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TACAN/DME DIGITAL DATA BROADCAST DESIGN PLAN

Vol. II – Synthesis of the Data Transmission and Formatting Techniques

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16. Abstract

The Digital Data Broadcasting Design Plan implements the system engineering process for the purpose of defining with supporting rationale a recommended ground/airborne equipment configuration and flight test program. This plan documents an approach to verify the operational significance and technical feasibility of utilizing existing DME and TACAN to provide the function of broadcasting data to aircraft for use in support of area navigation in addition to its normal function. The Design Plan is structured as follows in five volumes:

Volume I - Operational Analysis
Volume II - Synthesis of the Data Transmission and Formatting Techniques
Volume III - Airborne Equipment
Volume IV - Ground Equipment
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TACAN/DME DIGITAL DATA BROADCAST

DESIGN PLAN

ERRATA SHEETS FOR VOLUME 2 --

SYNTHESIS OF THE DATA TRANSMISSION AND FORMATTING TECHNIQUES

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MAY 1973

Page No.	Comments
25	Line 10, change"...43 microseconds, to"...63 microseconds"
29	Line 14 should read "...modification in the Transponder..." (This word added)
32	In the second paragraph, reference is made to a 45 microsecond interval preceding each Reference Burst. This represents a 5 microsecond safety margin over the 40 microsecond quantity stated on page 31.
41	In Figure 2-9, the value B should be defined as the Decoding Threshold.
52	Last paragraph, "...0.5%....should be "...0.15%...."
65	In the sixth line there should be a comma instead of a period ofter the word possible
69	In the last paragraph, second line, the word "efficiency" is mispelled.
74	At the end of the first paragraph, the word "structure" is mispelled

TABLE OF CONTENTS

VOLUME 2 - SYNTHESIS OF THE DATA TRANSMISSION AND FORMATTING TECHNIQUES

		Page Numbers
2.1	Introduction	1
2.2	Review of Possible Modulation Techniques	2
2.2.1	Differential Phase Shift Keying (DPSK)	2
2.2.2	Distributed Reference Quantized Pulse Position Modulation (DR-QPPM)	3
2.2.3	System Defined by FAA Specification ER-330-023, September 1971	4
2.2.4	Time Interval Coding System	5
2.2.5	Concentrated Synch Quantized Pulse Position Modulation (CS-QPPM)	8
2.2.6	Asynchronous Data System (ADS)	9
2.2.6.1	Overall System Description	9
2.2.6.2	Development of the System Concept	16
2.2.6.3	Selection of Data Pulse Positions	18
2.2.6.4	Restrictions on Replies, Squitter and Data Prior to Each Reference Burst	31
2.2.6.5	Calculation of S/N Ratio vs. Range	33
2.2.6.6	Calculation of Bit Error Rate	37
2.2.6.7	System Operation During Identity Tone Transmission	48
2.3	Comparison of Concentrated Synch QPPM and ADS	51
2.3.1	Effect on Transponder Reply Efficiency	52
2.3.2	Effect on Bearing Measurement	53
2.3.3	Interference With Existing TACAN/DME Functions	55

Page Numbers

2.3.4 Transmitter Energy Required Per Bit of Data 56

2.3.5 Growth Potential 57

2.3.6 Susceptibility to Multipath 58

2.3.7 Susceptibility to Random Interference Pulses 60

2.3.8 Error Rate 62

2.3.9 Hardware Requirements 63

2.3.10 Comparison Summary and Recommended System Approach 63

2.4 Data Formatting 65

2.4.1 Development of Word Structure 65

2.4.2 Word Redundancy Analysis 71

2.4.3 Word Synchronization and Overall Data Structure 75

2.4.4 Data Acceptance Criteria in the Airborne Equipment 78

2.5 System Bit Rate and Power Requirements 79

References

VOLUME 2 - SYNTHESIS OF THE DATA TRANSMISSION AND FORMATTING TECHNIQUES

2.1 Introduction

The purpose of this section of the Design Plan is to develop a modulation technique and data format consistent with achieving the most practical system possible. Particular emphasis is placed on devising techniques which will minimize the quantity and complexity of the airborne equipment. The selection of a modulation technique is accomplished by first evaluating a number of systems which have been proposed in the past and a new "Asynchronous Data System" (ADS) technique developed by EDMAC Associates Inc. during the course of the present FAA program. The data format development basically consists of efficiently grouping the data in a manner which minimizes pads (empty data spaces) and provides enough uniformity to enable simple processing in the airborne equipment.

The paragraphs which follow will summarize the characteristics of each modulation technique in sufficient detail to allow the selection of the best approach. From the standpoint of Digital Data Broadcast only (which is the only practical consideration here) two of the methods - "Concentrated Synch QPPM" (Reference 1) and "ADS" have obvious implementation and performance advantages over the others. The main portion of this effort was therefore directed toward a relative comparison of these two techniques in terms of their growth potential (more data and/or shorter cycle time),

impact on DME reply efficiency and TACAN Bearing measurement, susceptibility to noise and multipath errors and the complexity of the hardware required at both the ground and airborne end of the system. This is followed by a discussion on the synthesis of a data format compatible with the modulation technique and overall system objectives.

2.2 Review of Possible Modulation Systems

2.2.1 Differential Phase Shift Keying (DPSK)

This method of broadcasting data consists of coding the phase of the RF signal in two successive pulses. The RF phase between the two pulses would either remain constant or would be reversed depending on whether a binary 0 or a binary 1 were to be transmitted. (Systems with four or more possible phases are also possible) From a theoretical standpoint, this data modulation method is the best of all considered inasmuch as it could be formulated to operate with very few extra pulses being transmitted. This can be accomplished by simply coding the relative RF phase of each squitter or reply pair in accordance with the data stream being sent. The only extra pulses which would then be required would be special synchronizing pulses for establishing the beginning and end of each data word. Spectrally, the concept of providing an RF phase reversal between two successive pulses gives approximately the same frequency distribution as does a pair of pulses with no phase reversal.

The fact that both the time and frequency spaces of a differential phase shift keyed system are only altered by a negligible amount

relative to a "standard" system makes this technique theoretically desirable. However, from a practical standpoint of both ground based and airborne hardware, this concept is not feasible. The reasons are many. First, based on tests made on the GFE ground equipment at EDMAC, the phase stability of the transmitted RF signal is not adequate to guarantee precise phase relationships between the first and second pulse of a pair. Second, even if the phase was perfectly stable, RF phase shifts due to multipath present a serious problem which will require special attention. Third, any modification kit to perform the demodulation of the differentially encoded data will require that an IF output be provided from the airborne interrogator whose phase stability is adequate to assure that the differential phase between first and second pulse can be accurately preserved. Fourth, the airborne hardware required to accurately measure the relative phase between two pulses spaced 12 or 30 us apart is significantly more complex than the other data broadcast possibilities being considered. These factors combine to make differential phase shift keying impractical for the current Digital Data Broadcast System.

2.2.2 Distributed Reference Quantized Pulse Position Modulation (QPPM)

This technique is described in detail in Reference 1. The concept basically consists of transmitting 110 distributed reference pulse pairs and an additional 364 data pulse pairs. By having the airborne equipment phase lock to the reference pairs and data pairs separately, reference timing

for bearing information can be derived from these two pulse trains and can be substituted for the north or auxiliary burst waveforms. In addition to their use in providing the bearing reference, each of the 364 data pulse pairs are positioned in one of four possible time slots in a 12 us interval, thus establishing the equivalent of 2 bits of binary data per pulse pair. This gives a total data capability of 728 bits per second in addition to an improved Bearing service and Time Dissemination Service for One-Way-Ranging.

Although this technique might provide improved bearing service for military users as well as a 728 bit per second data capacity, it would be more difficult to implement than the recommended system (described in a later section) from both the ground and airborne equipment standpoints. It also has limited growth capability for adding more data bits, and although it makes provisions for easily establishing bit synchronization, the problem of deriving word synchronization is more complex. In addition to the above disadvantages there appears to be a possible error in calculating the time positions of the data bits given on page 33 of Reference 1. The data pulse times shown are inconsistent with the total data period and with each other. From the primary Data Broadcast standpoint, this system has no advantages and a number of disadvantages relative to the recommended system (to be described later). Hence, it is not considered feasible for this application.

2.2.3 System Defined by Specification FAA-ER-330-023

The Digital Data Broadcast system concept described in the subject specification was addressed

by EDMAC Associates Inc. in response to RFP WA5R-1 0594 of January 1972. The concept consisted of sending 30 bits of data in a 1000 microsecond time slot following each North Reference Burst, giving a maximum data capacity of 450 bits per second. The system was intended to accommodate up to 18 waypoints.

Although the hardware implementation for this system is relatively straightforward, the data capacity is limited. Although the system may have enough capacity to meet the initial Terminal area requirement shown in Section 2.5, there is insufficient growth potential for adding more waypoints and/or decreasing the data cycle time. Additional growth could be achieved by adding data intervals after Auxiliary Bursts as well as North Bursts, but this would further degrade the Range reply efficiency and cause further increase in Bearing error. Therefore this system was not considered feasible for this application.

2.2.4 Time Interval Coding System

In October 1971, EDMAC Associates Inc. submitted a proposal in response to RFP WA5R-0-0222 wherein a Data Broadcast System called "Time Interval Coding" was described. The system basically consists of using the time interval between two coded pulse groups (for example, pulse triplets) to indicate the magnitude of the quantity being transmitted.

There are a large number of ways in which this type of system can be implemented and an infinite number of scale factors or data resolutions which can be used. Numerous time intervals can be placed one following the other in order to

transmit several pieces of data. Numbers with many significant digits can be made into two time interval words with different scale factors for each word. If the time interval is made long and/ or the time resolution is small, it is readily seen that a single "start" pulse group and a corresponding "stop" pulse group can convey a large number of data bits. This system is actually a form of Pulse Position Modulation and conveys a large number of data bits per pulse of energy transmitted. A special coded pulse group such as a pulse triplet could be used to determine the "start" time of an interval and a second unique triplet could be used to indicate the "stop" time. These triplet pulse spacings must be chosen such that they do not "activate" the TACAN or DME pulse pair decoders.

In implementing this system, the total message is arranged in blocks of several words each. One block could be used to broadcast VORTAC station data, and another for each of the waypoints. Each block would be divided into time slots, one time slot for each data word. A normal system dead time of 60 microseconds would separate each time slot. The time interval from the start of each time slot to the stop pulse represents the value of the data to be transmitted. A timing diagram of this system is shown in Figure 2-1.

Careful examination of this system and the Concentrated Synch Quantized Pulse Position Modulation (QPPM) System described in the next section, (and in Reference 1) indicates that both are very similar in concept. The EDMAC Time

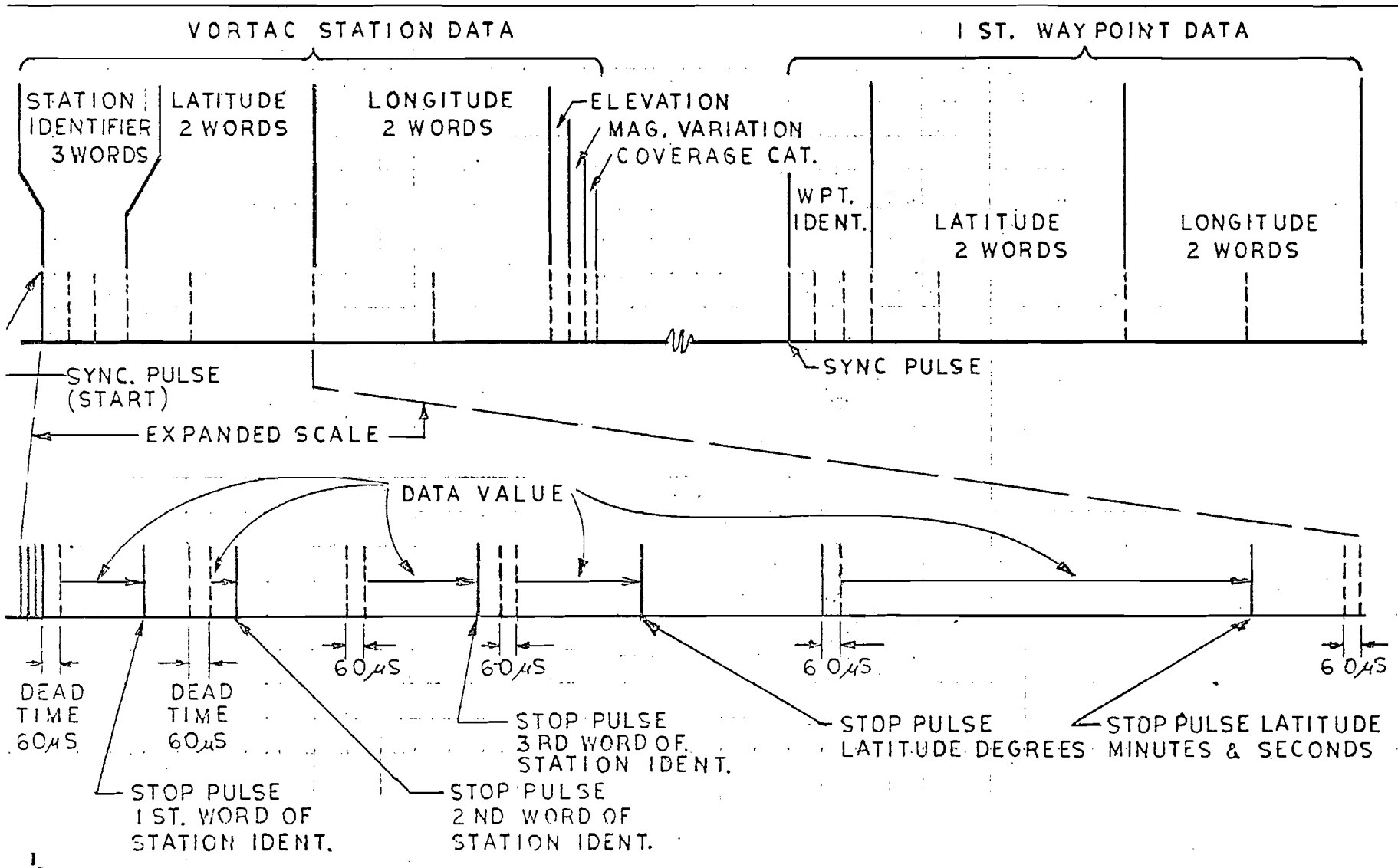


FIGURE 2-1. TIMING DIAGRAM, TIME INTERVAL CODE

Interval system was only developed through the proposal stage, whereas the QPPM system was more fully defined because it was developed as a part of a funded study program. For this reason the Concentrated Synch QPPM has been chosen as one of the final candidate systems to be compared with the ADS system. These will be discussed in more detail in the paragraphs which follow.

