

**Project Report
ATC-25**

DABS/ATCRBS Transponder Bench Testing Program

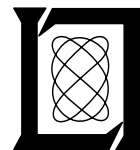
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28 November 1973

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Prepared for the Federal Aviation Administration,
Washington, D.C. 20591

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1. Report No. FAA-RD-73-160		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle DABS/ATCRBS Transponder Bench Testing Program				5. Report Date 28 November 1973	
				6. Performing Organization Code	
7. Author(s) J. R. Samson, J. D. Welch, E. R. Becotte, E. A. Crocker and H. D. Schofield				8. Performing Organization Report No. ATC-25	
9. Performing Organization Name and Address Massachusetts Institute of Technology Lincoln Laboratory P.O. Box 73 Lexington, Massachusetts 02173				10. Work Unit No. Project No. 034-241-012	
				11. Contract or Grant No. DOT-FA 72 WAI-261	
				13. Type of Report and Period Covered Project Report	
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20591				14. Sponsoring Agency Code	
				15. Supplementary Notes The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under Air Force Contract F19628-73-C-0002.	
16. Abstract The objective of this program was the determination of the effect on ATCRBS transponders of candidate modulation schemes in DABS uplink transmissions. Bench tests were conducted on twenty-two different transponder samples, including representative air carrier and general aviation transponders and a military transponder. In this report, individual test procedures are outlined, the reduced data are presented, and some conclusions regarding the selection of the DABS uplink waveforms based upon the data are given. The basis of these conclusions is a DABS design goal of generating the least possible interference to the existing ATCRBS system. In addition to performing tests whose purpose was the direct measurement of response of ATCRBS transponders to candidate DABS uplink waveforms, tests were also run to obtain other link-related characteristics, such as response to non-standard pulses. Conclusions, based upon the tests performed, were that DABS signals modulated by either PSK or FSK would be demodulated by a significant fraction of ATCRBS transponders and that there are no feasible PAM pulse widths or spacings which would not be decoded by a significant fraction of ATCRBS transponders. ATCRBS transponder reply probability drops nearly to zero when the DABS message (of arbitrary modulation type) has a duration less than 30 μ sec and is preceded by ATCRBS suppressing preamble. It was further shown that the reliability of suppression at interrogation levels near MTL can be improved by increasing the peak power of the preamble relative to the message.					
17. Key Words ATCRBS DABS Secondary Surveillance Radar Beacon, Transponders Interference, Uplink			18. Distribution Statement Availability is unlimited. Document may be released to the National Technical Information Service, Springfield, Virginia 22151, for sale to the public.		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 102	22. Price 4.25 HC 1.45 MF

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ACKNOWLEDGMENTS

The contributions of all the people who worked on this program are appreciated and hereby acknowledged. Thanks go to D. Boucher, chief tester for a major portion of the program; to J. Cataldo, E. Pelrine, G. Rezendes, F. Simonds, A. Smith, and D. Sunstein, who designed and constructed the special testing apparatus; and to M. Virbalis, who aided in the final testing stages of the program. The advice and guidance of G. V. Colby throughout the course of the tests is specially acknowledged.

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1.0 SYSTEM CONSIDERATIONS AND SUMMARY OF RESULTS

1.1 ORGANIZATION OF THE REPORT

This report describes the results of a series of laboratory measurements of ATCRBS transponder characteristics designed to determine the response of the existing population of ATCRBS transponders to candidate DABS uplink transmissions (on 1030 MHz, the existing ATCRBS uplink frequency). This chapter includes background material and serves as an executive summary. It reviews the purpose and the scope of the tests, the potential effects of DABS uplink transmissions on the ATCRBS system, and general conclusions regarding the alternative methods available for minimizing DABS interference to the ATCRBS system.

1.2 PURPOSE AND SCOPE OF THE STUDY

The purpose of the experiments reported herein was to assure that the DABS uplink transmissions ultimately selected will result in minimum interference between ATCRBS and DABS. Selection of the DABS link frequencies and modulation types obviously involves a trade-off between link performance and cost. Existing ATCRBS channels and signal formats would be attractive choices for the DABS system because equipment compatibility between the two systems would then be maximized. This is a particularly significant consideration because of the possibility of having to support and maintain two distinct systems during the transition period from all-ATCRBS to all-DABS

operation. Transponder compatibility is also desirable since DABS transponders will be required to provide standard ATCRBS capability during this period. It has been shown that the cost of a dual service transponder will be minimized if common components are shared between the two services wherever possible.

However, as the degree of commonality is increased, the potential for interference between the two systems is also increased. Both uplink and downlink interference can occur from common channel use and in each link the mutual interference may be from DABS to ATCRBS or from ATCRBS to DABS. This investigation focuses on the uplink and treats the effect of DABS interrogations on ATCRBS transponders specifically.

1.3 REVIEW OF EFFECTS OF DABS UPLINK TRANSMISSION ON THE ATCRBS SYSTEM

Inherent in a DABS uplink transmission on 1030 MHz are two possible interference threats: a) unwanted triggering of Mode A or C replies from ATCRBS transponders in the DABS beam, and b) unwanted triggering of the sidelobe suppression circuitry of ATCRBS transponders. A particular DABS interrogation may be capable of either of these effects, depending on the message content and other system factors. Longer DABS messages could actually result in average reply and suppression rates for ATCRBS transponders in excess of one per interrogation. This section reviews the effects of unwanted reply or suppression triggering on the ATCRBS system.

Three principle problems result from false triggering of replies from ATCRBS transponders. First, a standard ATCRBS transponder is suppressed for an interval ranging from 25 to 125 μ sec after the receipt of a Mode A or C interrogation. Thus, when false triggering occurs, the accessibility of the

transponder to ATCRBS interrogations is reduced. The result is a reduction of the ATCRBS system round reliability.

Another problem resulting from false reply triggering of ATCRBS transponders is the possible generation of synchronous downlink garble in the DABS system. Any ATCRBS equipped aircraft in close enough proximity to a DABS transponder, could respond with a reply that overlaps the DABS reply message. Assuming that the DABS downlink message duration is approximately 50 μ sec and that the ATCRBS reply is falsely triggered at the beginning of the DABS interrogation, this proximity region extends from approximately 2 nmi closer to the DABS interrogator beacon to 4 nmi further away from the beacon within the main interrogation beam.

The third problem arising from false ATCRBS triggering by DABS interrogations is the generation of additional replies which would appear as non-synchronous (fruit) interference to the ATCRBS System. ATCRBS transponders in the side or back lobes of the DABS interrogator would also be subject to false triggering by each DABS interrogation. Under peak DABS traffic conditions, ATCRBS transponders in the sidelobes of a DABS interrogator could have sufficiently high false reply rates to produce reply rate limiting. A DABS interrogator which elicits false replies from ATCRBS beacons is equivalent to a variable repetition-rate ATCRBS interrogator without sidelobe suppression. The interference generated by such an interrogator is, of course, strongly dependent on the DABS traffic load.

In contrast with false reply triggering, the triggering of false ATCRBS sidelobe suppression decodes by DABS interrogations has only the single effect of reducing the accessibility of the ATCRBS transponder. In fact, since the

maximum allowable suppression time (45 μ sec) is shorter than the maximum allowable reply dead time (125 μ sec), the overall ATCRBS system round reliability reduction due to false SLS decodes should be smaller than the system round reliability reduction due to false reply triggering.

Examination of the consequences of the three possible interference effects indicates that ATCRBS suppression is the least undesirable. Assuming that all ATCRBS transponders within range of the DABS interrogator beam are suppressed once per DABS interrogation, it is expected that the net reduction of ATCRBS round reliability would only be significant for aircraft traversing the side and back lobes of the DABS antenna pattern, the effect of DABS suppression on these close-in aircraft depending on the DABS sensor traffic load.

1.4 SUMMARY OF TECHNIQUES FOR MINIMIZATION OF INTERFERENCE TO ATCRBS FROM DABS UPLINK DATA TRANSMISSIONS

1.4.1 Alternatives

The possible strategies for minimizing interference to ATCRBS from DABS uplink data transmissions on the 1030 MHz channel are:

- Do nothing. Use an ATCRBS-like format and allow the DABS uplink transmissions to trigger ATCRBS replies and suppressions.
- Seek a format which is invisible to ATCRBS transponders so as to reduce the rates of both false reply and false suppression decodes. Invisibility may be achieved by transmitting a DABS waveform which is either: a) not demodulated by ATCRBS transponders, or b) demodulated by ATCRBS transponders but rejected by the ATCRBS decoding circuitry.

- Intentionally suppress all ATCRBS transponders. Intentional suppression can be achieved by preceding the DABS interrogation with a suppressing preamble and either: a) restricting the duration of the DABS interrogation so that it is complete within one ATCRBS suppression interval, or b) if the interrogation is longer than the ATCRBS suppression interval, including provision for resuppression of ATCRBS transponders.

Each of these alternatives will be examined in order.

1.4.2 The Effects of An ATCRBS-like Format

The first alternative raises the question, "How bad is the problem of false reply triggering? Is it necessary to do anything about it?" It was concluded early in this investigation that, if an ATCRBS-like format were used for the DABS uplink, the false reply problem would be serious. Experiments were run with random strings of 0.6 μ sec pulses with 1.0 μ sec interpulse spacing (Section 4.1.2). Even with a short 25-bit uplink message, this format resulted in 100% of the tested transponders responding with average reply rates exceeding 0.1 replies per interrogation, (i. e., on the average, each transponder replies to more than 10% of the interrogations), and over 85% of the transponders had average reply rates exceeding 0.5 per interrogation. When the message length was increased to 50 bits, 100% of the tested transponders had average reply rates in excess of 0.5 per interrogation and 65% had average reply rates exceeding 1.0 per interrogation due to the fact that the 50 μ sec message length allowed some transponders to be triggered twice per interrogation. Comparable false suppression rates were also measured in each case.

It is concluded that triggering rates in excess of 0.5 per interrogation can be expected for the ATCRBS transponder population if an ATCRBS-like format is used in the DABS uplink. In view of the discussion in Section 1.2, the use of such transmissions could lead to serious system interference.

1.4.3 Invisible Modulation Types

It is evident from the above-stated results that an attempt should be made to reduce the false triggering rate. This conclusion leads to the second alternative: that of attempting to find a modulation type, other than the ATCRBS-like PAM, which may be less likely to elicit false decodes in ATCRBS transponders. One possibility was the use of PAM in both systems, but with different pulse widths and/or spacings in the DABS uplink transmissions in an attempt to reduce the triggering of ATCRBS replies. Other modulation types investigated were Frequency Shift Keying (FSK) and Phase Shift Keying (PSK). These alternatives will be examined in turn in this section.

The use of non-standard PAM waveforms for the DABS uplink had been studied previously with the tentative conclusion being that there is probably no combination of PAM parameters which are compatible with the channel bandwidth limitations, and which provide an acceptable data rate that will not be decoded as ATCRBS interrogations by some segment of the ATCRBS transponder population. The main hope for achieving invisibility was seen as the use of PAM pulses shorter than the minimum allowable ATCRBS pulse width. A number of experiments were included in this test program (Section 3) to check these conclusions. It was found (see Section 3.3) that a significant fraction of the sampled transponders accepted Mode-A ATCRBS interrogations with $1/4$ μ sec or narrower pulses as valid at some input power level within the specified dynamic range of the ATCRBS receiver.

