

1 Unpublished MoD Report: Specification No IT1110, Specification for the Development and Supply of dedicated PCM Flight Termination Command equipment, 1982.

2 Unpublished MoD Report: Specification AB/IN/192, Specification for a Flight Termination Ground Transmitter System for Aberporth Range, 1988.

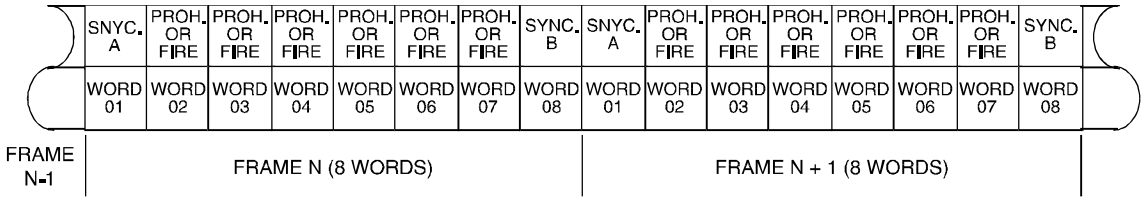

FIGURE 1 (A) SINGLE TRANSMITTER COMMAND FORMAT

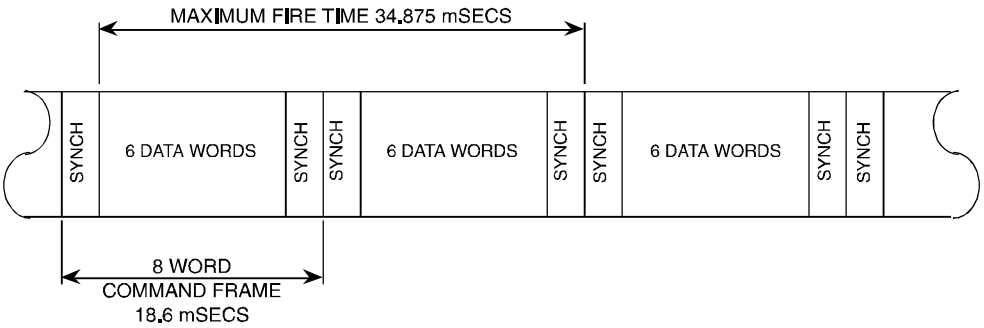

FIGURE 1 (B) SINGLE TRANSMITTER FORMAT TIMING

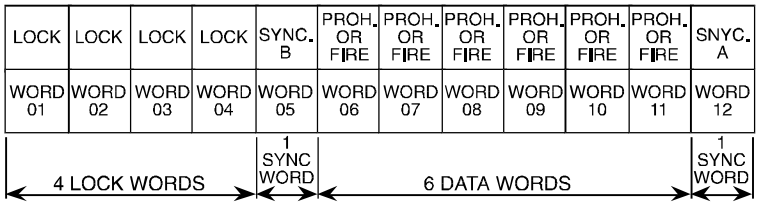

FIGURE 2 (A) DUAL TRANSMITTER COMMAND FORMAT

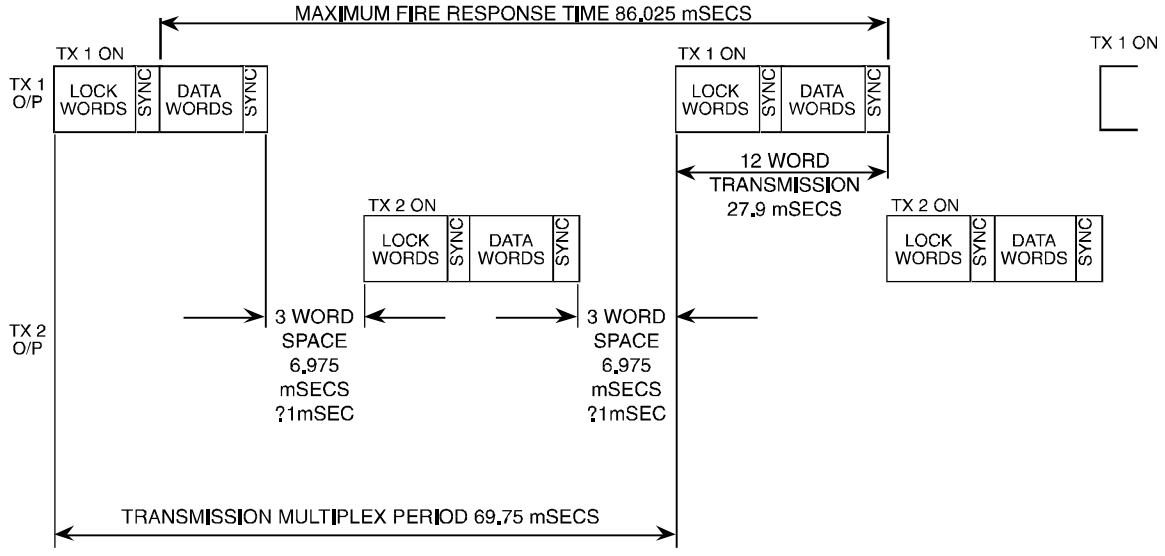

FIGURE 2 (B) DUAL TRANSMITTER COMMAND FORMAT TIMING

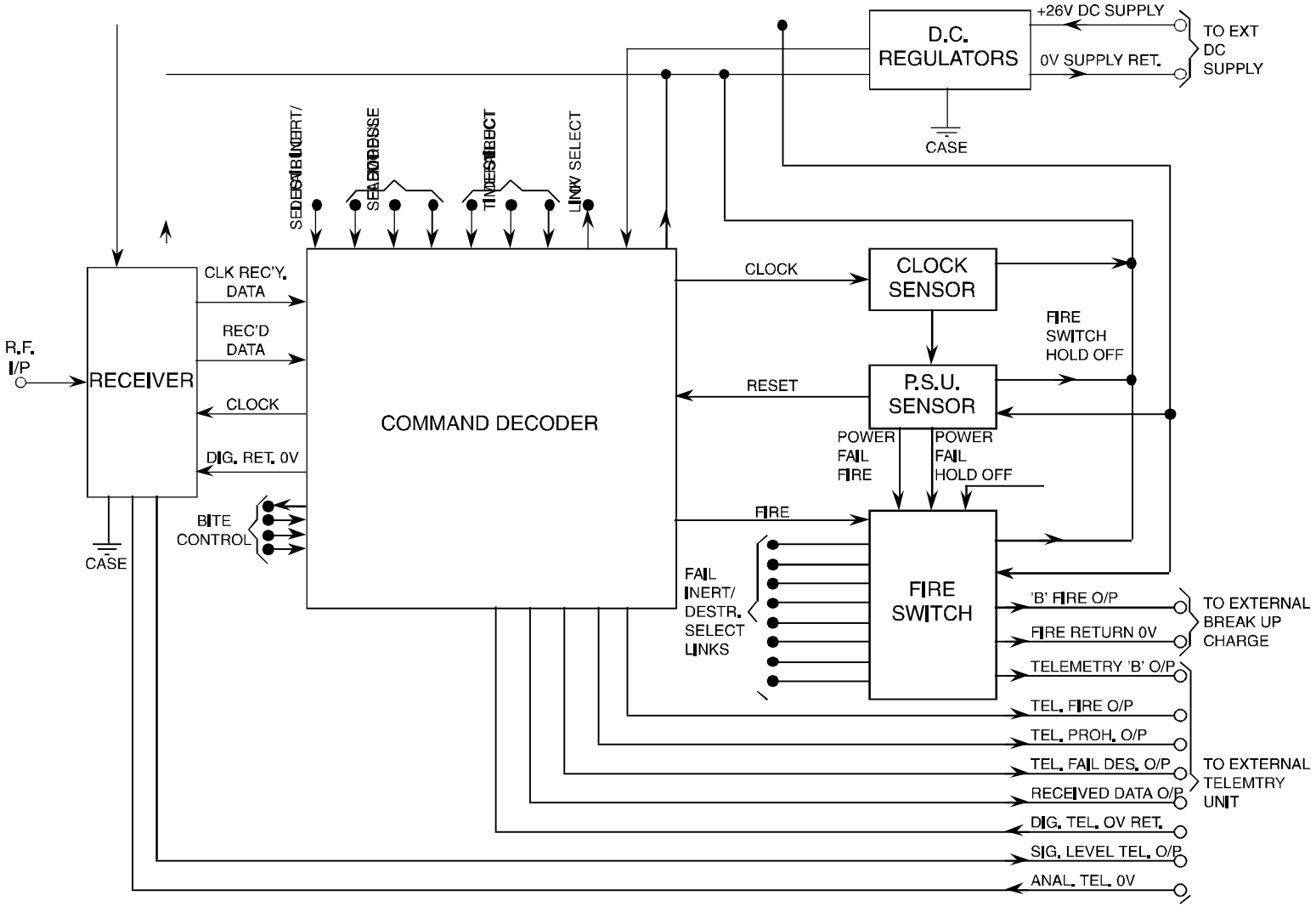

FIGURE 3 - PCM FTS AIRBORNE UNIT FUNCTIONAL BLOCK DIAGRAM

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