2.2.5 Concentrated Synch Quantized Pulse Position Modulation

This system is a "strictly Data Broadcast" oriented technique proposed in Reference 1. As opposed to other techniques described therein, the Concentrated Synch QPPM system provides a high data capacity capability with a minimum of energy and can be implemented in a straightforward manner. As previously mentioned, this technique is very similar to the EDMAC Time Interval method and it has been described in detail in Reference 1 to operate with a specific set of resolution cells and timing sequence.

The system basically consists of broadcasting data which is spread over the entire interval between the North Reference Burst and the first Auxiliary Reference Burst. The data sequence is initiated by a unique synchronizing triplet followed by seven data triplets (whose pulse spacings differ from the synch triplet pulse spacing). Each data triplet will be broadcast in any one of 256 adjacent 3 microsecond slots. Therefore, the time position of each data triplet defines 8 bits of data. A system such as the one

$2^8 = 256$

specified in Reference 1 with seven data triplets following each North Burst gives 56 bits per burst or 840 bits per second. These 840 bits are broadcast using only 120 triplets or 360 single pulses per second, thus giving a transmitter "efficiency" of approximately 2.3 bits per pulse. A simplified timing diagram of this system is reprinted here from Reference 1 to illustrate the format described above. This is given in Figure 2-2 of this Design Plan.

The synch triplet for this system was selected to have interpulse spacings of 18 and 32 microseconds and the data triplet spacings would be 21 and 27 microseconds. Unfortunately the choice of 32 us spacing can potentially interfere with Airborne TACAN Y Mode DME and Bearing operation because the normal spacing for this Mode is 30 microseconds. However, since the 32 microsecond spacing is part of the synch triplet, which only occurs 15 times per second, it may not be the cause of any significant problem. To a lesser extent the 32 microsecond pairing can begin to activate an Airborne X Mode North Burst Detector in those TACAN sets where the North Burst is not preceded by a pulse pair decoder. Other factors to be considered in a later section are the system's impact on DME reply efficiency and Bearing service.

2.2.6 Asynchronous Data System (ADS)

2.2.6.1 Overall System Description

The Asynchronous Data System (ADS) was developed by EDMAC Associates Inc. during the course of the current DME/TACAN Ground Equipment Modification

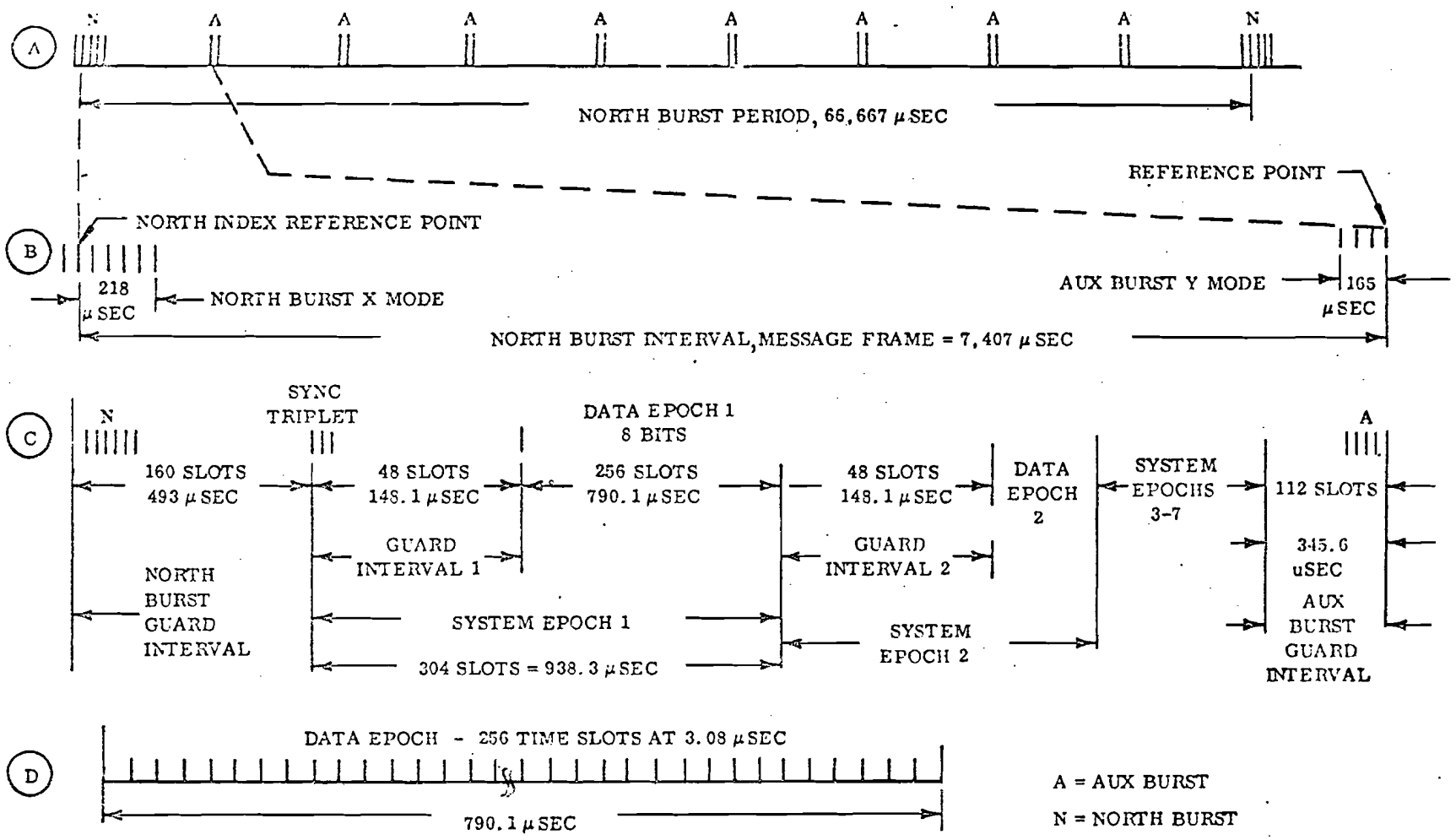
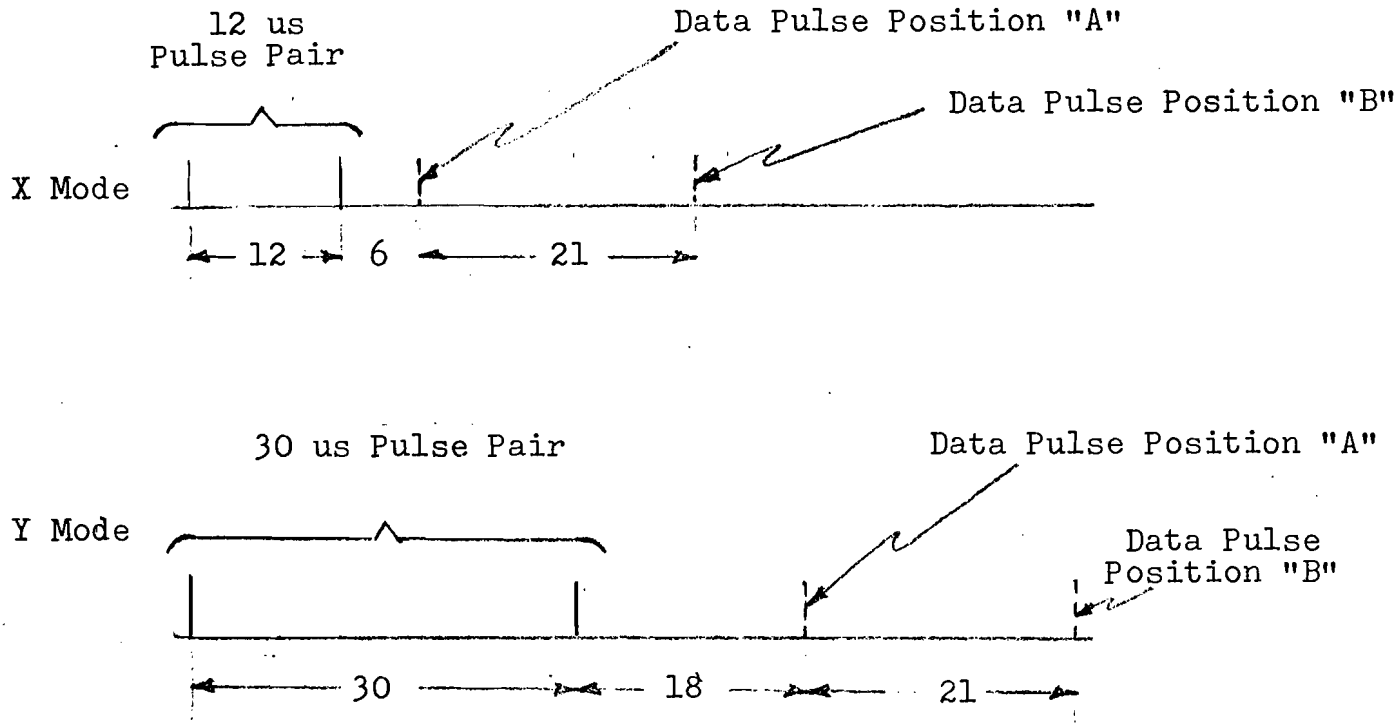


Figure 2-2. Concentrated Sync QPPM System Timing Diagram

Program. ADS accomplishes the Data Broadcast Function by adding a single data pulse in either of two positions after a normal TACAN reply or squitter pair. A timing diagram is shown in Figure 2-3. As shown in the diagram, a pulse in position A corresponds to a logical 0, a pulse in position B corresponds to a logical 1, pulses in both positions signify a word synch character and pulses in neither position indicate that no data is present.

Airborne processing of the data would take place in a modification kit called an "Airborne Data Decoder". This unit will only require a video output and an X/Y Mode Control line from a DME Interrogator or TACAN set. The pulse spacings have been chosen so that the data pulses will not interfere with normal DME or TACAN operation and normal pulse pair transmissions will not trigger the Data Decoder.

Using this approach of adding data to existing pairs, it is readily seen that from a system standpoint, ADS can support up to 2700 data bits per second (this being the normal squitter plus reply rate). The only limitation in actually achieving this data rate in practice is imposed by the power constraints of the transmitter and power supplies. Hence, the concept of starting with a limited data rate (for example 600-900 bits per second) and later expanding up to 2700, will not impact the overall system concept. Hence, the described system has excellent growth potential for adding more data and/or reducing the cycle time of the present data.



Code Structure:	Data Pulse Position	Code
	"A"	Binary 0
	"B"	Binary 1
	Both "A" and "B"	Word Synch
	Neither "A" or "B"	No Data

NOTE: All Time Intervals Shown in Microseconds

Figure 2-3. X and Y Mode Data Coding for ADS

Although the ADS system is strictly Data Broadcast oriented, its use does not preclude the later addition of other types of TACAN improvements such as Time Dissemination service for One-Way-Ranging and/or various forms of improved Bearing service (See Reference 1). Furthermore, it will cause less than a 1% loss in reply efficiency and a correspondingly negligible degradation in Bearing accuracy. These two areas will be covered in more detail in subsequent sections. The system is Asynchronous in the sense that the beginning and end of any data word is not referenced to any synchronous signal generated within the Transponder. The beginning of each word will be designated by the special data doublet shown in Figure 2-3. No data will be added to any pulse pairs that comprise the Reference Bursts. (The method by which the Airborne equipment will completely ignore Reference Bursts will be described later.) Since the airborne equipment receives squitter and reply pairs at random times, those pairs which have data added will also arrive at random times and be stored in appropriate registers in the Data Decoder. Special word synchronizing data pulse doublets (pulses in both A and B positions) will be sent every N bits where N is the number of bits per word (to be selected based on results of word structure study covered later in this report). Each word will have appropriate addresses, data content, pads and a parity bit. In order for the word to be accepted as valid, it must contain the right number of bits and have the correct parity.

In order to provide data redundancy and validation, each word will be sent twice. This feature is desirable from pure redundancy and validation standpoints but is also necessary in the sense that DME or TACAN Interrogators generate a Receiver Blanking Gate each time they transmit. Therefore, there is a finite probability that a data pulse or word synch pulse doublet will be blanked during that time and thus cause the entire word to be incorrect. If N is on the order of 32 or less and the squitter rate is 2700 or more, the chances of two successive words being contaminated by two successive Blanking Gates is negligibly small. (This statement is based on a maximum Interrogation rate of 30 PPS and random arrival times for the replies and squitter.) The blanking problem can be avoided if the DME or TACAN is further modified so that interrogations can only occur after the receipt of data. Such a concept was proposed in Reference 1. However, in order to keep the Airborne DME or TACAN modification as simple as possible, EDMAC Associates Inc. recommends that only a video output and an X/Y Mode Control line be required from the Interrogator units. The complication of modifying the Airborne Interrogator circuits to externally control the permissible Interrogation Pulse times is considered too unwieldy for this application. Hence, EDMAC has adopted the guideline that no Interrogator modification be required except for providing a video output line which is gain controlled by the normal Airborne DME or TACAN receiver AGC system.

Consideration has also been given to operating the DDBS system with a DME only Transponder. Fundamentally, there is no reason why the ADS cannot work with a DME only Transponder except that its data capacity would be based on their nominal squitter rate which typically runs between 800 and 1350 pulse pairs per second. Thus, merely adding data pulses to these pairs would give a more limited data rate capability than for the TACAN Transponders. Additionally, the lower squitter rate would not preclude the possibility of 2 successive 30 PPS Interrogator Blanking Gates from interfering with 2 successive data words (again assuming an approximate word length of N = 32 bits). These problem areas related to the "DME only" Transponders were discussed with FAA personnel, and EDMAC has been directed not to constrain the design of a DDBS with the parameters of "DME only" Transponders. This decision was primarily based on the scarcity of these Transponders in current use. In spite of this decision and the problems cited above, it should be emphasized that DDB using the ADS system can still be implemented with "DME only" Transponders but with reduced data capacity.

Since the ADS system represents a new data transmission concept, the following paragraphs will be devoted to providing a detailed description of the system synthesis and performance capabilities.

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2.2.6.2 Development of the System Concept

After examining the various Data Broadcast techniques proposed in the past, EDMAC Associates began an investigation to uncover a concept which would more efficiently utilize the time available in the TACAN signal. With this thought in mind, it soon became evident that because of Transponder Dead Time, there is a nominal 60 microseconds between the second pulse of each squitter or reply pair, and the first pulse of the next pair. Since this "space" is always guaranteed to be empty, it appeared logical that if data pulses were added during those intervals, the impact of Data Broadcast on the Range and Bearing service would be minimal. The fact that data would be communicated at random time intervals with each pulse pair poses no problem because it would merely be stored in appropriate registers which could be read synchronously or upon external command.