The PAM modulation investigated for invisibility (Section 4.1.2) consisted of random strings of $0.25 \mu\text{sec}$ wide pulses with $0.5 \mu\text{sec}$ interpulse spacing. The reply rates of ATCRBS transponders to a 50-bit transmission using this waveform were only slightly lower than the reply rates of the transponders to the 25-bit transmissions of the 1 Mb/s PAM transmission discussed above. Approximately 80% of the transponders subjected to this waveform replied with average reply rates in excess of 0.1 per interrogation as compared to the 100% figure for 1 Mb/s PAM. This is still an unacceptably high reply rate, since it was subsequently shown that the reply rate could be substantially reduced either by using a modulation type other than PAM for the DABS uplink transmissions or by preceding the data with an intentional suppression preamble.

It was expected that another modulation type such as Frequency Shift Keying (FSK) or Phase Shift Keying (PSK) could be used for the uplink waveform and would trigger somewhat fewer replies from the PAM receivers of the ATCRBS transponders than would PAM. This expectation was borne out by experiment. Using constant envelope binary FSK modulation with random 25-bit messages at a 1 Mb/s rate, it was found (Section 4.1.1) that approximately 50% of the tested transponders replied with average rates exceeding 0.1 per interrogation, as compared with the 80% figure for 50 bit, 1 Mb/s PAM stated above. Fifty percent of these transponders were suppressed at average rates exceeding 0.1 per interrogation.

Similar improvement was obtained by using a constant envelope binary PSK modulation with random 100-bit messages at a 4 Mb/s data rate. In this case, it was found (Section 4.1.3) that only 40% of the transponders tested

replied with average rates exceeding 0.1 per interrogation. Fifty percent of these transponders were suppressed at average rates exceeding 0.1 per interrogation.

1.4.4 Intentional Suppression

The third alternative strategy for handling DABS interference to ATCRBS on the uplink is intentional suppression of ATCRBS transponders.

Intentional suppression of ATCRBS transponders by the DABS uplink waveform is a more reliable way of preventing false reply triggering than attempting to reply on an invisible DABS transmission because the suppression mechanisms of ATCRBS transponders are known to be more carefully and uniformly controlled than the mechanisms for rejecting non-standard signals in the ATCRBS band. That is, a pair of standard ATCRBS suppression pulses preceding the DABS uplink message should reliably suppress all ATCRBS transponders (regardless of the modulation used in the rest of the message) provided they are operating within specification; whereas, due to the random content of a DABS message and the variations in demodulator and decoder circuits from model to model, it is difficult to assure that a waveform will be invisible to all transponders under all operating conditions even if it is found to be invisible to a sample of transponders tested in the laboratory. In general, it would be best to follow a conservative uplink design, based on characteristics specified by the ATCRBS National Standard and closely adhered to by the transponder manufacturers.

One of the difficulties with intentional suppression arises when the DABS interrogation is longer than the ATCRBS suppression interval. In a typical ATCRBS transponder, suppression is not retriggerable, i. e., it is necessary

to wait for the suppression interval to end before the transponder can be resuppressed because received signals are either not demodulated or not decoded during the suppression interval. If we assume the DABS interrogation always starts with a pair of suppression pulses, additional intentional resuppression pulse pairs should be inserted into the DABS uplink waveform after the ATCRBS transponders have come out of suppression. The loose ATCRBS suppression time tolerance ($35 \mu\text{sec} \pm 10 \mu\text{sec}$) makes it impossible to determine exactly when this occurs.

One way to solve the problem of resuppression is to modify all operational ATCRBS transponders. Possible modifications are the addition of a retriggerable suppression circuit or tightening the tolerance on the suppression interval. Such retrofits are technically feasible, but are not practical for economic reasons and were not considered as serious possibilities until all other possibilities had been explored and exhausted.

An alternate possibility with an intentional suppression waveform is the use of pulsed PSK in which a pulse envelope is added to the phase modulation to automatically suppress (and resuppress) ATCRBS transponders while the PSK modulation carries the data. In addition, this waveform would be capable of achieving bit synchronization and leading edge ranging by means of its amplitude envelope alone. Pulsed PSK will be demodulated by all ATCRBS transponders as a string of identical RF pulses. Given the proper pulse width and spacing, it appears reasonable to expect that such a pulse train would indefinitely suppress most ATCRBS transponders. An experiment was included in the measurement program to test this hypothesis (Section 4.1.2). It was found that ATCRBS transponders could not be reliably resuppressed by a

uniform sequence of return to zero (RZ) PAM pulses simulating pulsed PSK, i. e., approximately 25% of the transponders tested replied with average rates exceeding 0.1 per interrogation to 25 bits of pulsed 1 Mb/s sec RZ-PAM, while approximately 50% replied in excess of 0.1 for a 100 bit message, indicating that some of the transponders which had been suppressed initially had not been effectively resuppressed. This effect is also noted in Section 4.2.1 where 100% of the transponders were suppressed by a suppressing preamble, but approximately 30% of the transponders failed to resuppress effectively on a pulsed waveform extending beyond the end of the initial suppression period.

This leaves as the only solution the use of a high data rate to assure that the entire message is contained within one nominal ATRBS suppression interval. The lower limit on the allowable ATRBS suppression interval is 25 μ sec. If the message is transmitted at a 4 Mb/s rate, 100 bits can be transmitted in 25 μ sec. At a 2 Mb/s rate, 50 bits can be transmitted in this time. Therefore, it appears feasible to use an uplink transmission consisting of an ATRBS $P_1 - P_2$ pulse pair as a suppression preamble followed either by 100 bits of data at a 4 Mb/s rate or 50 bits of data at a 2 Mb/s rate without running into the resuppression problem. If a 4 Mb/s rate is required, the channel bandwidth utilization may be minimized by using either constant-envelope, binary PSK or PAM with non-return-to zero (NRZ) modulation. FSK was not considered for this purpose because it offers no compelling cost or performance advantages, and is more complex and requires greater bandwidth than PAM or PSK.

A series of experiments were included to verify these predictions (Section 4.2). It was found that the percentage of transponders replying to

either NRZ-PAM or PSK transmissions following suppression preamble is indeed negligible, provided the overall transmission is complete in 30 μ sec or less. The transponder reply rate to this type of transmission is in most cases zero over nearly the entire specified ATCRBS dynamic range except for a region around the minimum triggering level (MTL). Around MTL the suppression circuitry of many transponders apparently fails to operate while the reply circuitry is still operative. Since in most of these transponders the maximum average reply rate in the reply range around MTL is less than 0.1 replies per interrogation and replies occur only in this narrow range of signal levels, this effect is relatively unimportant.

1.5 THE DABS ALL-CALL MODE

A requirement of the DABS system is an acquisition mode in which previously unidentified DABS transponders are requested to reply with their DABS identification. This is most efficiently accomplished by the addition of a special characteristic to the ATCRBS interrogations transmitted from DABS sensors to indicate they are not from conventional ATCRBS interrogators. This added characteristic must be invisible to conventional ATCRBS transponders and it must occur early enough in the All-Call transmission to allow an unacquired DABS transponder to inhibit an ATCRBS reply before transmitting the All-Call reply.

Of the schemes which could be used for this purpose, one which was found to satisfy the requirements stated above was the transmission of an extra pulse following the P_3 pulse of the ATCRBS Mode A or Mode C transmission.

2.0 THE MEASUREMENT PROGRAM

2.1 ORGANIZATION OF THE TESTS

The measurement program consisted of tests performed on a sample of 22 different types of ATCRBS transponders including general aviation and air carrier transponders in current use, and one widely-deployed military transponder. The transponders included in the sample are listed in Table 2.1. The bench tests were not intended as a comprehensive evaluation of all transponder characteristics or as a competitive evaluation of units of different manufacture. Since the information presented in this report was obtained from tests on a single transponder of each type, it should not be considered representative of all transponders of a given type.

A related program, completed in April 1972, obtained measurements in the field of the performance of a large random sample of operational ATCRBS transponders installed in aircraft. That field test program was conducted to determine the compliance of representative operational transponders to the ATCRBS Minimum Operational Characteristics and to evaluate the validity of a statistical sampling of these transponders.

Each of the transponders in the present testing program was, upon receipt, subjected to a standard ATCRBS compliance test which included the basic measurements employed in the ATCRBS field tests. The results of the basic ATCRBS compliance tests are not included in this report. For a description of these tests and a discussion of the results of the field tests on the large sample of ATCRBS transponders, see Reference [1].

Table 2.1. Transponder Testing Population.

Transponder Identification
Number

- ① = Military APX-72
- ② = Regency 505-I
- ③ = Wilcox 1014-A
- ④ = Genave 4096
- ⑤ = Bendix TR-611
- ⑥ = Narco AT5-A
- ⑦ = King KT-75
- ⑧ = Narco AT-50
- ⑨ = ARC RT506-A
- ⑩ = IFD Century 31
- ⑪ = Wilcox 914-A
- ⑫ = RCA AVQ-65
- ⑬ = Narco UAT-1
- ⑭ = Bendix TR641-B
- ⑮ = Genave 5000
- ⑯ = King KXP-750
- ⑰ = IFD Skyline 300
- ⑱ = Bendix TRA-61A
- ⑲ = King KT-76
- ⑳ = King KT-78
- ㉑ = Collins 621-A6
- ㉒ = Collins 621-A3

These basic tests were followed by the measurements concerned directly with the response of ATCRBS transponders to candidate DABS uplink transmissions. These measurements fall into two categories:

Group 1: Extended ATCRBS tests - These tests were intended to provide accurate information on the operation of the ATCRBS transponder in sufficient detail to permit an uplink design decision. These tests investigated such characteristics as the receiver pass band, resuppression time interval, sensitivity to CW transmissions, and response to non-standard pulse widths and spacings.

Group 2: Direct Response to Candidate DABS Uplink Transmissions - These tests examined average false-reply and false-suppression counts from the ATCRBS transponders when interrogated by simulated DABS uplink messages using the major candidate modulation schemes.

The second category of tests determined the overall response of ATCRBS transponders to candidate DABS uplink transmissions. The preliminary DABS tests were intended to investigate the invisibility of the basic modulation types (PAM, FSK, and PSK) to ATCRBS transponders (i. e., determine to what extent false replies and suppressions were triggered in ATCRBS transponders). These tests investigated the response as a function of interrogation power level, message length, and data rate for both random and deterministic message sequences. Subsequent tests investigated similar response characteristics with mixed modulation types used in the preamble and the message data block (e. g., PAM preamble and PSK data) of the uplink transmission. Tests were also included which examined in more detail the response as a function of message length following an intentional ATCRBS suppressing preamble, and

the effects of increasing the transmitted peak power of the preamble relative to the message in an effort to improve the reliability of this intentional suppression at interrogation levels near MTL. The last test investigating ATCRBS response to candidate DABS interrogations examined the effects of ATCRBS reply rate limiting function on the DABS interrogation repetition rate. Since the proposed DABS All-Call transmissions (for insertion of unidentified DABS transponders into the roll call order) were to be coincident with (and actually part of) the standard ATCRBS interrogations, the effects of two methods for DABS/ATCRBS discrimination on the response of ATCRBS transponders were investigated to insure that DABS All-Call does not degrade the performance of the ATCRBS system.

The specific tests included in each category of the testing program are listed in Table 2. 2.

2.2 DATA REPORTING

In this report, the individual test procedures are outlined, the reduced data are presented, and some of the conclusions regarding the selection of the DABS uplink waveform presented. In the event that the data for a particular test do not include all transponders in the sample, that test was not run on the particular transponder(s) because: 1) the transponder was not available, 2) the transponder had been borrowed temporarily for testing in another segment of the DABS program, or 3) a limited sample of the transponders was sufficient. Those tests falling into this third category are clearly designated as such.

Table 2.2. DABS-ATCRBS Transponder Bench Testing Program.