The first step in formulating a method for adding data during this Dead Time interval consisted of considering a single time slot after each squitter or reply pair. If a data pulse was present during this slot, the data would be decoded as a binary 1. If no pulse was present, a binary zero would be decoded. Although such a system uses about one-half as many pulses as the one described in the previous Section, it suffers from a number of disadvantages. First, such a system would still require some additional pulse codes to signify the beginning and end of a word. Second, there is no way to discriminate between a binary zero and a "no data" condition. Third, from an information theory

standpoint, the error rate of such a system which uses only one-half as much extra energy as the previously described system would be poorer. Fourth, the presence of a multipath noise pulse during the time slot when a binary zero (no pulse) is being sent will give an undetectable error. In the ADS system described in the previous section, such a multipath will cause either a binary one or zero to look like a word synch doublet but this would be an easily detected error and the corresponding word would be rejected.

The disadvantages listed above led to the development of the present ADS concept which is illustrated in Figure 2-3. It is particularly important to note the significance of the "no data" condition whereby the ADS system can selectively apply data to replies and squitter in accordance with the required bit rate. For example, suppose a 675 bit per second rate was required from a Transponder operating at 2700 pairs per second. A typical method of implementing DDB for these parameters would be to transmit 2 successive identical words (approximately 64 bits) in conjunction with 64 consecutive pulse pairs (word synch pulse doublets will be ignored here for simplicity). Then the next 3 x 64 or 192 pulse pairs would be sent with no data pulses. The process would then be repeated for the next word group. This provides a 25% duty cycle for the data and would yield the required 675 bits per second. If higher data rates were desired, the duty cycle would simply be altered to something less than 192 pulse pairs of no data. The "no data" condition is also significant in the case of the ADS Data Decoder's ability to ignore reference bursts. The system will

be designed so that no data pulses will ever be sent with Burst pulse pairs. Hence, whenever the ADS Airborne Data Decoder receives pulse pairs which make up a Reference Burst, these pairs will contain "no data". This is accomplished by choosing the data spacings properly and will be discussed in the next section. By designing a system which does not utilize Reference Bursts, the Airborne system can receive data from either a TACAN or "DME only" Transponder.

2.2.6.3 Selections of Data Pulse Positions

There are four basic constraints which were considered in the selection of the data pulse positions previously shown in Figure 2-3. These are listed below:

1. Avoid generating spurious pulse pairs which can trigger Ground or Airborne Pulse Pair Decoders and/or Airborne TACAN Burst Detectors.

2. Avoid pulse spacings less than 5 microseconds apart to prevent pulse distortion.

3. Avoid large spacings so that no spurious pairs will be formed by data pulse and the next TACAN/DME pairs following the System Dead Time.

4. Avoid spacings where Reference Burst Pulses can be mistaken for data pulses. (This will occur if the data spacing is coincident with Burst pulse spacings).

The remainder of this Section will be devoted to describing the steps which were taken to arrive at the selected spacings under the constraints listed.

The first major consideration in designing the Data Pulse positions is the interference that the extra pulses can cause with existing TACAN/DME equipment (Constraint Number 1). The design must avoid generating spurious pairs which could trigger existing Airborne or Ground Based TACAN/DME equipment. This applies for all possible modes of operation including X and Y and both Air-to-Ground, and Air-to-Air operations.

The specific equipments which must be considered are the Pulse Pair Decoders of TACAN/DME Interrogators and Transponders, and the Reference Burst Detectors of TACAN Interrogators. All potential data pulse spacings which could "activate" those units should be avoided even when there appears to be frequency protection. (It is not desirable to depend on frequency protection because in many such cases there still exists the possibility of generating spurious image frequencies in the frequency converters within each Receiver. Although these images will in most cases be attenuated by pre-selectors, they could still cause problems.) Although it would be impossible to select reasonably short data pulse positions which would satisfy all of the above constraints, these factors should be considered in performing any trade-off to minimize interference problems. The data below indicates which "on channel" equipments would be affected by spurious data pairs transmitted from X and Y mode transponders.

X Mode Transponder

Pair Spacings to Avoid	"On Channel" Equipment Which Could Be Affected
12 ± 5 us*	Airborne TACAN/DME X Mode Pulse Pair Decoders
12 ± 2 us 24 ± 2 us 36 ± 2 us • • etc.	Airborne TACAN X Mode Auxiliary Burst Decoder
30 ± 2 us 60 ± 2 us • • etc.	Airborne TACAN X Mode North Burst Detector

*Many Airborne TACAN/DME Interrogators have decoding tolerances specified up to ± 5 us.

Y Mode Transponder

Pair Spacings to Avoid	"On Channel" Equipment Which Could be Affected
12 ± 5 us	Airborne TACAN X Mode Air-to-Air Pulse Pair Decoder
15 ± 2 us 30 ± 2 us 45 ± 2 us etc.	Airborne TACAN Y Mode North and Auxiliary Reference Burst Detectors
24 ± 5 us	Airborne TACAN Y Mode Air-to-Air Pulse Pair Decoder
30 ± 5 us	Airborne TACAN Y Mode Ground-to-Air Pulse Pair Decoder
36 ± 2 us	Y Mode Ground Transponder Pulse Pair Decoder

As previously stated, any pulse pair spacings caused by either X or Y mode DDB should ideally be chosen so that they do not interfere with either "off channel" or "on channel" equipment. Such an idealization would limit the selection of data pulse positions so that no conflict will exist with either the X or Y restrictions given above.

After a number of trial solutions it was apparent that all of the idealized conditions stated could not be achieved. The approach used to analyze the spurious pair spacings which could be generated, was to consider all possible extra pulse pair combinations which are formed when two data pulse positions are added to each TACAN/DME squitter or reply pair. By relaxing the idealized "off channel" constraints in X Mode and tolerating an occasional 21 microsecond spacing in Y Mode, it was possible to develop the final TACAN/DME/DDB group spacing defined in Figure 2-3. The justification for allowing some of the constraints to be removed is based on the fact that the possible interference cases created by the DDB pulses are remote and would have a negligible effect on TACAN/DME performance. This is discussed in more detail in later paragraphs.

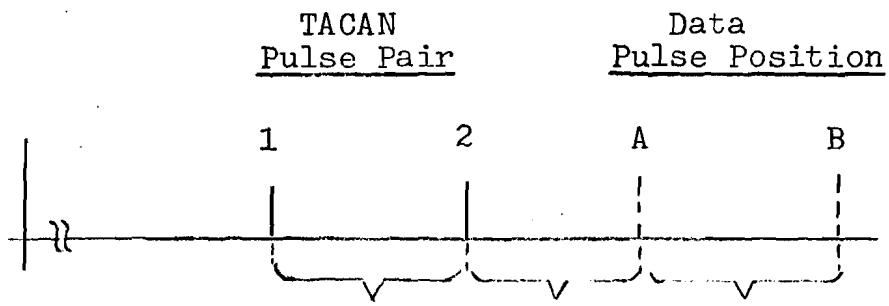
The actual procedure for deriving the data pulse positions shown in Figure 2-3 consisted of a set of iterative solutions based on the first three constraints listed (interference, keeping pulses at least 5 microseconds apart and minimizing the total data span) followed by a check to see whether the resulting pattern conflicted with constraint number 4 (Burst Interference).

In order to provide some insight into the analysis which preceded the final solutions, Figure 2-4 shows the spurious pulse pair combinations which are formed for the selected X Mode and Y Mode group spacings of (12, 6, 21) and (30, 13, 21) microseconds respectively. The same type of pulse pair combination analysis was applied to all other spacings which were attempted during the iterative process.

The paragraphs which follow discuss the degree of conformance of each of the selected group spacings with the constraints previously given.

X Mode Analysis - Group Spacing of (12, 6, 18) Microseconds

Constraint No. 1 was already discussed in the previous paragraphs. All conditions are satisfied except for "off channel" interference when the 21 and 27 microsecond spacings are generated. These should have negligible effect on Y Mode equipment and hence the "off channel" restriction was removed.



X Mode	12	6	21
Y Mode	30	18	21

Pulse Combinations	X Mode Spacing (us)	Y Mode Spacing (us)
1-2	12	30
1-A	18	48
1-B	39	69
2-A	6	18
2-B	27	39
A-B	21	21

NOTE: All Time Values in microseconds

Figure 2-4 - All Combinations of Pulse Pair Spacings Resulting from Selected Code Structure

Since no two pulses are less than 5 microseconds apart, Constraint No. 2 is satisfied. Since the total data span is 12 + 6 + 21 = 39 microseconds, a System Dead Time of "D" microseconds (measured from first pulse to first pulse) could give pair spacings of D-39 microseconds between the last data pulse and first pulse of a pair following System Dead Time. For D $\geqslant$ 72 microseconds the system will be acceptable. Even for smaller values of D down to 43 microseconds, the only aircraft that would be affected would be those whose TACAN sets did not have a pulse pair decoder preceding the Reference Burst Detectors. Even in those cases the effects are negligible and hence the selected X Mode spacing definitely satisfies Constraints 1, 2 and 3.

Constraint No. 4 is best analyzed by referring to Figure 2-5. Here the timing of a TACAN/DME pair is drawn coincident with a corresponding pair of the X Mode North and Auxiliary Bursts. The diagram shows that no burst pulses fall within $\pm$ 1.5 microseconds of positions where data pulses may be anticipated. It can also be seen on this same figure that the data pulses will not tend to activate any of the TACAN Burst Detectors.

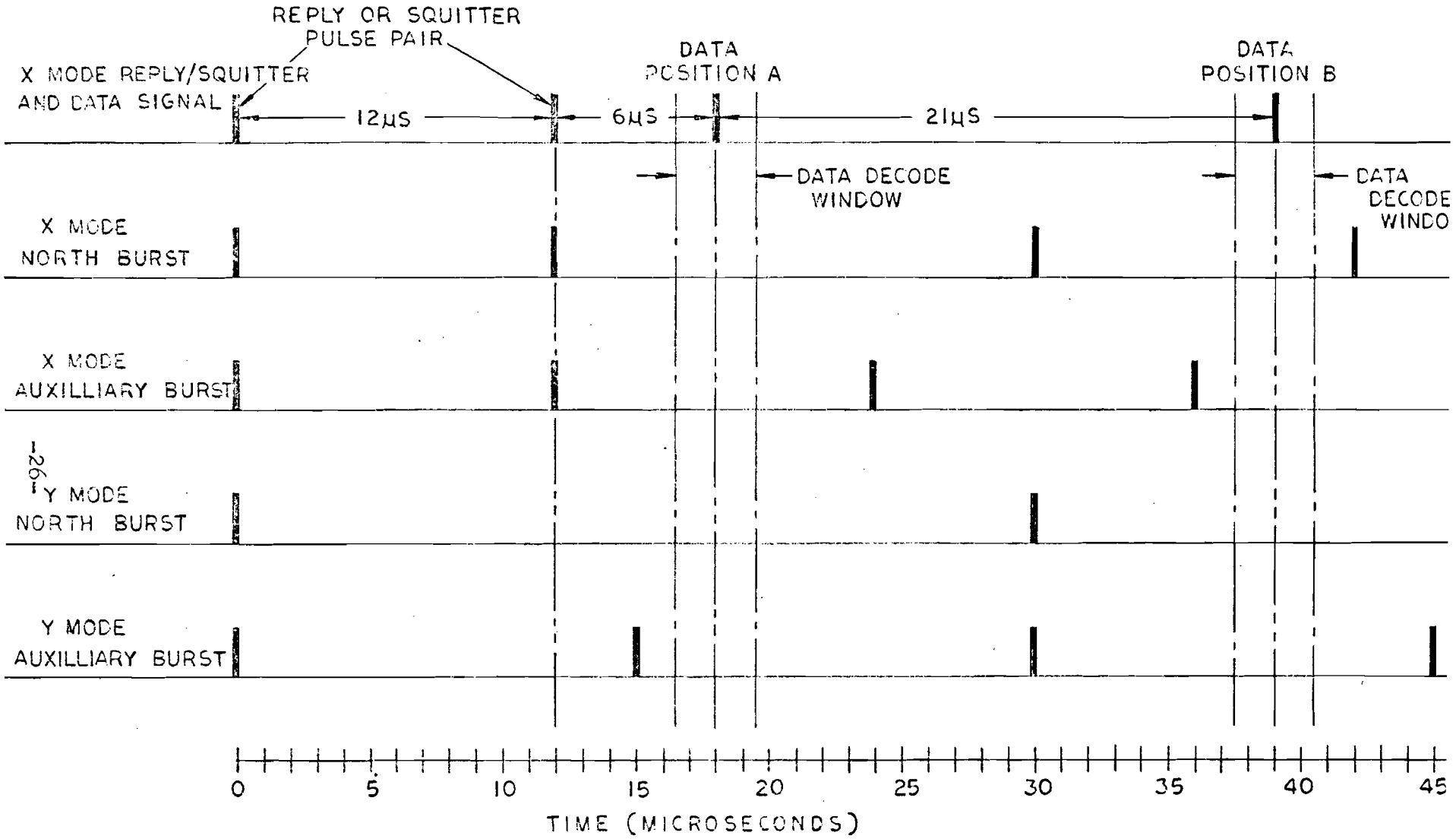


Figure 2-5 Relative Timing of Selected Data Signal to Reference Burst Signals (X - Mode)

Y Mode Analysis - Group Spacing of (30, 18, 21) Microseconds

As previously mentioned, in calculating the trial solutions for Y Mode it was necessary to remove one portion of the idealized "on channel" constraints. The choice was between generating a 27 microsecond spacing which might occasionally trigger a Y Mode Airborne TACAN/DME Pulse Pair Decoder (nominal spacing of 30 microseconds), or a 21 microsecond spacing which would likewise occasionally trigger an Airborne TACAN Y Mode Air-to-Air Pulse Pair Decoder. (nominal spacing of 24 microseconds). Both data spacings differ from their nominal interference spacings by 3 microseconds and hence would only cause a problem in certain equipment types having relatively wide decoding tolerances. It was decided that of the two, the Y Mode Air-to-Air would be less likely to be interfered with for two reasons. First, there will be relatively few Air-to-Air Y Mode sets in operation and second, many of those that are being used have decoding tolerances which are tighter than $\pm$ 3 microseconds. The severity of the problem created with either a 21 or 27 microsecond spacing becomes even less significant when we consider the fact that these spacings will only appear when word synchronization doublets are sent at the beginning and end of each word.