Test Group 1:

- a) Sensitivity to CW Interrogations
- b) Sensitivity vs Frequency
- c) Minimum Pulse Width to Trigger
- d) Minimum Pulse Width to Suppress
- e) $P_1 - P_2$ Spacing Tolerance
- f) $P_1 - P_3$ Spacing Tolerance
- g) Resuppression Time

Test Group 2:

- a) Preliminary DABS Tests
 - i) CW-FSK - Response to N-bit Random and Fixed FSK Interrogations
 - ii) PAM - 1) Response to N-bit Short-Pulse Random and Fixed PAM
2) Response to N-bit Long-Pulse Random and Fixed PAM
 - iii) CW-PSK - Response to N-bit Random PSK Interrogations
- b) ATCRBS Suppressing Formats
 - i) Response to Long and Short-Pulse PAM with ATCRBS Suppressing Preamble
 - ii) Response to PSK with ATCRBS Suppressing Preamble
 - iii) Response to NRZ-PAM with ATCRBS Suppressing Preamble
 - iv) Transponder Response As a Function of DABS Message Length Following an ATCRBS Suppressing Preamble (Message: 2Mb/s NRZ-PAM)
 - v) Effect of 0-3 dB Increase in Transmitted Peak Power of Preamble relative to Message (Message: 4Mb/s PSK)
 - vi) Transponder Response As a Function of Interrogation Repetition Rate
- c) DABS/ATCRBS Discrimination (DABS All-Call)
 - i) PSK Within Standard ATCRBS Pulses
 - ii) Transponder Response As a Function of Position of P_4 Pulse Added To Mode-A Interrogations

In all of the tests associated with transponder response, the basic data collected were average reply and suppression counts per interrogation. These responses were determined by counting the average number of detected reply pulse groupings or suppression gate triggerings per interrogation. The suppression gate circuitry of each transponder was monitored by means of a test point added to the transponder for this purpose. For intentionally-suppressed transponders, at interrogation levels near MTL the suppression circuitry fails to suppress reliably and in many cases significant reply rates are exhibited. In these cases, in addition to the basic recorded data, the reply range (from the level above MTL where suppression first becomes erratic down to the interrogation level where Mode-A replies are no longer observed) and the maximum reply rate within that range are recorded.

Most of the data obtained from test Group 2 is presented in the form of bar-circle charts, which are explained in detail in Section 4. These charts preserve the test results of individual transponders, identifiable by the circled numbers (e. g., ①) which refer to the transponder list of Table 2.1. Circled numbers are also used in reporting other tests results where the graphical presentation would otherwise be cluttered by transponder identification.

An effort was made to include reduced data typical of the response of all transponders or indicative of a response trend sufficiently general to support the test conclusion.

Since this program was intended to provide information concerning the ~~overall response of a cross section of the ATCRBS population to candidate~~ overall response of a cross-section of the ATCRBS population to candidate DABS uplink transmissions, no attempt was made to explain in detail the responses

analysis of the RF, encoding, decoding, and suppression circuitry of each individual transponder, tasks considered beyond the scope of this report.

2.3 GENERAL TESTING CONDITIONS

A block diagram of the basic set-up employed in all of the tests is illustrated in Figure 1. Unless otherwise noted in the individual test descriptions, 1030 MHz was used as the uplink frequency, and the interrogations were applied at a constant 500 Hz rate. The tests were conducted in an unshielded laboratory, and adequate grounding was provided.

Several pieces of special test equipment, which were constructed for general DABS program testing, were incorporated into these tests. Referring to the block diagram of Figure 1, this equipment fits into the blocks labeled modulation generator and RF source and modulation circuitry. A brief description of this equipment is given below:

DABS Interrogator Modulator (DIM)

This unit accepts input modulation for PAM, PSK, FSK, and combinations of PAM-PSK or PAM-FSK. It contains a constant frequency 1030 MHz source, a VCO for frequency modulation, and necessary circuitry for generating the modulated RF waveforms.

Modulator Control Unit (MCU)

This unit was designed to feed the required modulating signals into the DIM. It provides two distinct output fields, a "preamble" field and a data field, with independently controlled field length and modulation type. It internally generates random and coherent (fixed) data message sequences, and provides for external modulation if desired.

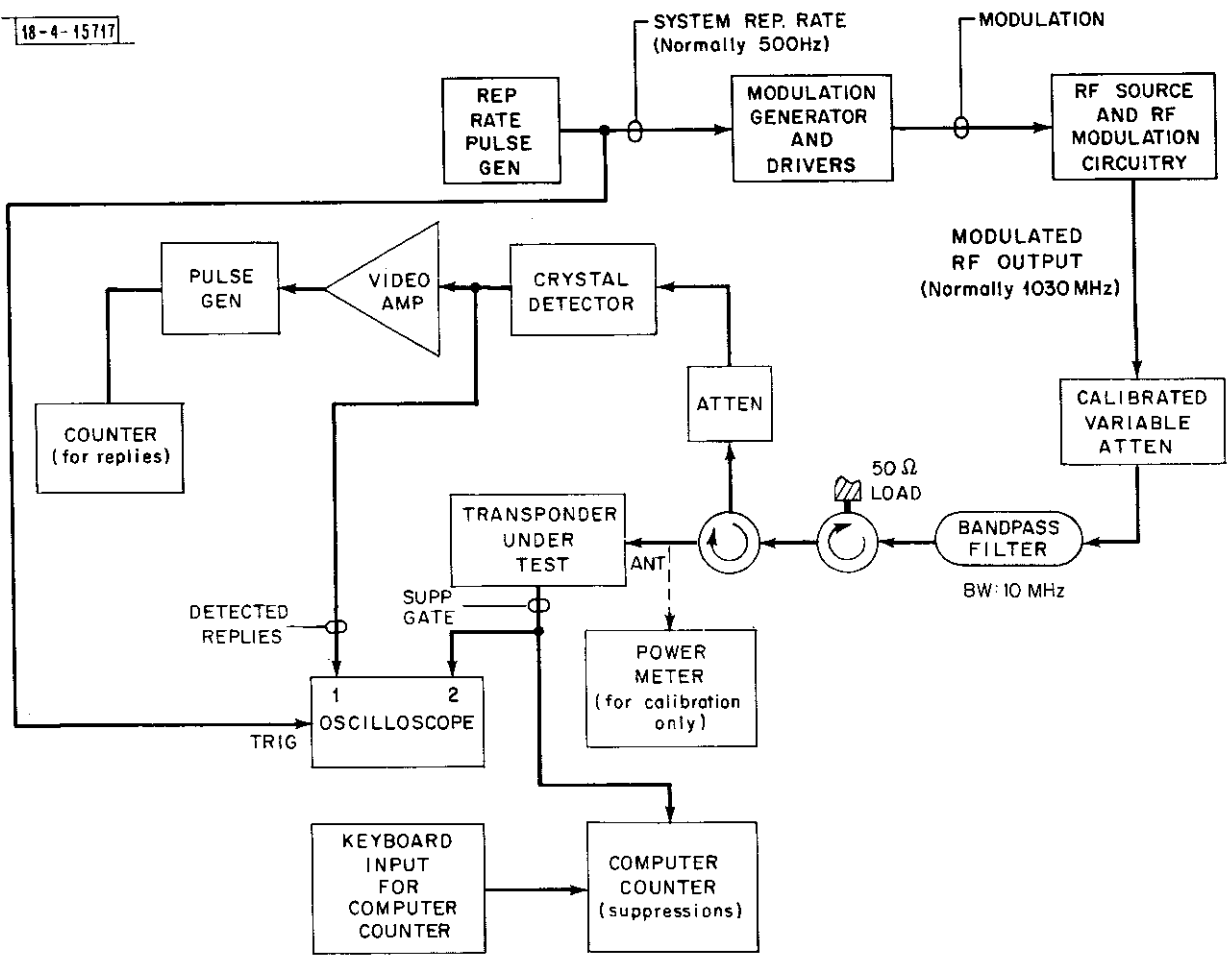


Fig. 1. Block Diagram of Basic Test Configuration.

ATCRBS Interrogator

This unit generated ATCRBS $P_1-P_2-P_3$ pulse sequences with provision for varying the spacings between pulses and the widths of individual pulses. Nominal pulse widths and spacings were as prescribed by the National Standard. The following outputs were provided: P_1-P_2 , P_2 , P_1-P_3 (Modes A and C), and $P_1-P_2-P_3$.

Random Message Generators

These generators provided pseudo-random (period 2^{30}) and fixed mode (mark-space) message modulations sequences.

Two generators were constructed, one for generating RZ sequences (RZ-PAM) and one for generating NRZ sequences (NRZ-PAM, FSK, and PSK).

A sketch of the output waveforms and a block diagram of the test configuration using the above equipment are included in the description of each test.

In tests where reply and suppression counts were recorded, the counts of detected replies and suppression gate triggerings were averaged over periods of one second. In tests where maximum reply rates were recorded, the numbers recorded were a consistent peak or average taken over several periods.

System calibration was checked prior to each test.

3.0 TEST GROUP 1 - DESCRIPTION AND RESULTS

This test group was intended to include tests on specific DABS-ATCRBS related parameters such as receiver passband, response to non-standard pulse widths and spacings, and resuppression time interval. The tests listed under Test Group 1 are considered as "extended ATCRBS tests."

3.1 SENSITIVITY TO CW INTERROGATIONS

In this test, the frequency of a continuous wave (unmodulated) signal was manually swept through the band 1015.0 MHz to 1045.0 MHz. This test checked the susceptibility of the transponders to unmodulated CW signals which could be generated as noise in the aircraft electrical system, as harmonics of TV signals, or as some form of CW-DABS uplink signal. Three of the transponders tested responded to this form of interrogation. Two of the three appeared to be intermittent: the Genave 4096, between -35 and -45 dBm at 1030.0 MHz; and the Wilcox 914-A at -15 dBm at 1040.0 MHz. The Regency 505-I responded solidly between -15 and 120 dBm at 1015.3 MHz and intermittently at -17 dBm at 1038.1 MHz. A block diagram of the test configuration is shown in Figure 2.

3.2 SENSITIVITY VS FREQUENCY

The sensitivity vs frequency measurements were made by observing the minimum triggering level (MTL) at selected frequencies within the uplink band. The testing frequencies were 1030.0 MHz, and ± 2.5 , ± 5.0 , ± 7.5 ,

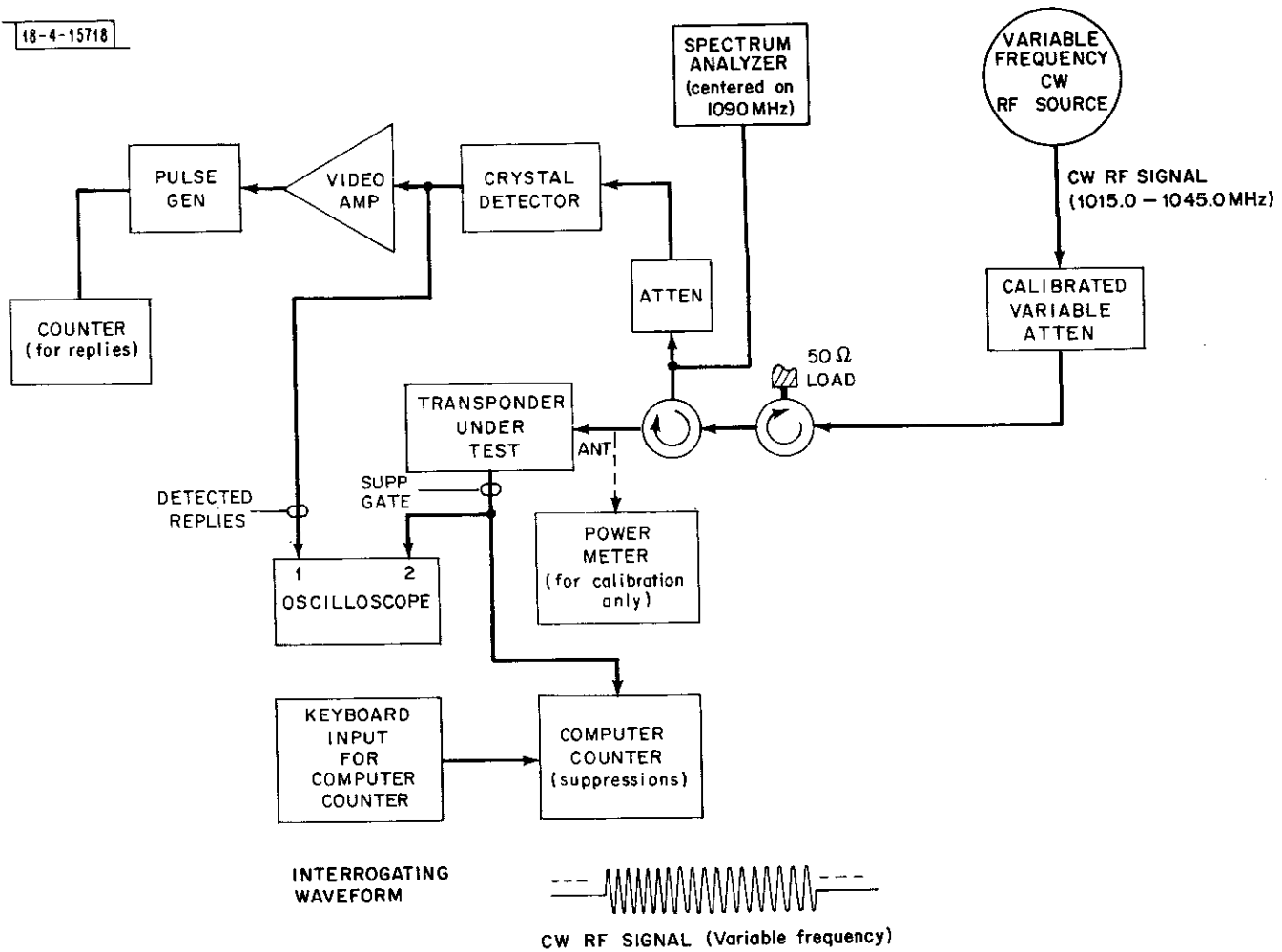


Fig. 2. Block Diagram of Test Configuration Sensitivity to CW Interrogations.

+ 10.0, + 15.0, and + 20.0 MHz centered about 1030.0 MHz. These tests were conducted to determine the receiver passband and asymmetry of sensitivity of ATCRBS transponders. A block diagram of this test configuration is given in Figure 3.

The receiver passband data are tabulated in Table 3.1. The approximate 3 dB bandwidths of the transponders were determined by interpolating linearly between sensitivity measurements at the specified testing frequencies. The table includes the upper and lower 3 dB frequencies and the frequency at which the peak value of sensitivity was measured. The 3 dB points were based on this peak sensitivity value.

Figure 4 indicates the asymmetry of sensitivity of the transponders, plotted as the difference (Δ MTL) between the minimum triggering levels measured at two frequencies centered about 1030 MHz. A symmetric sensitivity curve would result in Δ MTL = 0 dB. The plots in Figure 4 are for $\Delta F = \underline{+ 2.5}$ MHz and $\Delta F = \underline{+ 5.0}$ MHz show the large asymmetry of sensitivity exhibited by this sample of transponders. The significance of this asymmetry is that if CW-FSK were to be used as the DABS uplink waveform, misalignment or asymmetry of sensitivity of a transponder receiver could cause it to act like an FM discriminator, converting the FSK to AM which may be interpreted as ATCRBS PAM.

3.3 MINIMUM PULSE WIDTH TO TRIGGER

The primary objective of this test was to determine whether a short pulse waveform is invisible to most ATCRBS transponders. In this test the transponder was interrogated with a P_1 - P_3 pulse pair at interrogation levels ranging from -70 dBm to -20 dBm. At each interrogation level, the widths

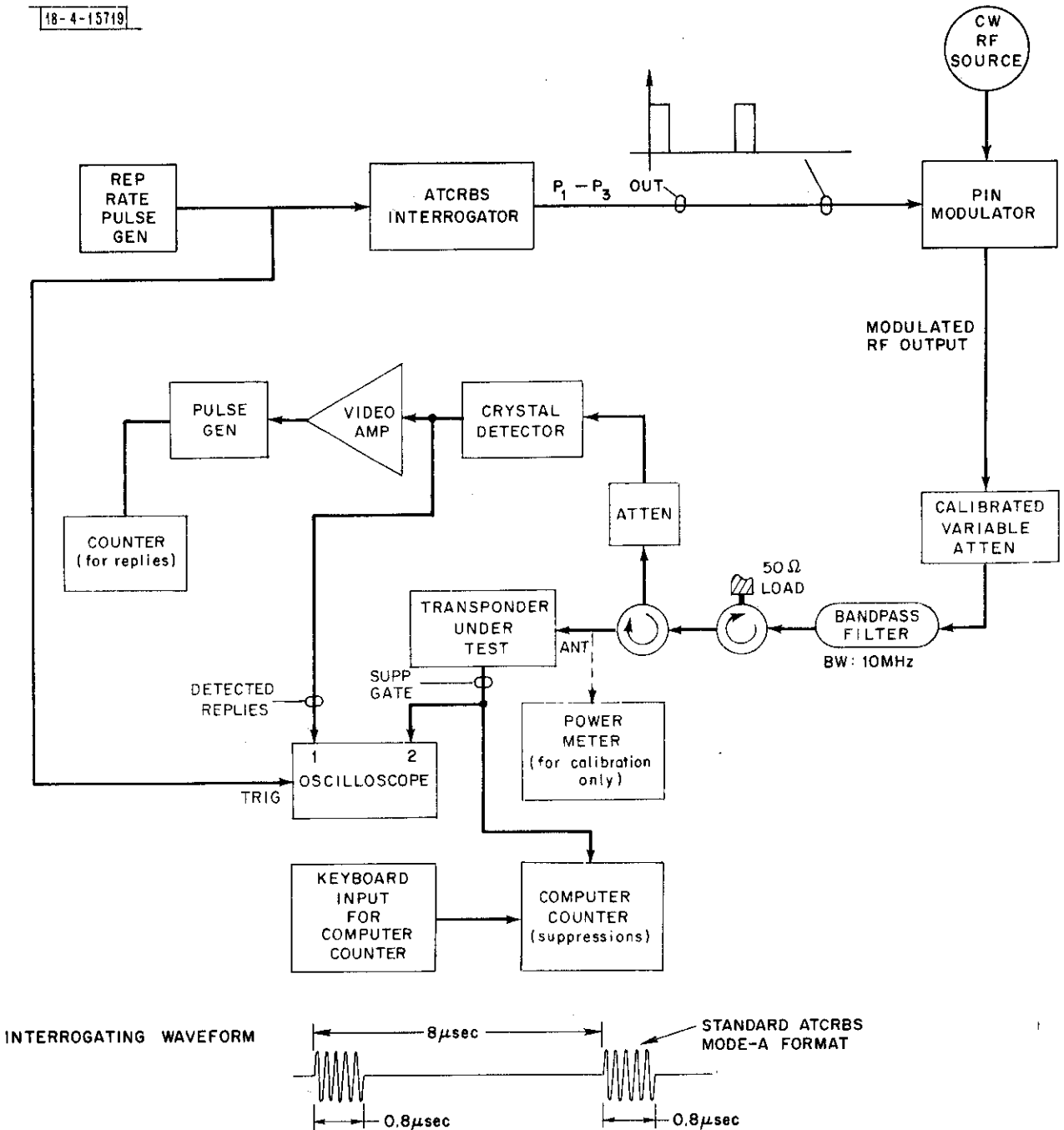


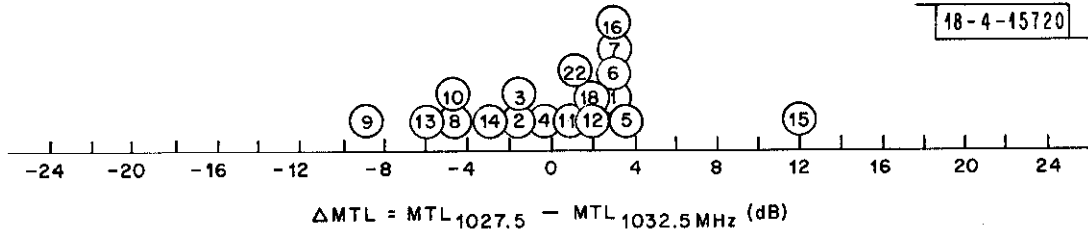
Fig. 3. Block Diagram of Test Configuration Sensitivity vs Frequency.

Table 3.1. ATCRBS Receiver Passband Data.
 (3 dB Bandwidth Based on Measured Peak Sensitivity)

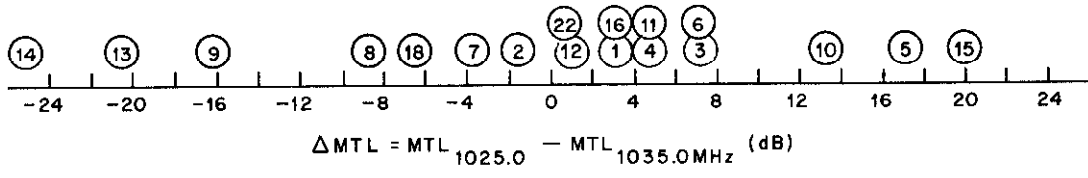
Transponder	f_{lower}	f_{upper}	Approx. 3 dB Bandwidth	f_{peak}
Military APX-72	1026.25	1033.0	6.75 MHz	1030.0
Regency 505-I	1027.5	1034.0	6.5 MHz	1030.0
Wilcox 1014-A	1027.25	1033.0	5.75 MHz	1030.0
Genave 4096	1028.5	1033.5	5.0 MHz	1030.0
Bendix TR-611	1027.5	1031.5	4.0 MHz	1030.0
Narco AT5-A	1029.0	1031.0	2.0 MHz	1030.0
King KT-75	1027.25	1032.0	4.75 MHz	1030.0
King KXP-750	1026.0	1032.5	6.5 MHz	1030.0
Narco AT-50	1029.0	1032.25	3.25 MHz	1030.0
Wilcox 914-A	1026.25	1033.0	6.75 MHz	1030.0
IFD Skyline 300	1031.75	1036.25	4.5 MHz	1030.0
RCA AVQ-65	1026.75	1033.5	6.75 MHz	1027.5-1030.0
Narco UAT-1	1028.5	1033.5	5.0 MHz	1030.0
ARC RT506-A	1029.5	1034.5	5.0 MHz	1032.5
Bendix TRA61-A	1027.5	1031.75	4.25 MHz	1030.0
IFD Century 31	1024.0	1033.5	9.5 MHz	1025.0 Double 1032.5 Peak
Bendix TR641-B	1028.5	1031.5	3.0 MHz	1030.0
Collins 621-A3	1026.0	1033.5	7.5 MHz	1027.5
			Avg. \approx 5.4 MHz	

Note: Sensitivity measurements are based on MTL to standard Mode-A Interrogations. The approximate 3 dB bandwidth measurements were made by linearly interpolating between measured MTL at specified testing frequencies.