Based on the above rationale, Y Mode spacings of (30, 18, 21) microseconds were selected. These obviously satisfy Constraint No. 2 but do

present a very minor exception to Constraint No. 3. The total data interval occupied by these pulses is 30 + 18 + 21 = 69 microseconds. With a first pulse to first pulse System Dead Time of D microseconds, spurious pairs could be formed with a spacing of $\geq$ D-69. If we wish to completely preclude the possibility of transmitting any spurious pair with spacing of 30 $\pm$ 5 microseconds, the minimum value of D should be selected as 104 microseconds instead of the current nominal value of 96. It should be noted, however, that a data pulse will occur in position B with only a 50% probability. In order to generate a spurious pair we must have both a data pulse in position B and a random squitter or reply pair occuring immediately. following the end of System Dead Time.

The consequences of an Airborne TACAN or DME Interrogator decoding an occasional spurious pair are actually quite small, particularly if such pairs occur on a random basis. The worst effect would be the impact on the Airborne TACAN's North Burst Detector. Even here, a spurious pair formed by an extraneous pulse occurring 30 microseconds before the first pulse of a "true" pair will only present 3 pulses out of the normal 13 to the Detector's input. Therefore, it is recommended that the System Dead Time be kept at its present value of 96 microseconds so that the Range Reply efficiency will not be reduced. (A 104 microsecond System Dead Time would cause approximately a 2.2% reduction in the reply efficiency relative to the

value obtained with a 96 microsecond System Dead Time.)

One way in which the reply efficiency problem can be minimized without generating any spurious pairs, is to selectively switch the System Dead Time from 96 microseconds to 104 microseconds whenever a "binary 1" data pulse or a word synch character is to be added to a normal pulse pair. Assuming a 675 bit per second data rate, and an equal number of ones and zeroes, this will only occur about 12.5% of the time and hence would only reduce the reply efficiency by approximately 0.3% instead of the original 2.2%. This type of system will require a hardware modification in the Receiver to provide the Dead Time switching logic. This switching feature appears to be of marginal value at this time but will nevertheless be investigated in more detail during the design phase of the program.

The impact of the selected spacings on Constraint No. 4 is best analyzed by referring to Figure 2-6. It is readily seen that no Reference Burst pulses fall within 3 microseconds of the anticipated data pulse position. It also can be seen that data pulses have no tendency to activate any of the TACAN Burst Detectors.

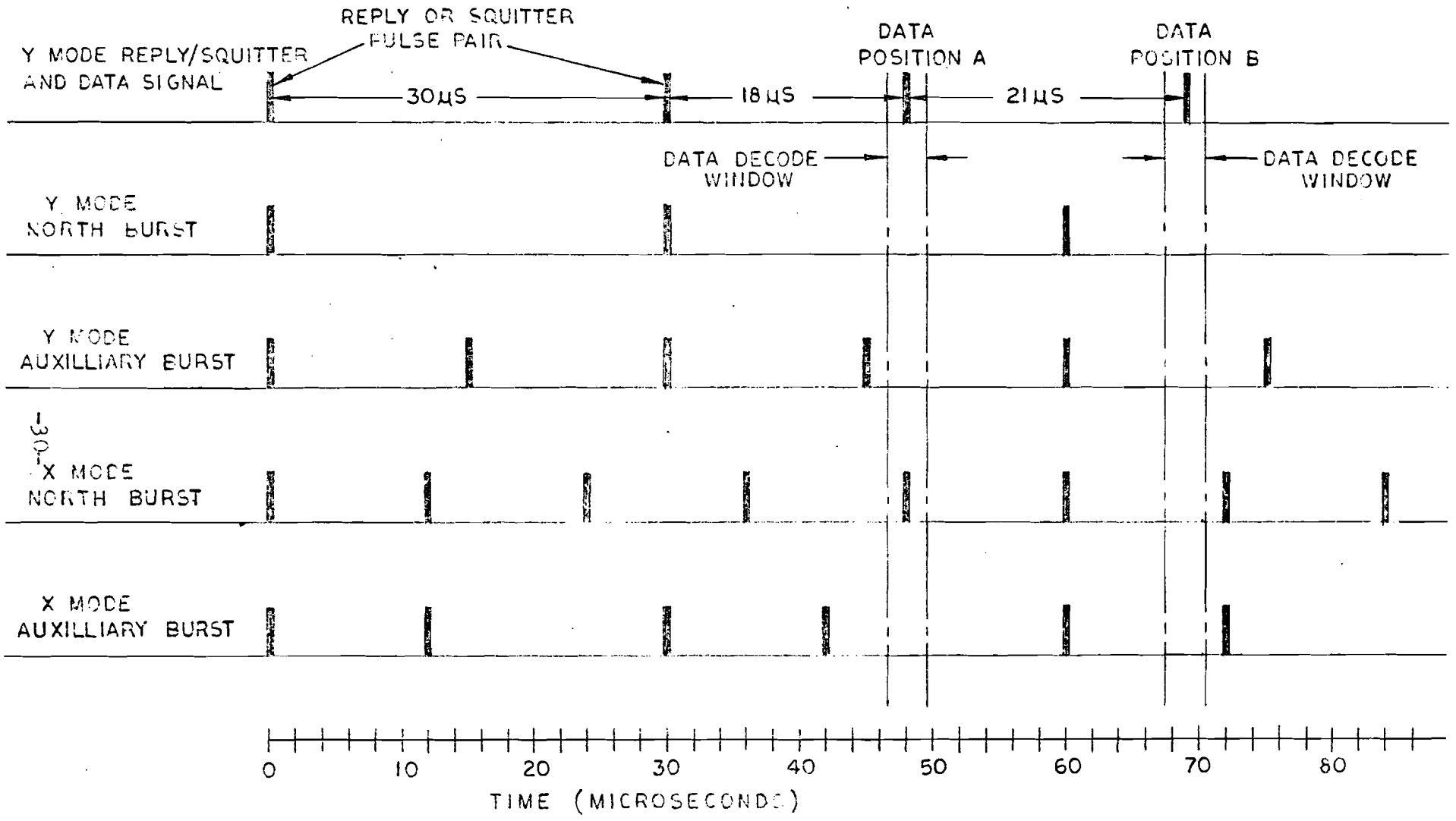


Figure 2-6 Relative Timing of Selected Data Signal to Reference Burst Signals (Y - Mode)

2.2.6.4 Restrictions on Squitter, Replies and Data Prior to Each Reference Burst

The operation of the Airborne Data Decoder portion of ADS will be discussed in detail in a subsequent Volume of the Design Plan. For the purposes of this discussion it will suffice to say that the Data Decoder will consist of a Pulse-Pair Decoder, (which decodes normal TACAN/DME reply and squitter pairs) followed by a Data Gate Generator whose output data gates examine the input video in each of the two anticipated positions (A and B) where data pulses might be present. Based on the logic table previously given in Figure 2-3, the data decoder will then conclude that either a "binary 0", "binary 1", "word synch", or "no data" was received.

If, during X Mode operation, a reply or squitter pair is transmitted with "no data", a "binary 0" or a "binary 1" data content, within a 40 microsecond interval preceding the first pulse of a Reference Burst, there exists a possibility that the first pulse of the Reference Burst could fall into one of the data decoding gates and be erroneously interpreted as a data pulse. If this happens, a "no data" transmission might erroneously be decoded as either a "binary 0" or "binary 1", and a "binary 0"or "binary 1" transmission could be decoded as a "word synch" indication. No significant system error will be created if a "no data" transmission gets decoded as a "binary 0"or "binary 1" since this will only cause a random isolated data bit to appear, with no natural word or data association, and it will be

logically dismissed from the data stream. However, if a data bit is being sent, it could represent, for example, the seventh bit of a word. (The eighth bit would then be sent after the completion of the Reference Burst pulses) If the seventh bit was erroneously decoded as a "word synch" then that entire word word would be rejected and the system would then have to rely completely on the two word redundancy feature to extract the desired information.

In order to avoid these problems in the X Mode, the simple "brute force" solution would be to inhibit all replies and squitter pairs (and their associated data pulses, if any) from being transmitted in the 45 microsecond interval preceding each Reference Burst. In the Y Mode, the inhibit interval would extend to approximately 75 microseconds. Such a solution would create an increased range reply "dead zone" of 135 x 45 = 6075 microseconds per second in X Mode and 135 x 75 = 10,125 microseconds per second in Y Mode. The corresponding reductions in reply efficiencies are 0.6% and 1.0% respectively.

These reply efficiency degradations can be reduced to approximately one-quarter of the stated values by allowing all pulse pairs containing "no data" to be sent during the restricted intervals and inhibiting only those which carry data bits or word synch information. With a 675 bit per second data rate (representing a one-quarter duty cycle for a 2700 pps Transponder) an average of only one-quarter of the pre-burst gates would be used and hence the X and Y Mode reply efficiencies will only be decreased by 0.15 and 0.25% respectively. Since the hardware required to implement this

more selective approach is not excessive, the latter approach will be used. The hardware description of how this will be achieved will be covered in the Data Generator Design Volume of the Design Plan.

2.2.6.5 Calculation of S/N Ratio vs. Range

This section provides the data necessary to determine the S/N ratio of a single TACAN pulse as received by a typical Airborne TACAN/DME Receiver from a worst case 5 kw Ground Transponder. Although the parameter values assumed below cannot be identical for every type of equipment in the field, they have been conservatively chosen so that they do depict a near worst case situation. The calculations are based on the familiar radar range equation which is given by:

$$S/N = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 R^2 K T_0 B \overline{NF} L_s}$$

The definition and values of each of the terms of the above equation are given in the table which follows. The values in the table are specified in decibels. A graph of S/N ratio vs. range is given in Figure 2-7.

			Decibel Tabulation	
			Numerator	Denominator
P_T	=	Peak Transponder Power (Watts) = 5000	37	
$*G_T$	=	Transponder Antenna Gain	-4	
G_R	=	Interrogator Antenna Gain	0	
λ	=	Wavelength in Miles $=1.67 \times 10^{-4}$ $\lambda^2 = 2.8 \times 10^{-8}$	-75.5	
$(4\pi)^2$	=	158		22
KTo	=	4×10^{-21} watt-sec		-204
B	=	Interrogator Receiver Noise Bandwidth = 4×10^5 Hz		56
NF	=	Interrogator Noise Figure		14
L_s	=	Cabling Losses		10
		Totals	-42.5	-102

$(S/N)_{DB} = 59.5 - 20 \text{ Log } [R]$; R Expressed In N. Miles

*Minimum Gain of the Transponder Antenna Pattern Is Used Here

EDYN
NATIONAL ... NG PA...
INDIANAPOLIS, INDIANA
NO 3470
...I-LOC... MIC- ...ES X ... THE

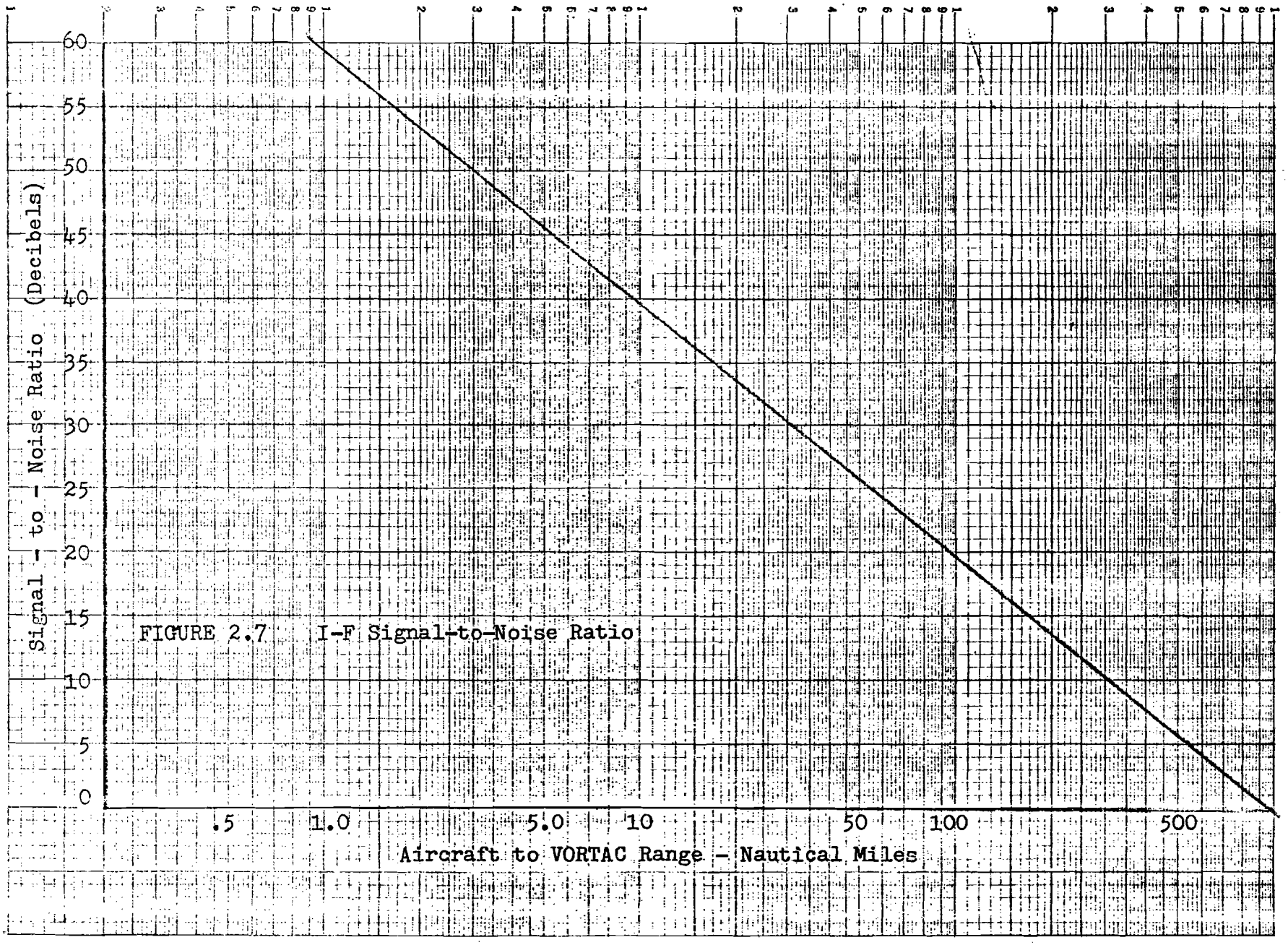


FIGURE 2.7 I-F Signal-to-Noise Ratio

From the derived equation and the curve of Figure 2-7, it is seen that at 130 n. miles (the maximum range of the DDBS in Enroute applications) the S/N ratio is 17.2 db. For the Terminal Area application (which is the only recommended operating area specified in Volume 1) the maximum range is only 40 n. miles, giving a minimum S/N ratio of 27.5 db. These numbers will be used as conservative estimates of S/N ratio in making any error predictions in the sections which follow.

2.2.6.6 Calculation of Bit Error Rate

This Section presents an analysis of errors caused by Receiver noise. This will give a first approximation to the ADS performance capabilities. The effects of interference pulses and multipath will not be considered here because there is no practical mathematical model to simulate their effects in any given field situation. The errors caused by these phenomena can best be analyzed through extensive flight test programs.

The noise analysis consists of dividing the time axis into 3 microsecond slots and assuming that each slot contains either a noise pulse or a signal-plus-noise pulse. A typical video representation of a "binary 1" data bit is shown in Figure 2-8.

In order to correctly decode the data bit shown, four independent conditions must be satisfied. This consists of detecting pulses in each of the positions 1, 2 and B, and detecting no pulse in position A. Any other combination of events will cause a system error. It will be shown later that once a word structure is established, we can discriminate between what we call detectable and undetectable errors. However, for the purpose of the analysis all errors will be pessimistically lumped into the same category.

If P_s represents the probability of signal-plus-noise crossing a decoding threshold and P_n is the probability of "noise only" crossing the threshold

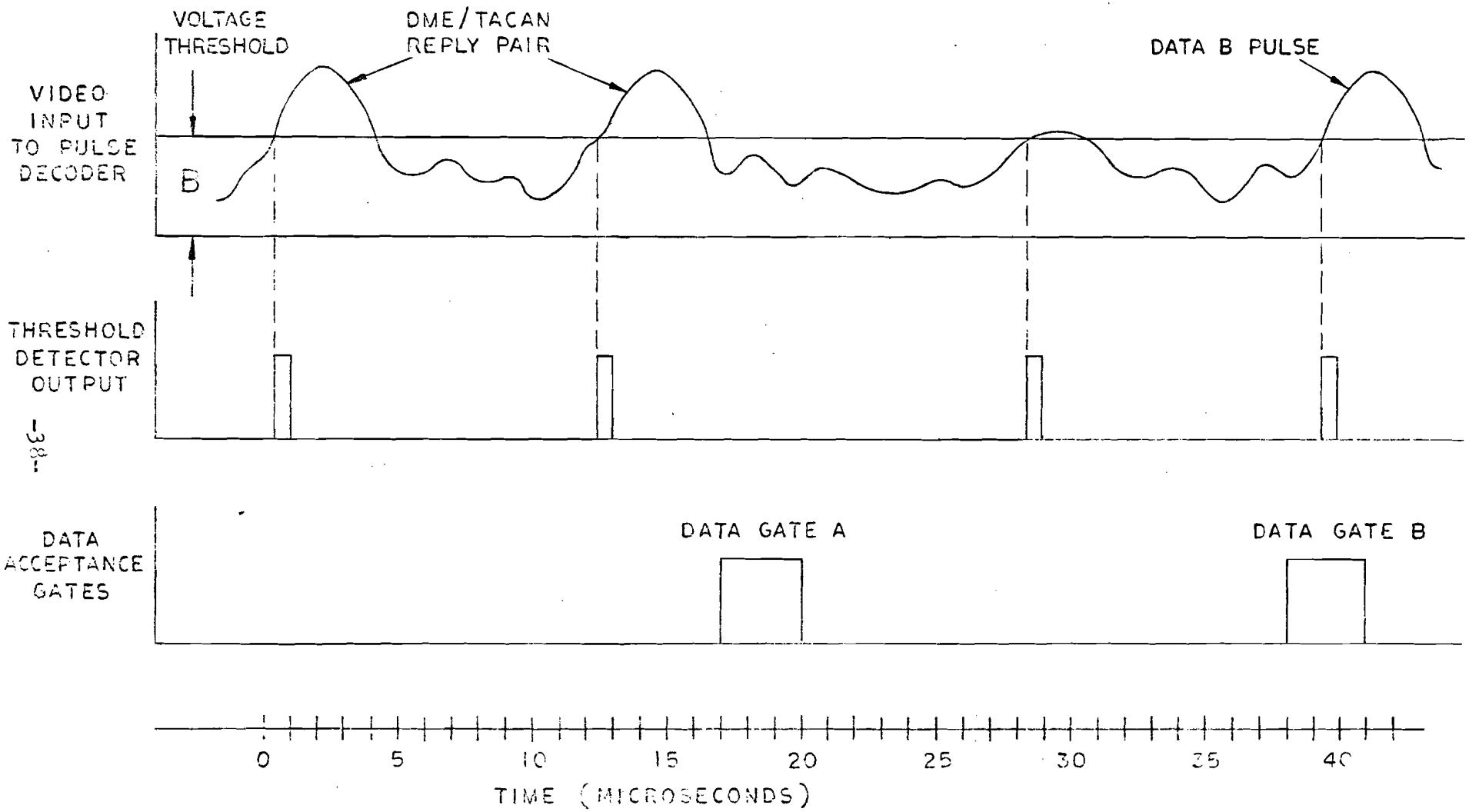


Figure 2-8 Typical Video Waveform and Threshold Detector Output for a "Binary 1" Data Bit

then the corresponding probability P_d of correctly decoding the data bit is given by:

$$P_d = P_s P_s (1 - P_n) P_s = P_s^3 (1 - P_n)$$

The corresponding error probability P_e, is then given by:

$$P_e = 1 - P_d = 1 - [P_s^3 (1 - P_n)]$$

In order to determine the values of P_s and P_n for a given S/N ratio and threshold setting B, we must refer to the probability density functions of noise and signal-plus-noise which are given by:*

p.d.f. of noise only = g(x) = $\left\{ \begin{array}{ll} \frac{x}{\sigma^2} e^{-x^2/2\sigma^2} & ; x \geq 0 \\ 0 & ; x < 0 \end{array} \right\}$ (Rayleigh density function)

p.d.f. of signal plus noise = h(x) = $\left\{ \begin{array}{ll} \frac{x}{\sigma^2} e^{-V^2 - x^2/2\sigma^2} I_0\left(\frac{\sqrt{2}\,xV}{\sigma}\right) & ; x \geq 0 \\ 0 & ; x < 0 \end{array} \right\}$ (Ricean density function)

Where:

σ^2 = mean square noise at the detector input

V = S/N ratio at the detector input

I_0 = modified Bessel Function of the first kind and order zero.

*S.O. Rice, "Mathematical Analysis of Random Noise", Bell Telephone Journal, Vol. 23, 1944.

A representative sketch of the two density functions is given in Figure 2-9. The density functions are shown assuming a fixed gain Receiver, which is adequate for the analysis which follows. At the end of this Section, a discussion will be presented on how the density functions vary as a function of signal strength when the Receiver is gain controlled.

The shaded areas shown depict the values of P_n, and $Q_s = 1 - P_s$, for a representative value of the threshold B. If noise and signal-plus-noise pulses occur with equal probability, then moving the threshold B to the point P where the curves g(x) and h(x) intersect represents the condition of minimum error. This can be proven by moving B slightly in either direction away from P. Then the increase in error probability from one curve is greater than the decrease from the other. Setting B to coincide with P therefore is optimum from the standpoint of minimizing $P_n + Q_s$. This does not imply, however, that the quantities P_n and Q_s are necessarily equal. If the two density functions are of different shape the shaded areas which correspond to optimum B are in general unequal. However, for the large S/N ratios of interest, setting B to the intersection of g(x) and h(x) is so close to setting B to the point where the shaded areas are equal that the error resulting from such a procedure is negligible. Hence, if a value P_n is desired, then the setting of B is given by:

$$\int_{B}^{\infty} \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}} dx = P_n$$

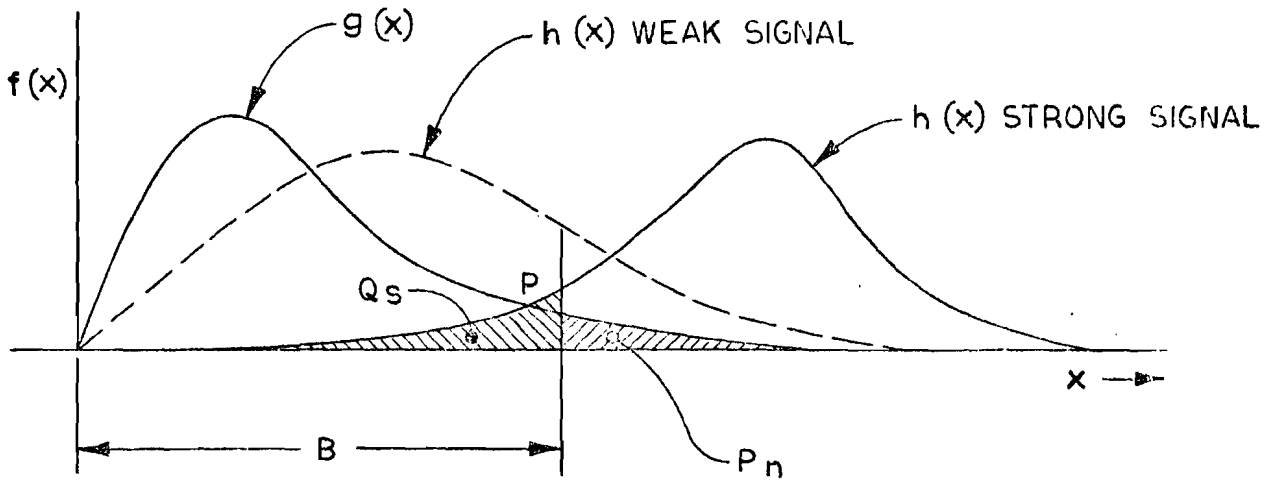


Figure 2-9 Typical p.d.f. For Envelopes of Noise, and Signal-Plus-Noise For Some Fixed σ (Fixed Gain Receiver)

giving:

$$P_n = e^{-B^2/2\sigma^2}$$

A plot of P_n vs. B/σ is shown in Figure 2-10.

After a series of trial solutions it was found that a worst case 17.2 db S/N ratio, which was calculated for a 130 n. mile range, could support a "raw" bit error rate of 2×10^{-6}. (This includes all types of errors including those which will be detected by parity checks, word redundancy, etc. The actual overall system error rate will be considerably smaller.) This is shown as follows:

If it is assumed that the threshold B is set so that $Q_s = P_n = \lambda$ (equal probability of making an error when either signal or noise is present) the error probability can be expressed as:

$$P_e = 1 - P_d = 1 - P_s^3 (1 - P_n)$$

$$= 1 - (1 - Q_s)^3 (1 - P_n)$$

$$= 1 - (1 - \lambda)^4$$

For small values of λ the above can be expanded in a Maclaurin series to give

$$P_e = 1 - P_d \approx 1 - [1 - 4\lambda] = 4\lambda$$

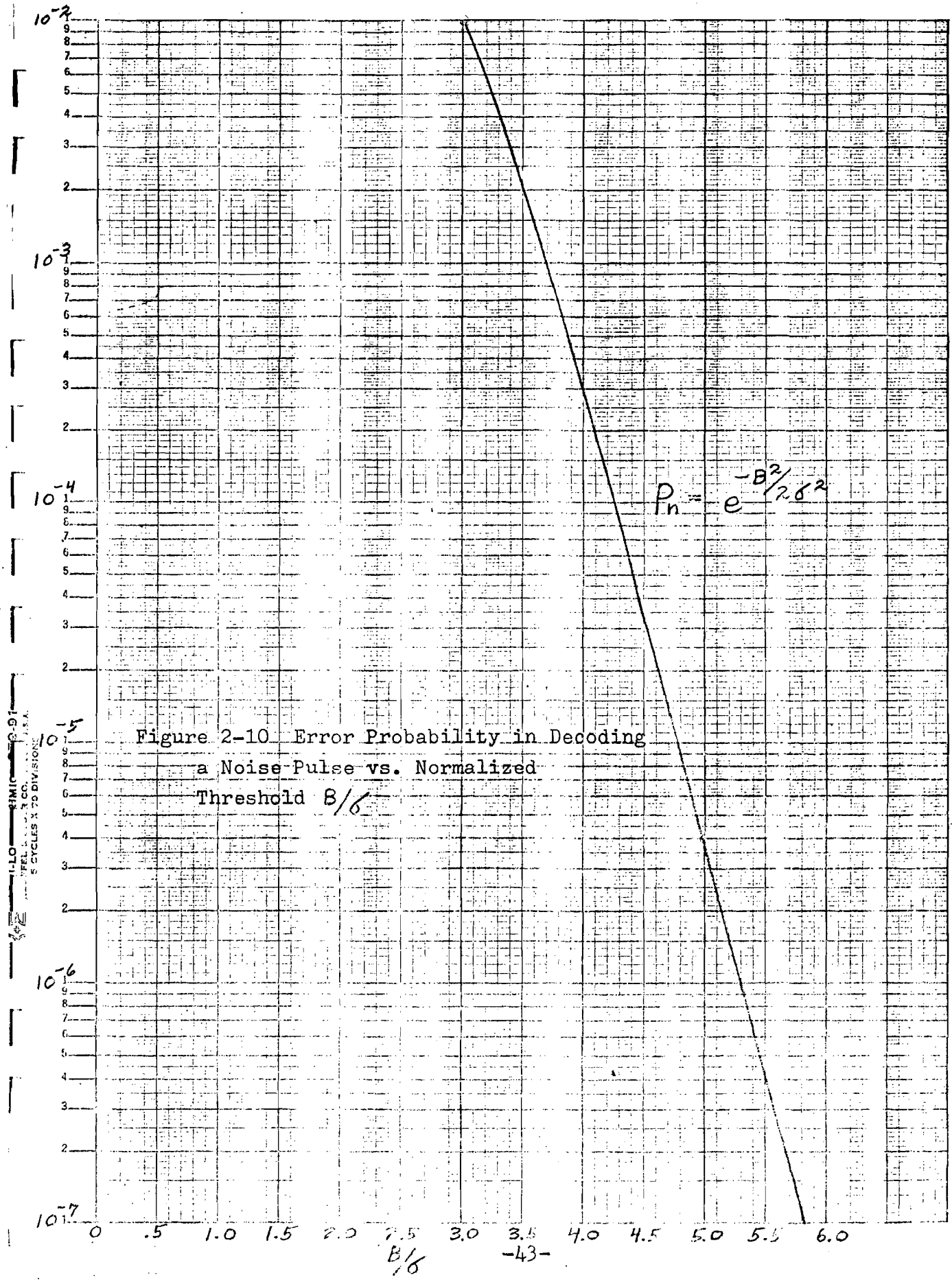


Figure 2-10 Error Probability in Decoding a Noise Pulse vs. Normalized Threshold B/σ

For $P_e = 2 \times 10^{-6}$, the corresponding single pulse error probability λ is thus given by:

$$\lambda = \frac{P_e}{4} = 5 \times 10^{-7} = Q_s = P_n$$

From Figure 2-10, the threshold value B which corresponds to $P_n = 5 \times 10^{-7}$ is given by $B = 5.4\sigma$. In order to find the corresponding S/N ratio required to achieve a comparable error probability of "missing" a signal-plus-noise pulse, we use the Normal approximation to the Ricean density function (an accurate approximation at high S/N ratios) given by:

$$h(x) \approx h_a(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{X-A}{\sigma}\right]^2}$$

where A is the average value of the signal

This density function is sketched in Figure 2-11.