18-4-15720



(a) DIFFERENCE IN MEASURED MTL AT FREQUENCIES ±2.5 MHz CENTERED ABOUT 1030.0 MHz



(b) DIFFERENCE IN MEASURED MTL AT FREQUENCIES ±5.0 MHz CENTERED ABOUT 1030.0 MHz

① = TRANSPONDER IDENTIFICATION NUMBER - SEE TABLE 1.1

Fig. 4. Asymmetry of Transponder Sensitivity.

of the pulses were increased simultaneously from zero until replies were first observed. A block diagram of the test configuration is shown in Figure 5. The ATCRBS National Standard [2] specifies the minimum pulse width for triggering replies to be 300 nsec, but this specification applies only at an interrogation level 6 dB above MTL. Almost all of the transponders satisfied this specification but eleven of the fifteen units tested replied to interrogations with pulse widths as short as 50 nsec at higher input levels (above -30 dBm). Six of the eleven replied to 50 nsec pulses at the -50 dBm level. The results of these tests are illustrated in Figure 6, which shows the range of minimum pulse widths measured as the interrogation power was varied from -70 dBm to -20 dBm. In most cases, the minimum pulse width required to trigger Mode-A replies decreases monotonically as the interrogation power level increases. These results indicate that short-pulse PAM is not an invisible waveform.

3.4 MINIMUM PULSE WIDTH TO SUPPRESS

The Mode-A decode circuitry in certain transponders detects pulses whose widths are less than the minimum pulse width required to trigger the suppression gate circuitry. Therefore a zone exists, for pulse widths which are less than the minimum required to trigger suppression, within which certain transponders could reply even though an SLS pulse is present in the interrogation. The purpose of this test was to determine the extent of this phenomenon in the sample transponders and to indicate whether a short pulse waveform that can suppress ATCRBS transponders would also trigger replies from a large fraction of the transponders.

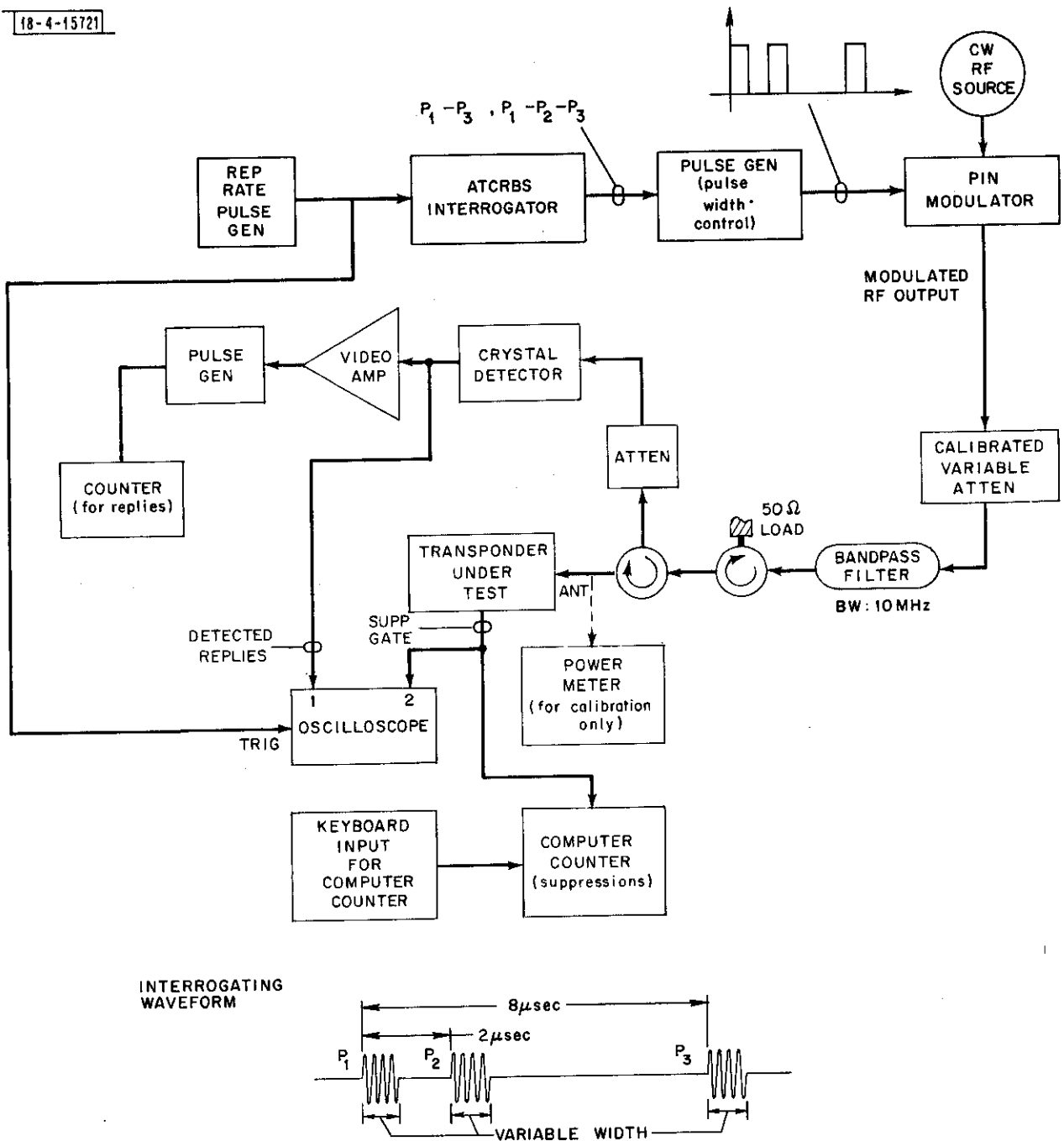


Fig. 5. Block Diagram of Test Configuration Minimum Pulse Width to Trigger and Minimum Pulse Width to Suppress.

TRANSPONDER

18-4-15722

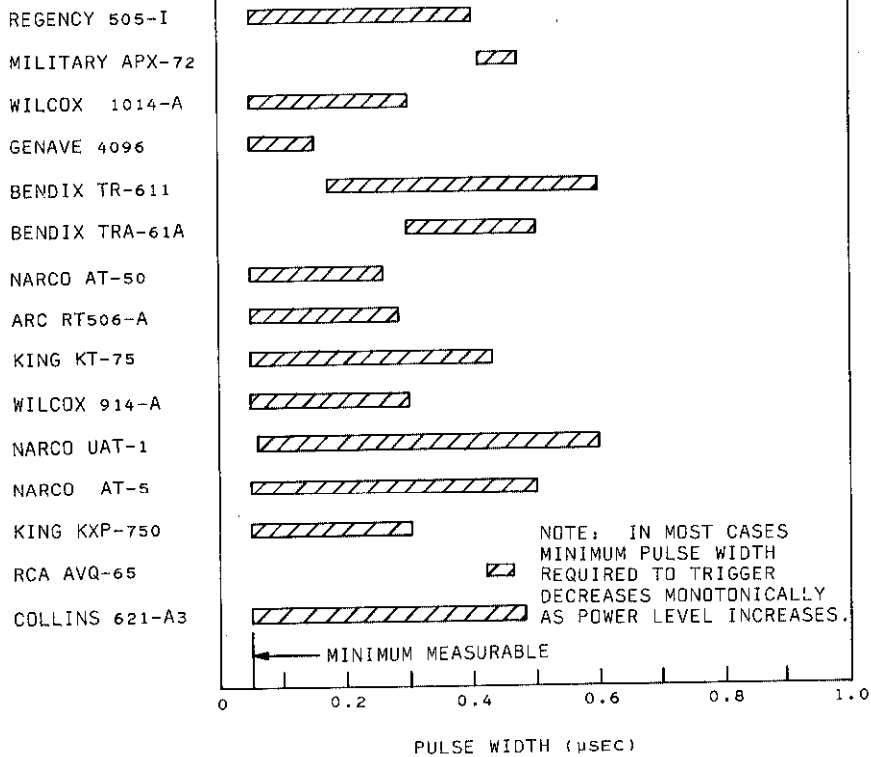


Fig. 6. Range of Minimum Pulse Widths Required to Trigger ATCRBS Replies As Interrogation Power Level Varies from -20 dBm to -70 dBm.

In this test, the transponders were interrogated with a Mode-A pulse pair (P_1 and P_3) plus a sidelobe suppression pulse (P_2) of the same amplitude as P_1 and P_3 . The widths of all three pulses were varied simultaneously to determine: a) the minimum width at which solid suppression occurred, and b) the range of pulse widths below this minimum over which replies were triggered with P_2 present. In the test procedure, the widths of all pulses in the P_1 - P_2 - P_3 pulse sequence were simultaneously increased until replies were first observed, and then increased further until solid suppression was obtained. These tests were conducted for a range of interrogation levels from -20 to -70 dBm. The block diagram for this test is the same as that shown in Figure 5.

The results of this test varied markedly over the range of interrogation levels and the individual transponders. For three of the fifteen transponders tested, suppression was reliable regardless of interrogation level or pulse width, while for the remaining transponders the response seemed highly dependent on interrogation level. As an indication of the type of response exhibited by the transponders, the data taken at the -60 dBm interrogation level are plotted in Figure 7. This figure is not necessarily a typical response characteristic, in that as the interrogation level was increased more transponders were found to be reliably suppressed (no replies regardless of pulse width), i. e., at -60 dBm, five transponders were reliably suppressed; at -50 dBm, eight transponders were reliably suppressed; and at -40 dBm, twelve transponders; etc. Four transponders also replied heavily at -20 dBm, but this could be attributed to saturation of the receivers since this is the extreme upper limit of the interrogation range specified by the ATCRBS Standard.

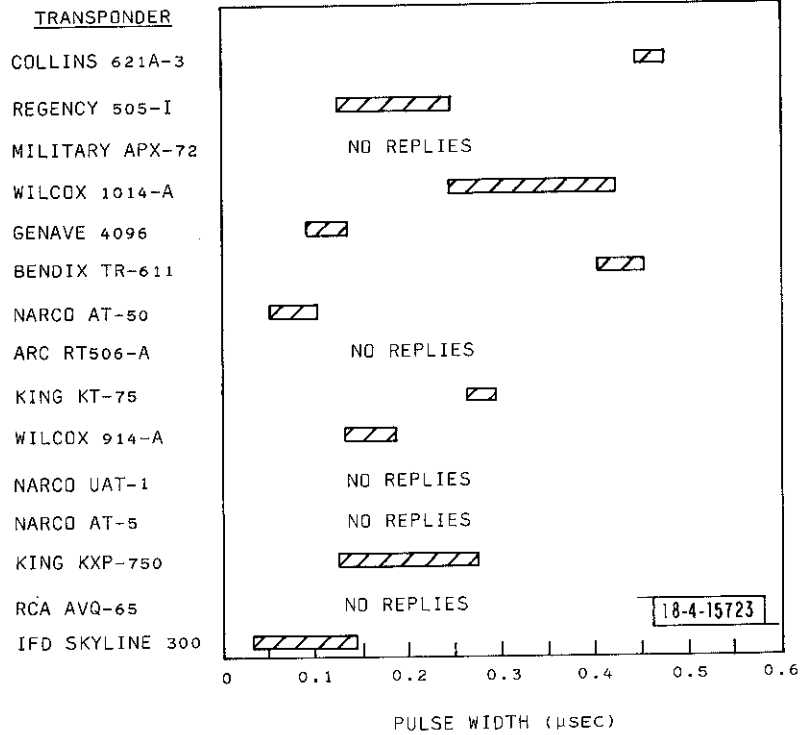


Fig. 7. Range of Pulse Widths, Below the Minimum Width Required to Trigger Solid Suppression, Over Which Replies are Obtained.

It can be concluded that the Mode-A decoding circuitry in most ATCRBS transponders detects pulses whose widths are less than the minimum required to suppress the transponders, and that any pulse width large enough to suppress the transponders would also be able to trigger replies from a significant fraction of the ATCRBS population.