Using tables of Normal Probability Functions, it can be shown that with B set at 5.4σ, the value of Z which gives a shaded area of 5×10^{-7} is given as 4.82σ. Therefore the corresponding value of A required is $5.4\sigma + 4.82\sigma = 10.22\sigma$. The S/N ratio in db is thus given by:

$$(S/N)_{db} = 10 \text{ Log } \left[\frac{A^2}{2\sigma^2}\right] = 10 \text{ Log } \left[\frac{10.22^2}{2}\right] = 17.2 \text{ db}$$

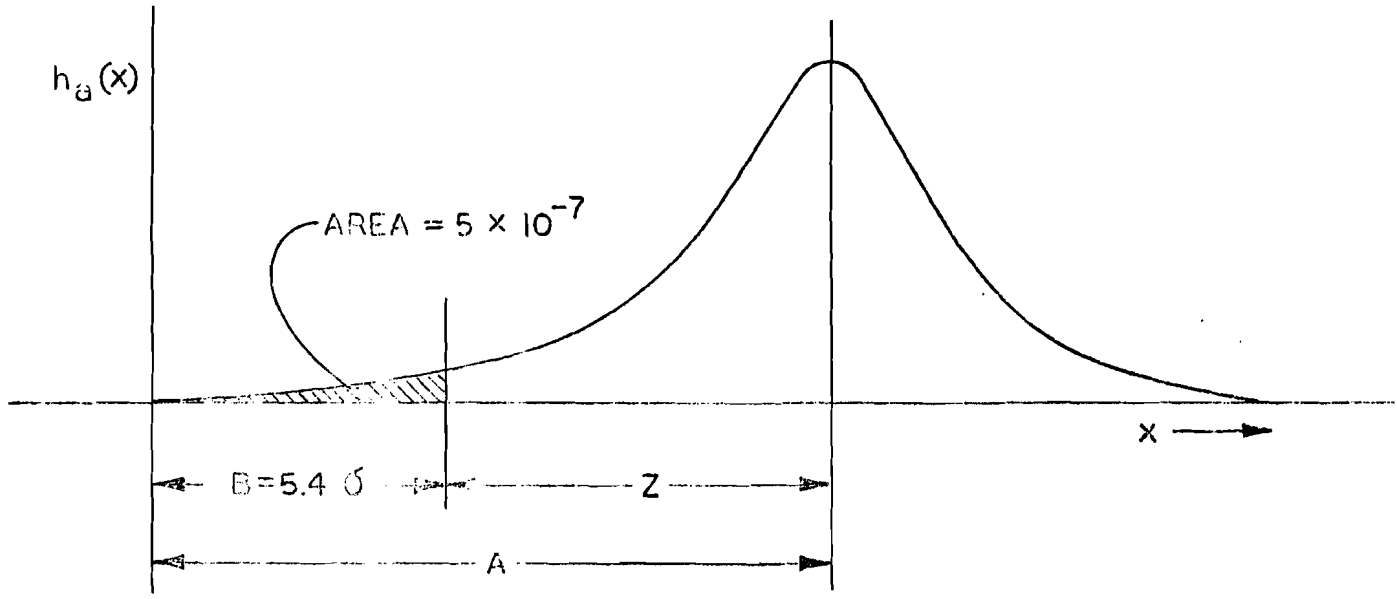


Figure 2-11 Sketch of Normal Approximation to Ricean Density Function

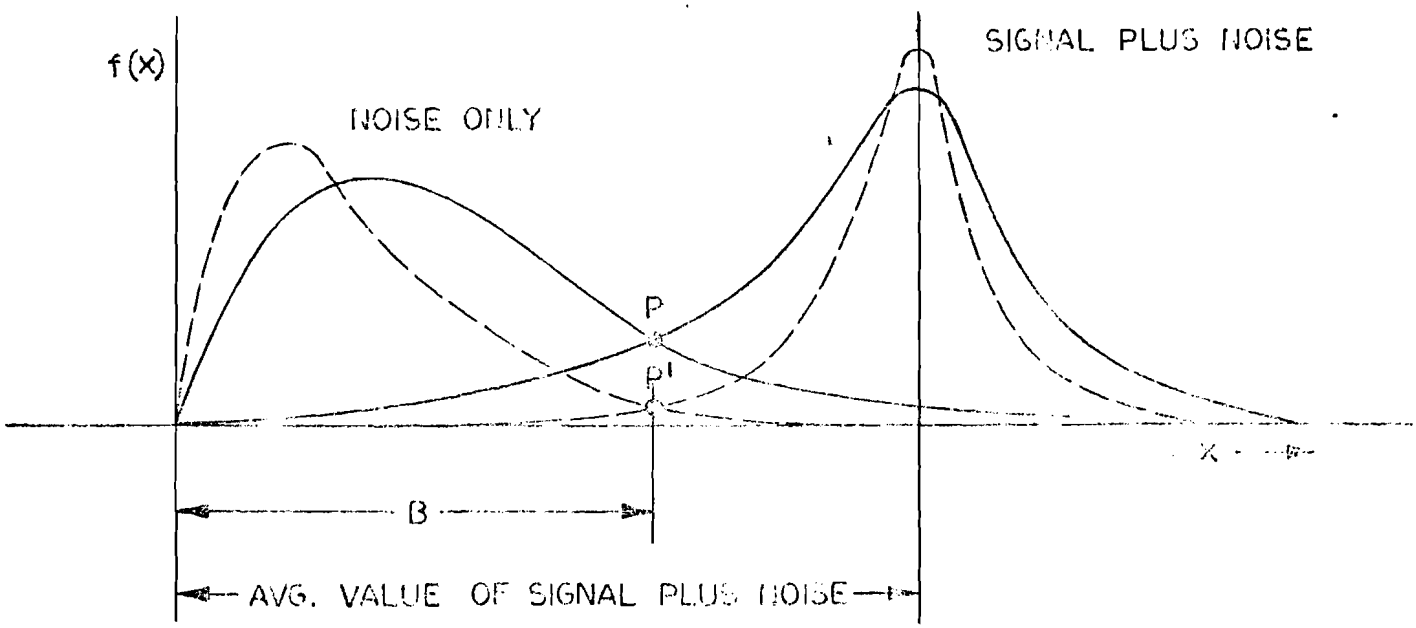


Figure 2-12 P.d.f. of Noise and Signal Plus-Noise In A Gain Controlled Receiver

It was previously shown that from the standpoint of optimizing the bit error probability, the optimum setting of B occurs where the two density functions of Figure 2-9 intersect. In general, the intersection point will differ for different noise levels and S/N ratios. If a system has AGC, the average value of the signal-plus-noise will be held constant whereas the variance of both the noise and signal plus noise will vary with changing S/N ratios. A typical representation of the probability density function would appear as shown below in Figure 2-12 where the S/N ratio is greater for the dotted curves.

One interesting observation that can be made from Figure 2-12 is that the threshold B can be optimized for the worst case S/N expected and <u>can be kept constant</u>. As signal strengths increase, the error probabilities will decrease and since the tails of both density functions fall in the region near B, the threshold setting remains near optimum for a wide-range of signal strengths.

It must be remembered that the actual corrected system error probability will be considerably lower than the 2×10^{-6} number which was derived above because many of the errors will be detected by parity checks, word redundancy (sending each word twice) and checking the word structure (number of bits, position of word synch characters, etc.) for each word of data transmitted. Even more significant is the fact that the calculated 17.2 db S/N ratio corresponds to worst case

conditions and a 130 n. mile range. Since the DDBS is only recommended for use in the Terminal Area, each airborne system user can begin to pick up reliable Terminal Area data from as far out as 130 n. miles (line of sight permitting) and the data will become progressively better as the distance to the Terminal Area diminishes.

2.2.6.7 System Operation During Identity Tone Transmission

During the periods when identity tone is being transmitted, the X Mode operation of the ADS System will basically be the same as previously described. Data pulses will be added to each identity tone pair and each equalizing pair in the same manner that data pulses are added to any normal reply or squitter pair. The previous requirement for generating a pre-burst blanking gate is not necessary for identity tone transmissions because no tone or equalizing pulses ever occur closer than approximately 600 microseconds before the beginning of any Reference Burst.

During Y Mode operation there is one refinement which is necessary to preclude the generation of a string of spurious pairs in the midst of the identity tone and equalizing pairs.

It was previously shown in Figures 2-3 and 2-4 that the selected Y Mode DDB spacings are (30, 18, 21) microseconds, and thus the total spacing from the first pulse of the pair to the last data pulse position B is 69 microseconds. Equalizing pairs nominally occur 100 microseconds after each identity tone pair. Hence, if no refinement were made to the ADS System previously described, any data pulse in position B which is added to an identity tone pair will form a spurious 31 microsecond pair with the first equalizing pulse. In order to prevent this from happening during the Y Mode operation, only "binary zero" data will be added to any identity tone pair. Whenever a "binary one" or a "word synch" character is scheduled to be transmitted, it will be added to the next equalizing pair. This poses no operational

problem because the Airborne Data Decoder will simply interpret each identity tone pair without data pulses added as "no data", and precede to decode the next bit from the equalizing pair which follows. The only effect of sending no "binary one" or "word synch" data with an identity tone pair is to reduce the data transmission capacity during Y Mode broadcast of identity tone.

If it were not for this restriction, every pulse-pair could carry a data bit and the maximum data rate would remain at 2700 bits per second, with one-half of the data bits added to the identity tone pairs and one-half added to the equalizing pulse-pairs. Assuming a long-term equal distribution of "ones" and "zeroes", one-half of the identity pairs would be followed by a "one". But, if we prevent "binary ones" from being added to the identity pairs, we will reduce the data capacity of the identity pairs by one-half, and reduce the capacity of the complete system by one-fourth (the data capacity of the equalizing pulse-pairs is unaffected). Consequently, the capacity of the system during identity tone transmission will be 2700 x .75 = 2025 bits per second.

In the worst case, identity tone and equalizing pairs are only transmitted for 4.5 seconds out of every 30 seconds of real time. This gives a duty cycle of 15%. Therefore, the overall reduction in data rate capacity which results from the stated

technique (inhibiting selected data from being broadcast on identity tone pairs) is only 15% of 25% or less than 3.8%.

However, as will be shown in Section 2.5, the data rate requirement of the system is less than 400 bits per second. Therefore, this small data capacity reduction will have no effect upon the operational capabilities of the system.

2.3 Comparison of Concentrated Synch QPPM and ADS

The foregoing discussions have described the general operating principles and some of the performance characteristics of a number of techniques for broadcasting digital data. Of all the cases considered, the concentrated synch QPPM (see Reference 1 for details) and the newly devised ADS technique have significant advantages over the others. This section will provide a comparison between these two approaches in order to determine which should be incorporated into the Digital Data Broadcast System.

The main factors which should be considered in evaluating any proposed system for adding data to the existing TACAN/DME carrier are listed below:

1. Effect on Transponder Reply Efficiency
2. Effect on Bearing Measurement
3. Interference with Existing TACAN/DME Functions Produced
4. Transmitter Energy Required Per Bit of Data
5. Growth Potential
6. Susceptibility to Multipath
7. Susceptibility to Interference Pulses
8. Error Rate
9. Hardware Requirements

Each of these topics will be considered separately for each of the two systems being considered.

2.3.1 Effect on Transponder Reply Efficiency

The reduction in Range reply efficiency caused by the addition of data pulses to the normal TACAN/DME signal is a key parameter to be considered in selecting a transmission technique for the DDBS. Assuming a nominal transmission rate of 840 bits per second, the Concentrated Synch QPPM system requires the transmission of 8 pulse triplets which cover a span of approximately 50 microseconds each. If an additional 25 microseconds is reserved for a blanking interval prior to and following each triplet (to prevent the formation of spurious TACAN/DME pairs), then each triplet will create an effective system dead zone of 100 microseconds. Since the proposed QPPM transmission format consists of 8 triplets per North Burst or 120 triplets per second, the total dead zone created is 12,000 microseconds per second. This corresponds to a 1.2% reduction in reply efficiency.

As explained in the previous section, the ADS system gives a reduction in reply efficiency of approximately 0.5% in X Mode and 0.25% in Y Mode for a 675 bit per second data rate. Extrapolating these calculations to 840 bits per second would give efficiency reductions of 0.19% in X Mode and 0.31% in Y Mode. Hence, from the standpoint of reply efficiency, the ADS system is clearly superior.

Another way of comparing the two systems is to consider the fact that in either X or Y Mode, the ADS system can transmit up to 2700 bits per second with less degradation in Reply Efficiency than the Concentrated Synch QPPM gives at 840 bits per second.

Another subtle disadvantage of the Concentrated Synch QPPM system is that all data triplets create clusters of dead zones during the 7.4 ms interval following each North Burst and these clusters therefore repeat themselves at a 15 Hz rate. Hence, if an Airborne Interrogator should happen to be interrogating at a nominal 30 Hz rate, there could be extended periods when every other interrogation could arrive at the Transponder during this 7.4 ms interval and hence be subjected to a more severe reduction in reply efficiency than would occur on a purely random basis.

2.3.2 Effect on Bearing Measurements

Any bearing errors introduced by the addition of a DDBS would be of primary concern to military users of TACAN and hence must be an important consideration in choosing the final configuration. The QPPM approach will, in effect, distort the envelope of the bearing modulation because it generates eight 100 microsecond dead zones in the interval following each North Burst. This distortion of the random pulse distribution will cause some small cyclic bearing error whose magnitude will depend on the bearing of the aircraft.

Although the exact magnitude of the error has not been determined, it undoubtedly will not be welcomed by military users.

In the ADS system there will likewise be a small distortion of the bearing modulation envelope because of the pre-burst blanking gate requirement discussed in a previous section. In the X Mode, a 45 microsecond blanking interval will be generated prior to each burst only when data pulses are "scheduled" to be added to the next TACAN/DME pulse pair. If we assume again an 840 bit per second data rate, then the 45 microsecond blanking gate will only occur about one-third of the time, on a random basis. On the average this will cause approximately 45 blanking gates (one-third of 135) of 45 microseconds each. The total blanking per second is therefore approximately 2000 microseconds and occurs on a random basis, whereas the QPPM blanking time per second is 800 x 15 = 12,000 microseconds and always occurs in the intervals between the North Burst and next Auxiliary Burst. Based on the above information, it appears that although each system will introduce some error in Bearing Measurement, the ADS error will be significantly less.

2.3.3 Interference with Existing TACAN/DME Functions

From the standpoint of the Airborne TACAN or DME user, both the Concentrated Synch QPPM and ADS systems introduce undesired pulses into the transmitted signal. However, the pulse positions and spacings have been selected to provide minimal interference with existing equipments. The selection of synch triplet spacings of 18 and 32 microseconds and data triplet spacings of 21 and 27 microseconds for the QPPM system described in Reference 1 do not appear to be the best possible spacings that could be selected. However, if the spacings were re-calculated using the constraints listed in this Design Plan the amount of interference produced by the QPPM could be less than the ADS system because fewer extra pulses would actually be transmitted. (Such an optimization of pulse spacings would probably require different codings for X and Y Modes).

The undesired features of extra pulses are related to the same undesired features of single random jamming pulses. Any extra pulse can potentially pair up with a noise pulse or a valid TACAN/DME pulse and thereby produce a spurious pair which will be decoded by a TACAN or DME interrogator.

Using the same 840 bit per second comparison basis, the Concentrated Synch QPPM system requires only 360 single pulses to be added to the nominal TACAN/DME pulse train. The ADS system requires approximately 840 pulses (plus a small number of extras for word synchronization).

Therefore, from a pulse interference standpoint the QPPM approach is superior. In either case, however, the number of times per second a data pulse will pair up with a noise pulse to form a decodeable pair will be very small and because the TACAN/DME system by its nature can tolerate a relatively large amount of interference, the probability of any measurable effect is very small.

2.3.4 Transmitter Energy Required Per Bit of Data

The calculations presented in the preceding paragraph show that the energy efficiency of the Concentrated Synch QPPM system is superior to the ADS system. The Concentrated Synch QPPM system transmits 840 bits of data with only 360 pulses, giving an efficiency of 2.33 bits per pulse. The ADS system gives slightly less than one bit per pulse. In either case, adding either 360 pulses (QPPM) or 840 pulses (ADS) to a TACAN/DME Transponder only increases the total energy requirement by a small amount. Without DDB, each Transponder transmits a total of 3600 pulse pairs per second (squitter plus replies plus reference bursts) or 7200 pulses per second. Therefore the QPPM approach would require 5% more average power and ADS would require approximately 12% more.

2.3.5 Growth Potential

The growth potential of each system refers to its ability to expand from a nominal data rate of 600 - 900 bits per second to higher rates which may be required at a future date. The Concentrated Synch QPPM system can expand its data capacity by adding data and synch triplets in any or all of the intervals between Auxiliary Bursts. This expanded capability can be accomplished efficiently from the standpoint of transmitter energy but will cause additional degradation in Reply efficiency and Bearing measurement. If the transmitter power constraints are ignored, this system could potentially deliver 9 x 840 = 7560 bits per second but only at the expense of a 9 x 1.2 = 10.8% reduction in Transponder Range reply efficiency and an increased Bearing error.

If this system were required to transmit 2700 bits per second (which is the maximum nominal capcity of ADS) the Range reply efficiency would be degraded (by direct proportion) to approximately 3.9% relative to the reply efficiency with no DDB or 2.7% relative to the reply efficiency with 840 bits per second.

The maximum data capacity of ADS is fixed at 2700 bits per second. (It is actually slightly less because word synch pulses must be used with some of the pulse pairs. This will be discussed in a later section.) This increase is accomplished at the expense of 2.3 times as much extra transmitter

energy as would be required by the Concentrated Synch QPPM approach. The ADS X Mode Range reply efficiency at 2700 bits per second is approximately 0.4% less than its efficiency at 840 bits per second and the corresponding decrease for Y Mode is only 0.7%. These reductions are clearly superior to the 2.7% values calculated for the Concentrated Synch QPPM System.

In assessing the growth potential of each system based on the above information, it has been concluded that the ADS system is superior because growth can be achieved without degrading system performance to any significant extent. Such growth however, can only be achieved within the constraints of having a transmitter which can reliably deliver the extra power. This constraint is imposed by the performance characteristics of a set of components rather than a system operating parameter such as reply efficiency. It would appear that requiring more transmitter power is a preferred growth constraint to requiring the acceptance of a poorer reply efficiency. The latter requirement cannot be solved technologically whereas the former can.

2.3.6 Susceptibility to Multipath

It is generally acknowledged that because of the AGC present in Airborne equipment, the effects of multipath in Ground-to-Air transmissions is less of a problem than in the Air-to-Ground case. However, multipath echoes still do occur and have

caused problems in airborne equipments. One particular problem that has been observed is the effect of the multipath from the first pulse of a pair contaminating the shape of the second pulse to the extent of producing range errors. As a result of this, developers of the more recent Airborne TACAN equipments have designed circuits which perform range measurements on the first pulse of a reply pair.

However, in decoding data pulses by either of the techniques being considered, errors will not occur unless the magnitude and phase of the multipath is sufficient to either cause a data pulse to be completely cancelled by an echo from a preceding pulse or cause an apparent extra pulse to appear in an anticipated data pulse position. Unlike the distance measuring function, distortion of the pulse shape or rise time will not cause a data error.

Because it would be impossible to postulate a practical mathematical model for multipath, it is very difficult to predict which of the two systems being considered would be superior. Even flight testing of both would not produce conclusive results unless all possible combinations of multipath conditions that can be encountered were examined. Qualitative examination of these two systems indicates that neither systems has any specific advantage over the other, and that neither system is particularly susceptible to multipath interference.

2.3.7 Susceptibility to Random Interference Pulses

The effects of random interference pulses can be analyzed in the same manner as random noise pulses. Their effects on DDB can only be assessed in terms of the probability that they will "pair up" with each other or existing pulses in the TACAN/DME/DDB data stream to cause a spurious combination.

In the case of the Concentrated Synch QPPM system, both the synch triplets and data triplets have unique pulse spacings which differ from each other and from existing TACAN/DME spacings. Thus the only way that interference pulses can cause a spurious triplet is by having two such pulses spaced properly with respect to each other and with an existing TACAN/DME or DDB pulse. The occurrence of two such interference pulses is quite unlikely. The occurrence of three in the proper position to form a synch data triplet is even less likely. Therefore the noise and interference immunity provided by the concentrated synch QPPM system is excellent.

The ADS system is more likely to have its Airborne Data Decoder respond to a spurious condition caused by interference pulses. This will happen if a single interference pulse follows any one of the 2700 TACAN/DME pulses in either of two possible time positions. Either of two error types will occur in these cases. Either a "no data" transmission will be decoded as a "binary 0" or "binary 1", or a binary "0" or "binary 1" data bit

will be decoded as a "word synch" character. In either event, the error is detectable (as explained in Section 2.2.6.4) in the sense that word will not be erroneously be presented to the R-NAV computer. However, if the number of interference pulses increase, the chances that a complete word will be unaffected diminishes accordingly.

The above discussion indicates that the Concentrated Synch QPPM System is more immune to random interference pulses than is ADS.

2.3.8 Error Rate

The bit error probability analysis for the ADS system was presented in Section 2.2.6.6 of this Design Plan. This error probability is the "raw" error rate and does not take in account any error detecting and/or error correcting features which might exist in the airborne data decoder. As will be shown in the description of the data format, Section 2.4, an in the description of the airborne equipment, Volume 3 of this Design Plan, the ADS system has several characteristics which make possible the use of simple error detecting and correction circuits. These techniques will effect a substantial improvement in the system error rate of the ADS.

In addition, the ADS system concentrates more energy into the data stream than does the concentrated Synch QPPM System. In accordance with fundamental information theory, the higher energy content of the ADS system will result in an overall lower error rate, assuming that both signal sets are processed in an optimum manner (or that both deviate from optimum by the same degree).

Although a quantitative comparison of expected error rates of each of these two data systems under all conditions of signal strength, data rate, DME traffic, etc. has not been made, the above considerations indicate that the overall error rate of the ADS system under practical operational con-

ditions will be acceptably small and substantially superior to the error rate of the Concentrated Synch QPPM System.

2.3.9 Hardware Requirements

A cursory investigation of the hardware requirements for implementing the Concentrated Synch QPPM and the ADS concepts indicates that they are of comparable complexity.

One advantage of the ADS concept stems from its complete independence on any accurate system clock. All data transmitted is received in an asynchronous manner and timing can be in error by as much as $\pm$ 1/2% without having any significant impact on system performance.

2.3.10 Comparison Summary and Recommended System Approach

The previous discussions provide a good basis for comparing the performance of the Concentrated Synch QPPM and ADS concepts. The listing below summarizes the relative status of each system with regards to each of the characteristics considered. For comparison purposes, each system is considered to be operating at a data rate of 840 bits per second.

	System Characteristics	Concentrated Synch QPPM	ADS
1.	Effect on Transponder Reply Efficiency	Moderate	Very small
2.	Effect on Bearing Measurement	Moderate	Very small
3.	Interference with Existing TACAN/DME Functions	Very small	small
4.	Transmitter Energy Required Per Bit of Data	Small	Moderate
5.	Growth Potential	Moderate	Large
6.	Susceptibility to Multipath	Small	Small
7.	Susceptibility to Interference Pulses	Very small	Small
8.	Error Rate	Small and Acceptable	Smaller and Acceptable
9.	Hardware Requirements	Moderate	Moderate

The above chart reveals that each system has areas of superiority over the other. While either system would be acceptable, a careful examination will show that in the highly important areas of reply efficiency, bearing measurement, growth, potential, and error rate the ADS system enjoys superiority. EDMAC Associates Inc. has recommended the ADS system for the Digital Data Broadcast function. The following section will describe the word formatting concept to be used with the ADS.

2.4 Data Formatting

2.4.1 Development of Word Structure

The purpose of this portion of the Design Plan effort was to devise an efficient word structure for the data to be broadcast. Particular emphasis was given to developing a format which would make the Airborne synchronization and processing functions as simple as possible. Within the constraints of good data transmission efficiency (minimizing the number of pads) and compatability with the selected ADS modulation technique.

The first step of the formatting development was to choose a word length. This choice was primarily determined by examining the Station and Terminal Area Waypoint data sequences presented in Volume 1 and grouping the data in a logical manner so that functional data elements were kept together and word lengths were kept as uniform as possible.

One subtle constraint which must be remembered in the analysis which follows at that word lengths should be kept in a general range of approximately 20 to 35 bits because of two factors. First, the longer the word, the higher the probability that an Airborne Interrogator will transmit during the word interval and hence the higher the probability that the Interrogator Receiver Blanking Gate will interfere with the reception of the entire word. This aspect will be analyzed in the next Section. Second, the shorter the word length the greater the percentage of word synchronization pulses which will be transmitted.

Although this provides excellent synchronization properties and immunity to having words disturbed by Interrogator Blanking Gates the data transmission will be correspondingly less efficient.

The generation of word groupings is best illustrated by referring to the original data lists which were presented in Volume 1 of the Design Plan. For convenience, pages 20 and 21 of Volume 1 have been reprinted here with penciled brackets and handwritten numbers added to indicate how the groupings were performed. These are labelled as Reprints 2-1 and 2-2, which correspond to the Station data and TMA Waypoint data respectively.

It can be seen from these reprints that the Station data words are efficiently grouped in blocks ranging from 17 to 22 data bits (provided that the Station Identification and Coverage Class are combined as are Elevation and Magnetic Variation) From Reprint 2-2 it is seen that Waypoint designators and Waypoint data are efficiently grouped in blocks ranging from 13 to 17 bits.

Reprint 2-1 Modified Copy of Volume 1, page 21

Station Data*	Range	Resolution	Type of Coding	Total Bits	
Station Identification	AAA-ZZZ	N/A	Alpha	15	17.
Coverage Class†	0-2	Integers	Binary	2	
Latitude	-90° to $+90^{\circ}$	0.1 min.	BCD + Sign	21	21
Longitude	-180° to $+180^{\circ}$	0.1 min.	BDC + Sign	22	22
Station Elevation	0 - 9900 ft.	100 feet	BCD	8	21
Magnetic Variation	-25° to $+25^{\circ}$	0.1°	BCD + Sign	13	

WORD GROUPINGS AND NUMBER OF DATA BITS PER WORD

† Since Coverage Class requires only two bits, it will be included in the data format for potential airborne use.

*Broadcast once per frame.

Reprint 2-2 Modified Copy of Volume 1, page 21

Common Arrival Waypoints*	Range	Resolution	Type of Coding	Total Bits	
Route Sequence Number	0-19	Integers	BCD	5	17
Unique Identification Number	0-999	Integers	BCD	12	
Bearing to VORTAC	0-359.9°	0.1°	BCD	14	14
Distance to VORTAC	0-130 miles	0.1 mile	BCD	13	13

SID/STAR Cluster Identifier**	Range	Resolution	Type of Coding	Total Bits	
First Letter	A or D	N/A	Binary	1	15
Arrival or Departure Heading	00-36	10°	BCD	6	
Traffic Flow	N,NE,E...NW	N/A	Binary	3	
Number of Waypoints	0-19	Integers	BCD	5	

Waypoint Data***	Range	Resolution	Type of Coding	Total Bits
(Same quantities as for Common Arrival Waypoints listed above.)				

WORD GROUPINGS AND NUMBER OF DATA BITS PER WORD

*Broadcast three times per frame - once for IAF, once for FAF and once for MAP.

**Broadcast a maximum of 10 groups of this data per frame.

***Broadcast a maximum of 47 groups of this data per frame.

In addition to the data bits shown, additional information bits must be added to each word to enable the Airborne system to properly identify, sort and store the desired data.

Since eleven different types of words are generated by the grouping shown, a 4 bit address is required at the beginning of each word to identify what it represents. Another bit will be added to identify whether it is the first or second word of the two word redundancy sequence (to be discussed in more detail later). One more bit will be added at the end of each word for parity. Therefore each word will contain its basic data bits plus six additional bits for redundancy identification, address and parity, plus any pad bits needed to keep the word length uniform.

Reprint 2-3 of the data sequence given in Volume 1 shows the total minimum number of bits (including addresses, parity, etc.) required for each of the eleven word types which were selected. By examining Reprint 2-3, it can be seen that the total bit requirement of the Station data range from 23 to 28 bits and the Waypoint bit requirements range from 19 to 23 bits.