It is further concluded that due to the wide variation in the tolerance to non-standard pulses, any uplink transmission using non-standard pulses at a usable data rate would trigger replies from a significant fraction of the ATCRBS population.

3.5 P_1 - P_2 SPACING TOLERANCE

The purpose of this test was to determine the range of P_1 - P_2 spacings over which the transponders suppress. Each transponder was interrogated with a standard Mode-A pulse sequence with an SLS suppression pulse (P_1 - P_2 - P_3).

The P_1 - P_2 spacing was varied in both directions about the standard (2 μ sec) until suppression ceased and a 90% reply rate was obtained. (Block diagram, Figure 8.) The range of spacings for suppression of each transponder in the sample is plotted in Figure 9.

These tests were conducted at interrogation levels of -30, -50, and -65 dBm. Little variation was found as a function of interrogation level.

3.6 P_1 - P_3 SPACING TOLERANCE

The objective of this test was to determine if there exists a non-standard pulse spacing for the DABS uplink transmission to which a majority of ATCRBS transponders would not reply. The transponders were interrogated with a standard Mode-A pulse pair (P_1 - P_3). The P_1 - P_3 spacing was varied in both directions

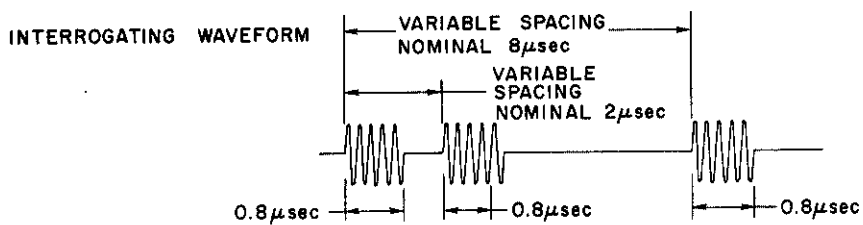
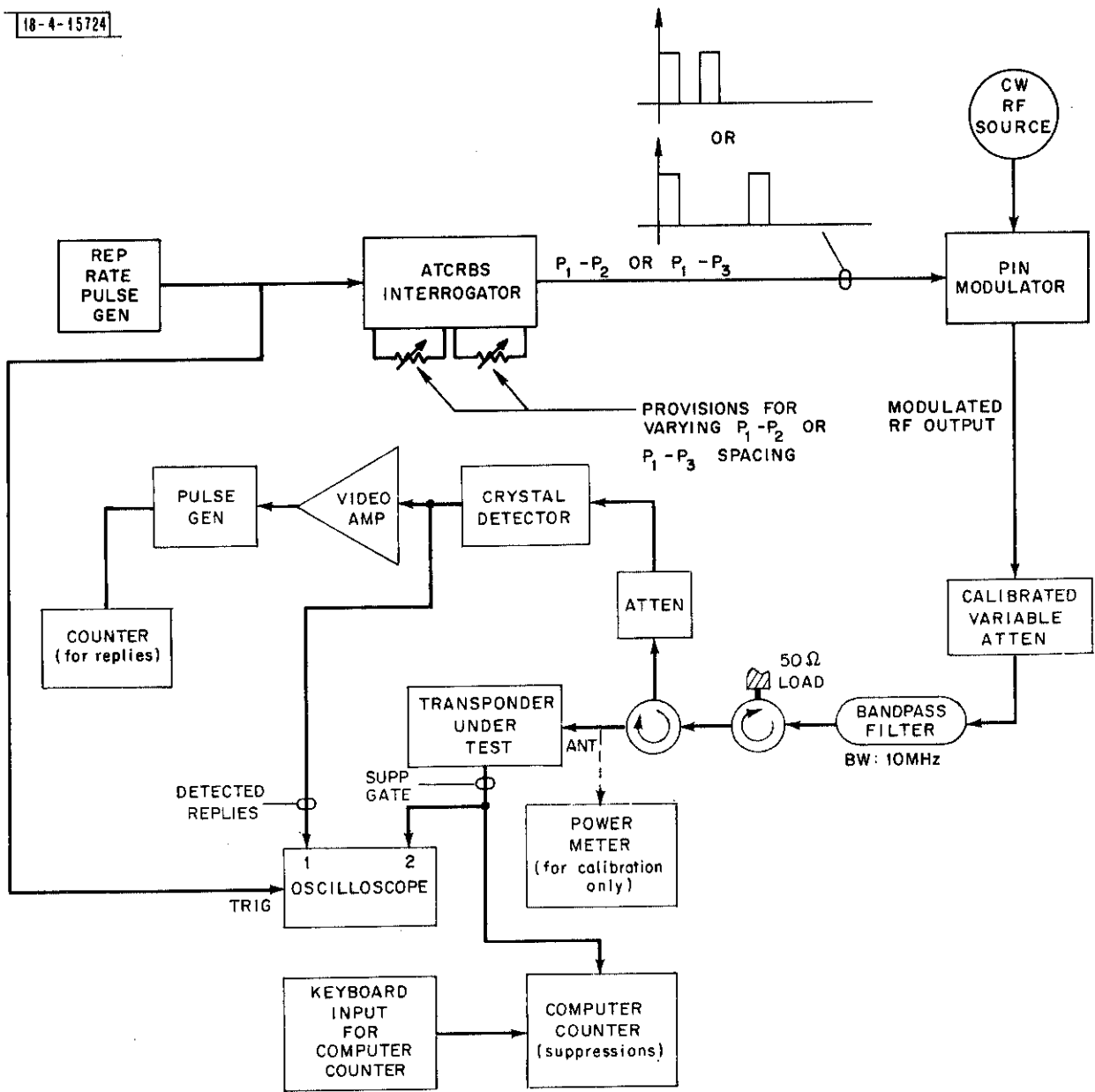


Fig. 8. Block Diagram of Test Configuration $P_1 - P_2$ Spacing Tolerance and $P_1 - P_3$ Spacing Tolerance.

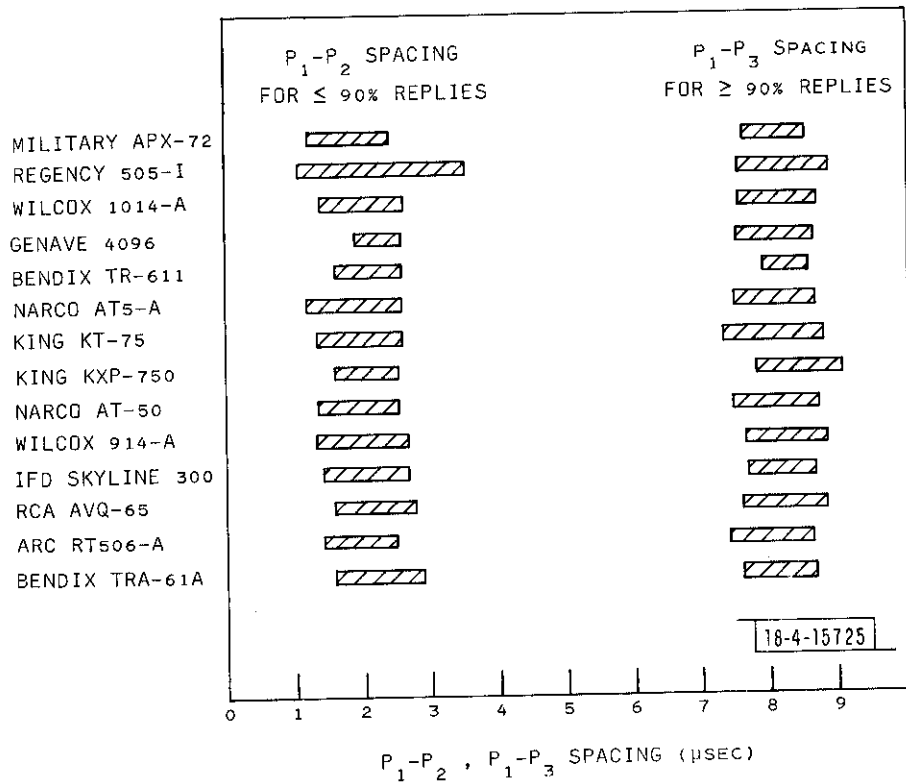


Fig. 9. P_1-P_2 , P_1-P_3 Spacing Tolerance.

from the standard (8 μ sec) until the reply rate dropped to 90%. (Block diagram, Figure 8.) The range of spacing over which replies were obtained from each transponder is also plotted in Figure 9.

These tests were conducted at interrogation levels of -30, -50, and -65 dBm with little variation in observed response as a function of interrogation level.

These measured tolerances indicate little likelihood of using standard pulses with non-standard spacings and a usable data rate (> 0.5 Mb/s) which would not elicit replies from some ATRBS transponders.

3.7 SUPPRESSION AND RESUPPRESSION TIME MEASUREMENTS

The purpose of this set of tests was to provide information regarding the suppression time, resuppression time, and resuppression time interval exhibited by ATRBS transponders. The suppression time measurement sets an upper limit on the allowed DABS message length in one of the proposed DABS uplink schemes, which intentionally suppresses ATRBS transponders with an SLS-like preamble and transmits the DABS message within one suppression period. Having intentionally suppressed the transponders, they should not reply to false decodes generated by the DABS message transmitted within the duration of the suppression period. The resuppression time measurement determines the minimum spacing of DABS interrogations with an ATRBS suppressing preamble which can reliably resuppress all ATRBS transponders in the interrogation beam. This parameter has significance when considering the likelihood of continued resuppression of ATRBS transponders during long DABS messages requiring multiple interrogations.

The resuppression time interval was determined from the measurement of the first two parameters: a) the minimum spacing between an SLS interrogation and a subsequent successful Mode-A interrogation (suppression time*), and b) the minimum spacing between two successful SLS decodes (resuppression time). The difference between these two measurements has been defined as the resuppression time interval. (Block diagram, Figure 10.)

Figure 11 illustrates the results of these measurements at the -50 dBm interrogation level. Little variation in these results was found as a function of interrogation level over a 35 dB test range, from -30 to -65 dBm.

The results show that suppression periods exhibited by the ATCRBS transponders in the sample cover the entire range allowed by the ATCRBS Standard ($35 \pm 10 \mu\text{sec}$). Examining the resuppression time data, one can conclude that the minimum spacing of DABS interrogations with an ATCRBS suppressing preamble would have to be approximately 50 μsec , enough time to allow transponders with the longest resuppression time to be reliably resuppressed.

The ATCRBS Standard states that a transponder must be able to resuppress for the full duration within 2 μsec after the end of any suppression period. From Figure 11 it can be seen that few of the transponders tested met this specification. Approximately one half of the transponders tested exhibited resup-

*The definition of ATCRBS suppression time given in the RTCA Standard [3] is the interval between the start of a P₂ pulse sufficient to cause suppression and the start of a subsequent successful Mode-A interrogation. In these tests, the suppression time is measured from the start of the interrogation. The discrepancy is not significant in the context of this report, since the important data is the end of the suppression period, which is the same in either case.