In order to provide a compromise between word length uniformity and transmission efficienty, it has been decided to use two different word lengths of 30 bits and 24 bits, for Station data and Waypoint data respectively. These numbers are convenient to implement from a hardware standpoint and also provide for at least one pad bit in each word which can be reserved for some future use. The Station words

RECOMMENDED TMA DDB SEQUENCE

	Data Sequence	Example	Total Bits
	Station Identifier and Coverage Class	XYZ	17 + 6 = 23
	Station Latitude	39° 45.1'	21 + 6 = 27
	Station Longitude	104° 50.6'	22 + 6 = 28
	Station Elevation	100 ft.	21 + 6 = 27
	Station Magnetic Variation	-3.6°	
IAF Data	IAF Arrival Route Sequence Number and Unique Waypoint Number	3-23	17 + 6 = 23
	IAF Range	ρ_3	13 + 6 = 19
	IAF Bearing	θ_3	14 + 6 = 20
FAF Data	FAF Arrival Route Sequence Number and Unique Waypoint Number	2-22	17 + 6 = 23
	FAF Range	ρ_2	13 + 6 = 19
	FAF Bearing	θ_2	14 + 6 = 20
MAP Data	MAP Arrival Route Sequence Number and Unique Waypoint Number	1-11	17 + 6 = 23
	MAP Range	ρ_1	13 + 6 = 19
	MAP Bearing	θ_1	14 + 6 = 20
	First Cluster Identifier and Number of Waypoints	A06W-6	15 + 6 = 21
1st	Waypoint Route Sequence Number and Unique Waypoint Number	6-12	17 + 6 = 23
	Waypoint Range	37.2 miles	13 + 6 = 19
	Waypoint Bearing	62.7°	14 + 6 = 20
2nd	Waypoint Route Sequence Number and Unique Waypoint Number	5-9	
	Waypoint Range	23.6 miles	
	etc.		
	Next Cluster Identifier and Number of Waypoints	D17W-4	
	etc.		

contain at least 2 pads each but this does not cause any significant reduction in data efficiency because Station data is only sent once per system cycle.

Tables 2-1 and 2-2 present the proposed word format for the Station data and Waypoint data respectively. It should be noted that the 4 bit address is arranged so that the first bit can be used to identify the length of the word being received. This will facilitate the data processing function in the Airborne equipment.

2.4.2 Word Redundancy Analysis

During the preceding sections, numerous references have been made to transmitting each word two times. This provides the user with a verification capability which is necessary to guarantee satisfactory system performance. In addition to the usual type of errors that can take place (due to noise, multipath, fading, etc.) one additional error source which must be considered in this application is that of having data blanked out by an Airborne Interrogator Receiver Blanking Gate which is generated each time a DME Interrogation takes place.

It was previously stated that EDMAC Associates Inc. considered it unwieldy to modify the DME Interrogator to externally control the Interrogation times. With this constraint, it is necessary to devise a system which will successfully process data in spite of the random blanking which takes place.

The selected method for implementing word transmission using the ADS concept is to broadcast two successive identical words (60 bits total

DATA WORD	DATA BITS REQ'D	DATA FORMAT
Station Identifier & Coverage Class	17	N 0 0 0 1 Ø Ø Ø Ø Ø Ø Ø ← Ident. → Cov. → P
Station Latitude	21	N 0 0 1 1 Ø Ø Ø ← Lat. → P
Station Longitude	22	N 0 1 1 1 Ø Ø Ø ← Long. → P
Station Elevation and Magnetic Variation	21	N 0 1 1 0 Ø Ø Ø ← Elev. → ← Mag. Var. → P
Date Bit Number		1 | 2 3 4 5 | 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
		| Address Bits |

Legend: N = Word Number Designation (First or Second Word of the Two Word Redundancy Sequence)
Ø = Pad (Binary 0)
P = Parity Bit

Notes: Address Bits Indicate the Type of Word Being Received
All Station Data Words Contain 30 Bits

Table 2-1. Word Organization for Station Data

DATA WORD	DATA BITS REQ'D	DATA FORMAT
IAF Arrival Route Sequence Number And Unique Waypoint Number	17	N 1 1 1 1 Ø ← Rte.No. → ← → W/P No. → P
FAF Arrival Route Sequence Number And Unique Waypoint Number	17	N 1 1 1 0 Ø ← Rte. No. → ← → W/P No. → P
MAP Arrival Route Sequence Number And Unique Waypoint Number	17	N 1 1 0 1 Ø ← Rte. No. → ← → W/P No. → P
Cluster Identifier and Number of Waypoints	15	N 1 1 0 0 Ø Ø Ø A/D ← Heading → ← Flow → No.ofW/P → P
Waypoint Route Sequence Number And Unique Waypoint Number	17	N 1 0 1 1 Ø ← Rte. No. → ← → W/P No. → P
Waypoint Range	13	N 1 0 1 0 Ø Ø Ø Ø Ø ← Range → P
Waypoint Bearing	14	N 1 0 0 1 Ø Ø Ø Ø ← Bearing → P
Data Bit Number	—	1 | 2 3 4 5 | 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Address Bits

Legend: N = Word Number Designator (First or Second Word of the Two Word Redundancy Sequence)
Ø = Pad (Binary 0)
A/D = Arrival or Departure Route Designation
P = Parity Bit

Notes: Address Bits Indicate the Type of Word Being Received
All Waypoint Data Words Contain 24 Bits

Table 2-2 - Word Organization for Waypoint Data

for Station data or 48 bits for Waypoint data, plus word synch pulses). If, for example, we assume that Waypoint data is to be broadcast and, for simplicity, we ignore the word synch pulses, then 48 successive bits will be broadcast (two identical words of 24 bits each) in conjunction with 48 consecutive pulse pairs. The next group of pulse pairs will then be sent with "no data" attached. The number of such "no data" pairs will be controlled by the duty cycle or data rate capacity which is required. By concentrating two successive words as close together as possible, the probability of having both affected by an Interrogator Receiver Blanking Gate is minimized. This will be shown in the following paragraphs. The actual overall structore of the words will be covered in the next section of the Design Plan.

For the purpose of this analysis it is assumed that the maximum Interrogation rate during Track is 30 per second. This corresponds to an average interval between interrogations of 1/30 of a second. The average number of squitter and reply pairs which occur during that time (assuming a 2700 pps Transponder) is 90. It can be assumed that the number of squitter pairs which occur during the 1/30 second interval is a Poisson distributed Random Variable with a mean of 90 and a standard deviation of $\sqrt{90} = 9.5$.

If the length of two successive words in the worst case correspond to 60 bits, we are interested in the probability that 60 or fewer squitter pairs can occur during this 1/30 second interval. This will cover the worst case possibility of having a blanking gate occur just at the beginning of word number 1 and again at the tail end of word number 2.

The Poisson distribution with a mean of 90 and a standard deviation of 9.5 can be very accurately approximated by a normal distribution with the same parameters. The "3σ" limits of the normal distribution (or 3 x 9.5 = 29) correspond to 99.7% of all values. This means that there is a 99.7% chance that the number of squitters occurring during this 1/30 second lies between the limits of (90-29) and 90+29). There is a corresponding 0.3% chance that the number falls outside these limits. Only half of these, or 0.15%, will be over 119 and the other 0.15% will be less than 61.

Based on the above, we can assume that there is approximately a 0.15% probability that fewer than 61 data bits are received between two successive Interrogations. There is, furthermore, only a small probability that the Blanking Gate (assumed to be a maximum of 40 microseconds) will interfere with the squitter pair and/or data pulses, even if it does occur during a word.

For Waypoint word lengths of only 24 bits, the corresponding probability that less than 48 bits will be transmitted during a 1/30 second interval is correspondingly smaller. Using Normal distribution tables, this probability is less than 0.005%. Although these calculations do not include the addition of pulses for word synch characters, it can readily be seen that the two word redundancy feature will, for all practical purposes, assure that both words will not be affected by the random occurance of Interrogator Receiver Blanking Gates.

2.4.3 Word Synchronization and Overall Data Structure

In order to determine the starting point of a word it is necessary to have some special coded identifier. The ADS concept provides this in the

form of a special word synch doublet as shown in Figure 2-3. Whenever the Airborne Equipment decodes such a doublet it will signify the possible initiation of a word. However, in order to account for the possibility that such a word synch character was formed by a data pulse and an extraneous interference pulse, the suggested word synchronization procedure will consist of sending two or more successive synch doublets at the beginning of each word. There still exists the chance, that if only two successive doublets are used, one of them could be blanked out by a Interrogator Blanking Gate. For this case, a single doublet would remain and would have to be interpreted as the beginning of a new word. A more reliable approach would be to send three successive doublets to identify the beginning of a word and make provisions in the Airborne Data Decoder to require a minimum of two successive doublets to signify the beginning of a new word. This reliability, is of course achieved at the expense of increased power requirements but this represents a worthwhile trade-off because it will make the DDBS more immune to interference pulses.

Using the above approach, the overall structure of a sequence of two identical words is shown in Figure 2-13.

One aspect of the overall data structure which must be considered, is how the data will be organized when a given word "straddles" a Reference Burst. Since the system is completely Asynchronous, occassionally a word sequence will begin just prior to a Reference Burst. This will alter the pattern of the sequence shown in Figure 2-13 because a set of "no data" characters might appear in the middle of any given word. This will cause no problem in the

Typical Data Sequence

...N N N W W W D D D D ~ D D D W W W D D D ~ D D D W W W N N N...

"No Data"	3 Word Synch Characters	First Word- 24 Data Pulses	3 Word Synch Characters	First Word- 24 Data Pulses	3 Word Synch Characters (End of Message Indication)	"No Data"

Legend: N = "No Data" Condition

W = Word Synch Doublets Added to TACAN/DME Pulse Pairs

D = Data Pulses Added to TACAN/DME Pulse Pairs

Note: Each letter shown (N, W or D) Corresponds to the Data Status of Each TACAN/DME Pulse Pair

Figure 2-13 Overall Data Structure For Two Successive 24 Bit Words

Airborne Equipment because the logic will naturally be set up to ignore all "no data" pairs. In effect all "no data" indications will be treated the same as if no pulse pair had been transmitted.

2.4.4 Data Acceptance Criteria in the Airborne Equipment

The recommended system approach described herein provides a multitude of data validation features which will enhance system performance and reliability. When a message is being received in the Airborne Equipment, a number of conditions must be satisfied before the data is transferred to the R-NAV computer. First, a word does not begin to get decoded until at least two successive Word Synch characters are received. Second, the number of data bits which are received before the next word Synch characters arrive must either be exactly 24 or 30, depending on the address code. Third, the word parity must be correct. Fourth, if both the first and second words of a two word redundancy group pass each of the first three conditions, the words must be identical or they are both rejected. On the other hand if one of the words passes the first three tests but the other word does not, the one which passes will be accepted as a valid word.

Considering all of the validation conditions which must be satisfied, it is apparent that the system objectives of high overall reliability will be achieved.

2.5 System Bit Rate and Power Requirements

Throughout the preceding discussions, there were numerous references to DDB bit rates in the range from 600 to 900 bits per second. These values were used as initial sample values based on preliminary results from CTI prior to the final completion of the Operational Analysis. It was stated in Volume 1 that the original Operational Analysis results indicated the desirability of transmitting data for both Enroute and Terminal Area Waypoints. A closer examination of the problem by EDMAC and CTI, led to the conclusion that since the Jeppesen Cross Enroute Waypoint Structure was recommended, there was no necessity to broadcast Enroute data. Hence the bit rates and power requirements which are calculated in this section will reflect a lower system data rate than the 600 - 900 bits per second previously mentioned.

The analysis will consist of two parts. First the number of actual data bits per second will be calculated for the worst case requirement of 60 Terminal Area Waypoints and an assumed worst case system data cycle time of 30 seconds (the 30 second minimum cycle time was recommended by CTI and is justified in Volume 1 of the Design Plan). The second part of the analysis will be a calculation of the number of word synch characters needed to support the complete data format. This is done separately because each word synch character consists of a pulse doublet added to each normal TACAN/DME

pair whereas each data bit consists of adding a single data pulse.

These calculations are best explained by referring to Figure 2-13, and Tables 2-1 and 2-2. The Station and Waypoint data and Word Synch requirements from these Tables are summarized in Table 2-3.

It can be seen from Figure 2-13 that if all words are broadcast in two-word redundancy groups, then a total of 9 word synch characters are required giving an average of 4.5 synch characters per word. While this type of broadcast is preferred from the standpoint of distributing the extra load on the transmitter over a longer time base, it is less efficient from the standpoint of the average number of word synch characters required for each word. For example if four consecutive words were sent instead of 2, then only 15 Word Synch groups are required for 4 words, giving an average of 3.75 Word Synch characters per word. This arrangement would cause more concentrated peak energy demands on the transmitter but less overall energy. From a logic implementation point of view, the systems are comparable. Since the peak loading of the transmitter is considered more critical than achieving a small decrease in total average power, the two-word group concept will be used. Therefore the overall average power requirement will be calculated based on an average of 4.5 word synch characters per word of data.

	A	B	C	D = ABC	E	F = EAB
Data Type	No. of Words Per Data Type	No. of Broadcasts Per Data Cycle Using 2 Word Redundancy	No. of Bits Per Word	No. of Bits Per Data Cycle	No. of Word Synch Characters Per Word	No. of Word Synch Characters Per Data Cycle
Station Data	4	2	30	240	4.5	36
IAF Waypoint Data	3	2	24	144	4.5	27
FAF Waypoint Data	3	2	24	144	4.5	27
MAP Waypoint Data	3	2	24	144	4.5	27
Cluster Identifier	1	20	24	480	4.5	90
Waypoint Data	3	114	24	8208	4.5	1539
TOTALS				9360	-	1746

Total Number of Extra Pulses Required Per Data Cycle	=	9360 + (2 x 1746) = 12,852 pulses
Number of Extra Pulses Required Per Second	=	12,852 pulses/data cycle ÷ 30 seconds/data cycle = 428 pulses/sec.
Number of Data Bits Broadcast Per Second	=	9360 data bits/data cycle ÷ 30 seconds/data cycle = 312 bits/second

TABLE 2-3 Number of Data Bits and Word Synch Characters Required Per System Data Cycle (No Word Redundancy Included)

The results shown in Table 2-3 indicate that the worst case DDBS requirements for the 60 Waypoint Terminal Area will require the addition of 428 single pulses per second to the normal TACAN signal. Since a 2700 pps Transponder actually transmits 3600 pulse pairs per second (including Reference Bursts) or 7200 single pulses per second, the addition of 428 more single pulses represents less than a 6% increase in average power requirements. It is therefore feasible to consider the future addition of more Waypoints and/or a future decrease in system data cycle time. Hence the growth capability of the recommended system is excellent.

The impact of this extra power required by the DDBS on the Increased Traffic Handling Capacity Modification Kit can be best evaluated as follows. If we assume that the stated Traffic Increase to 4000 pulse pairs per second is the absolute limit of the Transmitter's capability, then the addition of the DDBS will require this capacity to be limited to approximately 3800 pulse pairs per second, thereby reducing the DME traffic capacity by about eight aircraft.

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