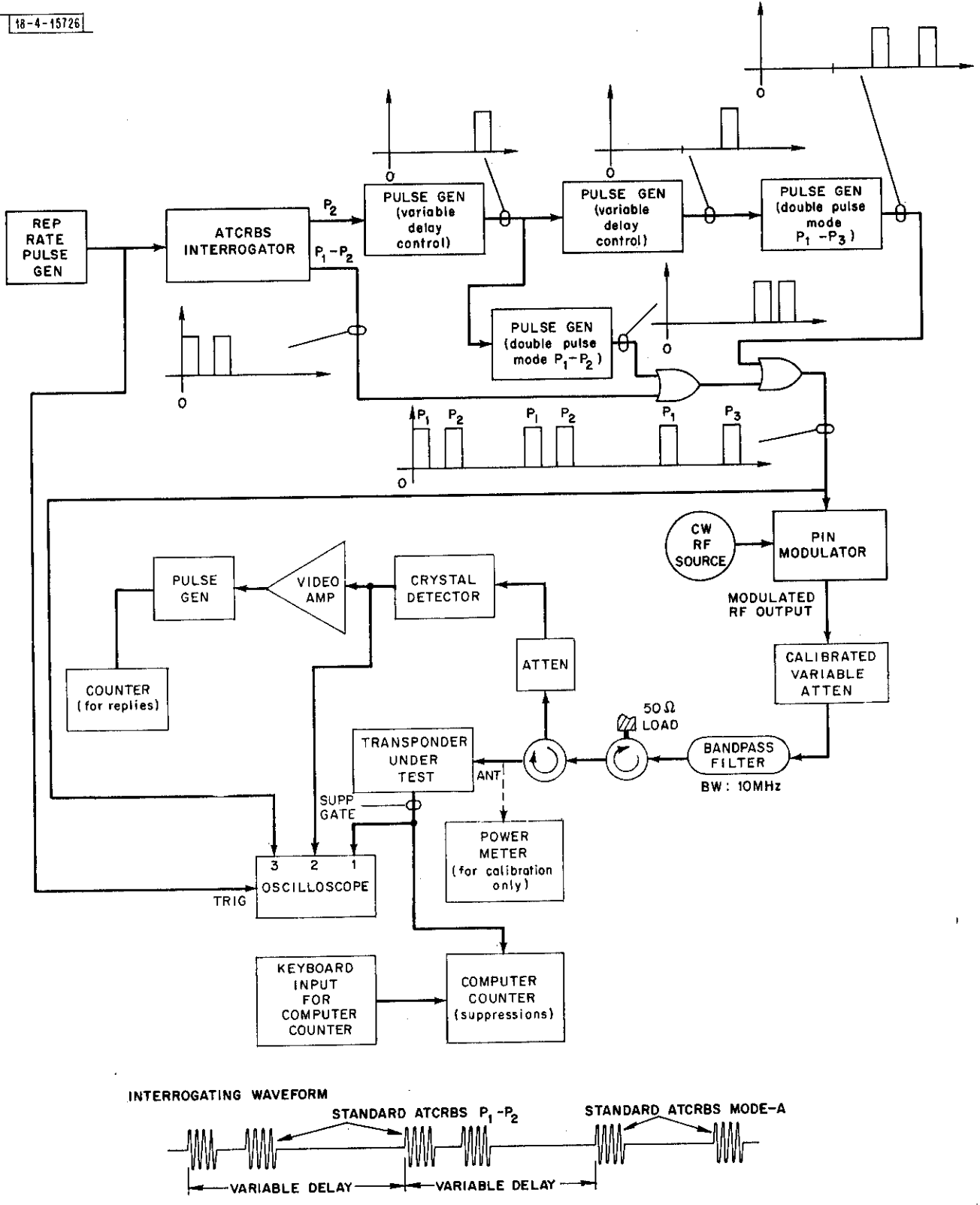
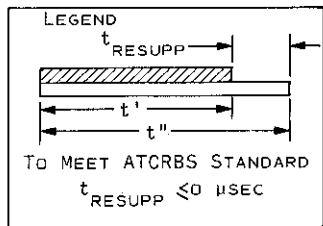
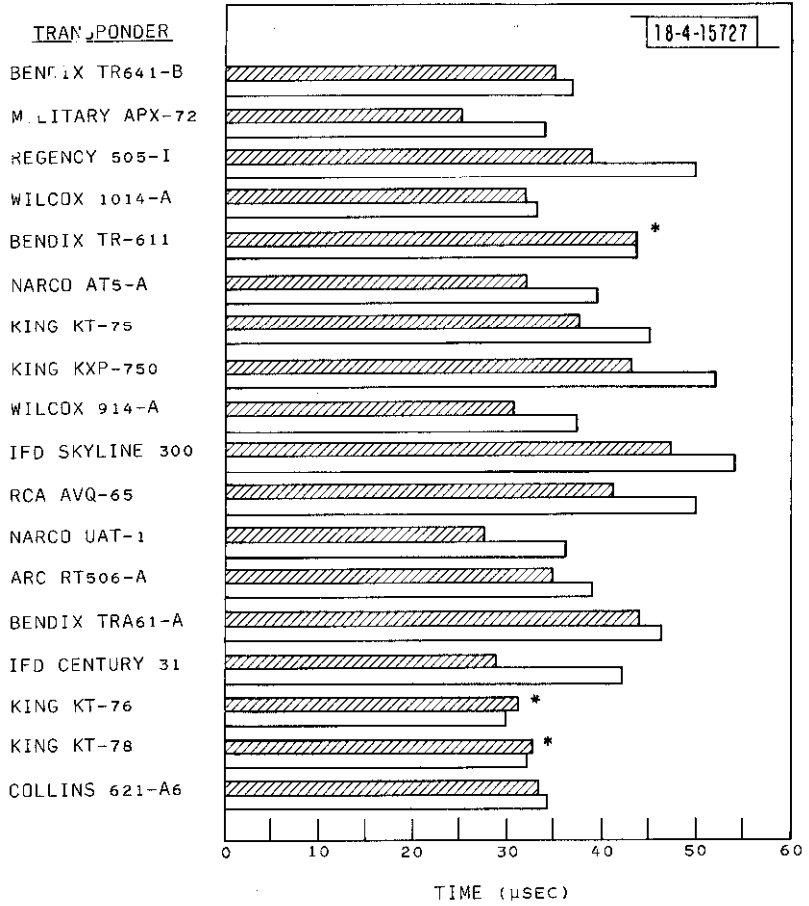


Fig. 10. Block Diagram of Test Configuration - Suppression and Resuppression Time Measurements.



* THESE TRANSPONDERS MET THE ATCRBS SPECIFICATION.

t' = THE MINIMUM P_1-P_1 SPACING BETWEEN AN SLS INTERROGATION AND A SUBSEQUENT SUCCESSFUL MODE-A INTERROGATION (SUPPRESSION TIME)

t'' = MINIMUM P_1-P_1 SPACING BETWEEN TWO SUCCESSFUL SLS DECODES (RESUPPRESSION TIME)

t_{RESUPP} = RESUPPRESSION TIME INTERVAL = $t''-t'$

Fig. 11. Resuppression Time Interval (t_{resupp}) at -50 dBm.

pression time intervals in the range of 6 to 8 μ sec. Since the resuppression time interval in many cases is of the same magnitude as, or greater than, the interval required for a valid Mode-A interrogation, no guarantee can be made that resuppression will occur before the transponder replies to a DABS waveform that is decoded as a valid ATCRBS interrogation.

4.0 TEST GROUP 2 DESCRIPTION AND RESULTS

Test Group 2, examining the direct response of ATCRBS transponders to candidate DABS waveforms, included: 1) Preliminary DABS Tests, 2) Intentional ATCRBS suppressing schemes, and 3) DABS/ATCRBS Discrimination Tests. The Preliminary DABS Tests checked the response of ATCRBS transponders to the basic types of modulation, CW-FSK, long and short-pulse PAM, and CW-PSK. The other two test segments examined the response to specific uplink transmissions.

In this section of the report, most of the data are presented in the form of bar-circle charts, indicating the number and types of transponders which reply as a function of received signal power and DABS message length and modulation scheme. At the top of each chart, pertinent information is included concerning the modulation scheme and/or test conditions for the data presented on the page. Also included is the threshold criterion used for making chart entries. The threshold criterion depends on the expected transponder behavior to the particular modulation scheme. An entry in the chart indicates that the average reply count exceeded the fixed threshold. The thresholds were set at 10 % if no response was expected and 90 % if a solid response was expected. No numerical counts of replies or suppressions per interrogation are given.

Each chart consists of four smaller charts, one for each DABS message length: 25, 50, 100, and 200 bits. The smaller charts indicate the number of units satisfying the set criterion at each interrogation level. In most of the

preliminary tests, the interrogation levels were -20, -30, -40, -50, -60, and -65 dBm. Since in almost every case the response at -40 dBm was identical to that recorded for -30 dBm, the -40 dBm data were omitted. Within the circles is the transponder identification number used in Table 2.1. The total number of transponders tested is also indicated by a dashed line, while the note at the bottom of the chart indicates the transponders which were not included in that test.

In those tests which used both random and deterministic (fixed-mode) interrogation sequences, and the data for both modes are presented in the same chart, a square symbol is used to denote fixed-mode. The fixed-mode interrogation consists of an alternating sequence of mark and space transmissions and the random mode consists of a sequence of mark and space transmissions with 0.5 probability of transition at each bit time.

In the case of DABS messages with ATCRBS suppressing preamble, it was found that at interrogation levels near MTL, the suppression circuitry of most transponders fails to suppress reliably, resulting in replies due to loss of initial suppression capability. As a result, these tests were also conducted at interrogation levels down to -70 and -75 dBm. Unless otherwise noted, in the tests with and intentional ATCRBS suppressing preamble, the spacing between the trailing edge of P_2 pulse in the preamble and the beginning of the DABS message was $0.5 \mu\text{sec}$.

4.1 PRELIMINARY DABS TESTS

The Preliminary DABS Tests checked the response of ATCRBS transponders to CW-FSK, long and short pulse PAM, and CW-PSK signals, partic-

ularly with regard to their invisibility. The data presented in the bar circle charts for the preliminary DABS tests indicate all of the transponders which replied to more than 10% of the interrogations.

4.1.1 Response to CW-FSK

The purpose of this test was to determine the response of ATCRBS transponders to continuous wave FSK modulated signals. These tests were conducted at interrogation levels of -30, -45, and -65 dBm. The FSK modulation was generated directly with an L-Band voltage controlled oscillator with a transition time of about 50 nsec and a frequency deviation of ± 2 MHz. A VCO was used so that the signal could be slewed rapidly between two binary frequencies without producing amplitude transients on the RF carrier. A block diagram of the test set-up and a sketch of a typical output waveform are given in Figure 12. The bit duration was 1.0 μ sec and the tests were conducted for random message sequences of lengths 25, 50, 100, and 200 bits, and fixed sequences 25 bits long. The data from these tests are plotted in Figure 13, based on a 10% reply criterion.

The results indicate that a significant fraction of the transponders replied to this waveform for all message lengths and interrogation levels. For example, for 50-bit messages at the -45 dBm interrogation level, 50% of the transponders tested replied with average reply rates exceeding the 10% level. (Of these same transponders, 50% were suppressed at an average rate greater than 10%.)

An asymmetry of the transponder receiver sensitivity characteristic about 1030 MHz or a misalignment of the local oscillator can cause the receiver to act like an FM discriminator which converts the FSK to PAM. If the transient resulting from this receiver asymmetry is of sufficient

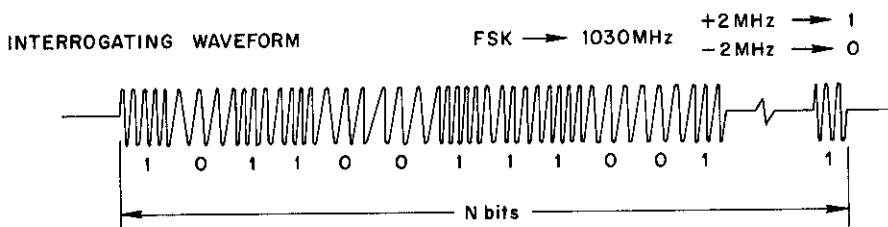
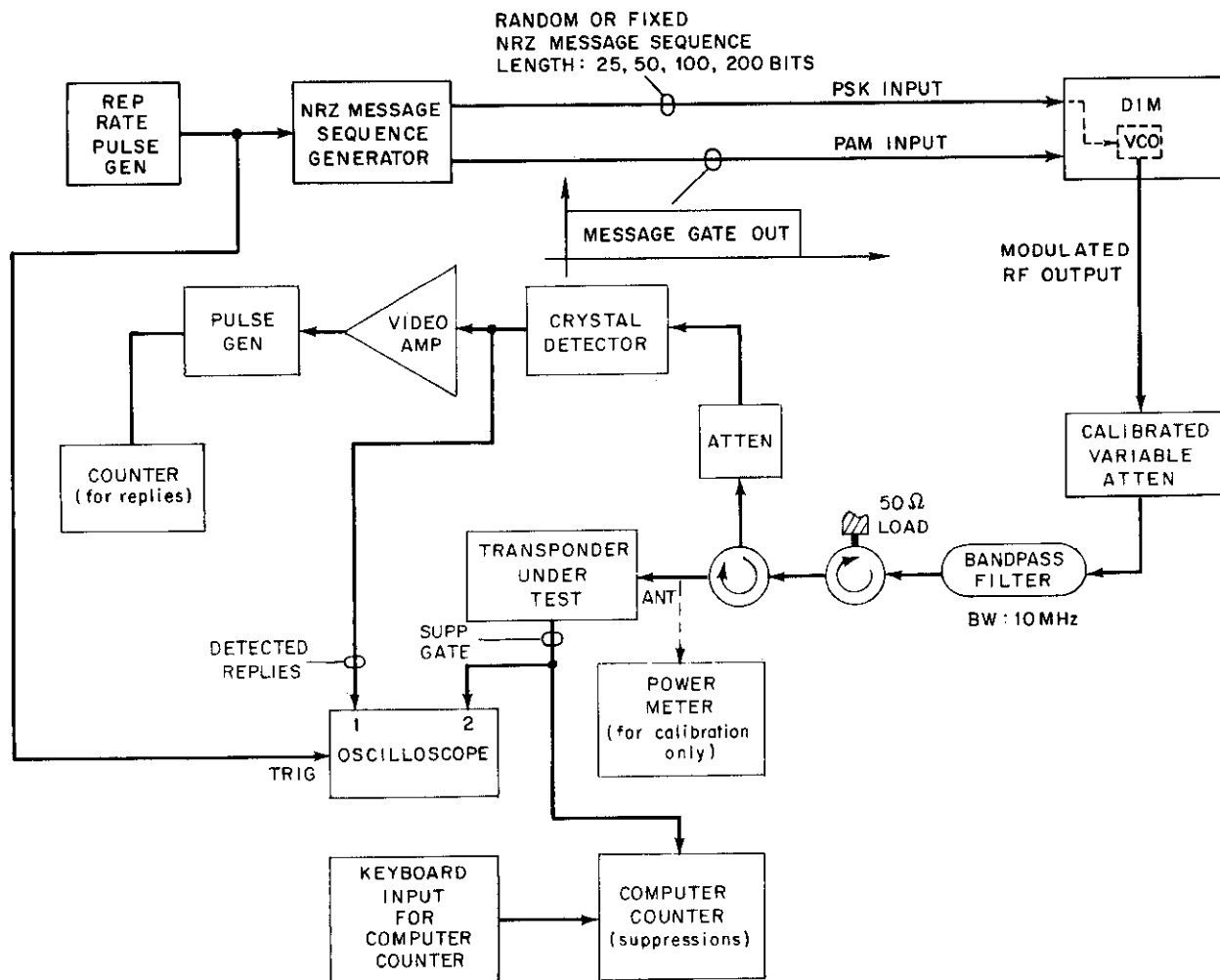
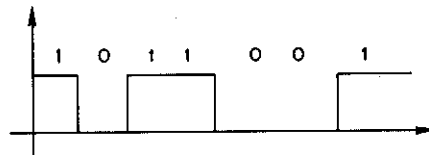
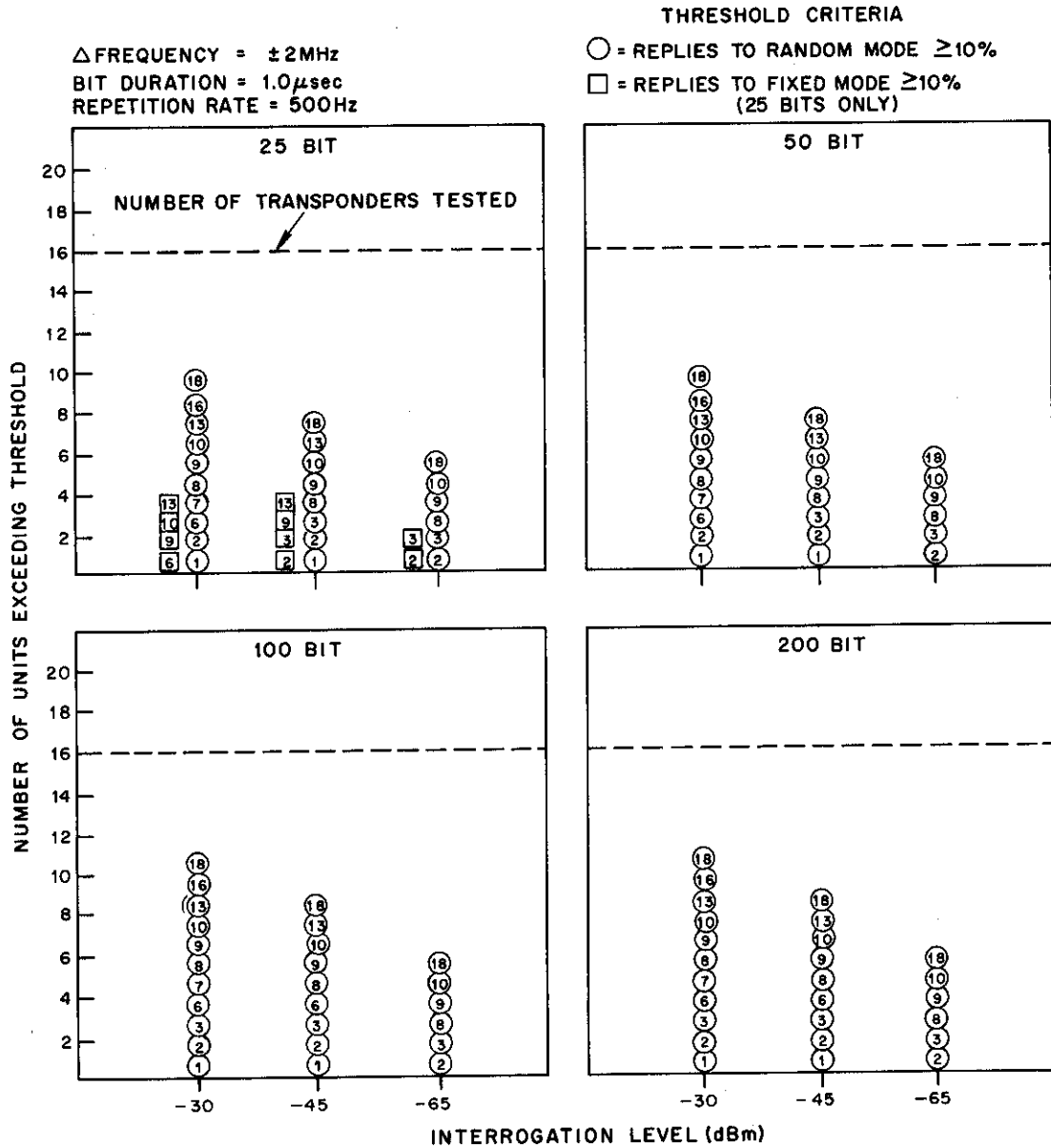


Fig. 12. Block Diagram of Test Configuration - Response to CW-FSK.



UNITS NOT TESTED - 4, 14, 15, 19, 20, 21

Fig. 13. Response to CW-FSK.

amplitude and duration such that the video pulse out of the receiver can be interpreted as an ATCRBS pulse, the FSK sequence may be decoded as an ATCRBS interrogation pair. About one half of the transponders tested exhibited asymmetries in sensitivity (measured MTL) of their receiver response of more than 3 dB at frequencies offset by 2.5 MHz from 1030 MHz (see Section 3.2). It should be noted that two of the transponders were found to have relatively asymmetrical receiver passbands yet did not reply heavily (> 10%) to FSK. The reply probability of a given transponder depends on other factors in addition to symmetry, such as: the gain characteristic of the IF amplifier, the tolerance of the decoder to non-standard pulses, and the characteristics of the SLS and echo suppression circuitry. In addition, in most transponders the receiver passband broadens with increases in the received signal strength due to the action of the logarithmic IF amplifier. However, a sufficiently high percentage of the transponders replied to CW-FSK interrogations to allow one to conclude with reasonable certainty that FSK is not an invisible waveform.

4.1.2 Response to PAM

The purpose of these tests was to examine the response of ATCRBS transponders to random PAM message sequences and fixed PAM sequences (simulating pulsed PSK modulation), checking the suppression and resuppression capabilities of each waveform. These tests were conducted at interrogation levels of -20, -30, -40, -50, -60 and -65 dBm. The random and fixed message sequences were tested for long-pulse (0.6 μ sec

pulse width at $1.0 \mu\text{sec}$ spacing) and short-pulse width at ($0.25 \mu\text{sec}$ pulse width at $0.5 \mu\text{sec}$ spacing) PAM. The random waveforms and the long-pulse fixed waveforms were tested with message lengths of 25, 50, 100, and 200 bits, while the short-pulse fixed waveforms were tested at 25 bits only. (Block diagram, Figure 14.) The results of these tests are presented in Figure 15 and 16, where the criterion for data entry is an average reply rate exceeding 10%.

As predicted in Sections 3.3 and 3.4, short pulse PAM is not an invisible waveform to most ATCRBS transponders. The random long pulse messages elicited greater than 10% reply rates from every transponder in the sample while the fixed-mode, long-pulse sequence caused fewer transponders to reply than did the random sequence. However, it is noteworthy that this fixed mode modulation (which simulated pulsed PSK) elicited greater than 10% reply rate from a significant fraction of the transponders at all message lengths and interrogation levels. It was expected that alternate pulse pairs (spaced $2 \mu\text{sec}$ apart) would act as standard $P_1 - P_2$ pairs to suppress and continually resuppress all ATCRBS transponders. It is clear from the 25-bit chart of Figure 16 that some transponders failed to suppress initially on this waveform. The other charts of Figure 16 indicate that many transponders also failed to resuppress on this waveform.

As an example of how serious the problem of false replies would be with a purely ATCRBS-type PAM transmission, for $25 \mu\text{sec}$ random messages at a 1Mb/s data rate, approximately 85% of the transponders tested replied on the average to more than 50% of the interrogations at the -50 dBm interrogation level.

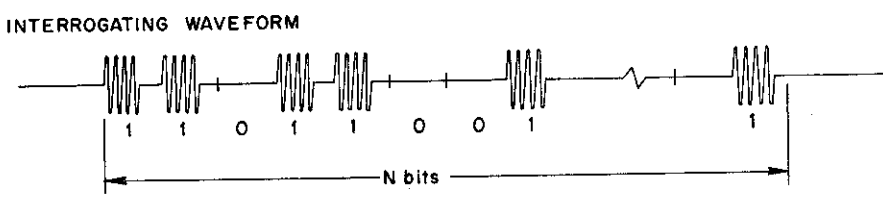
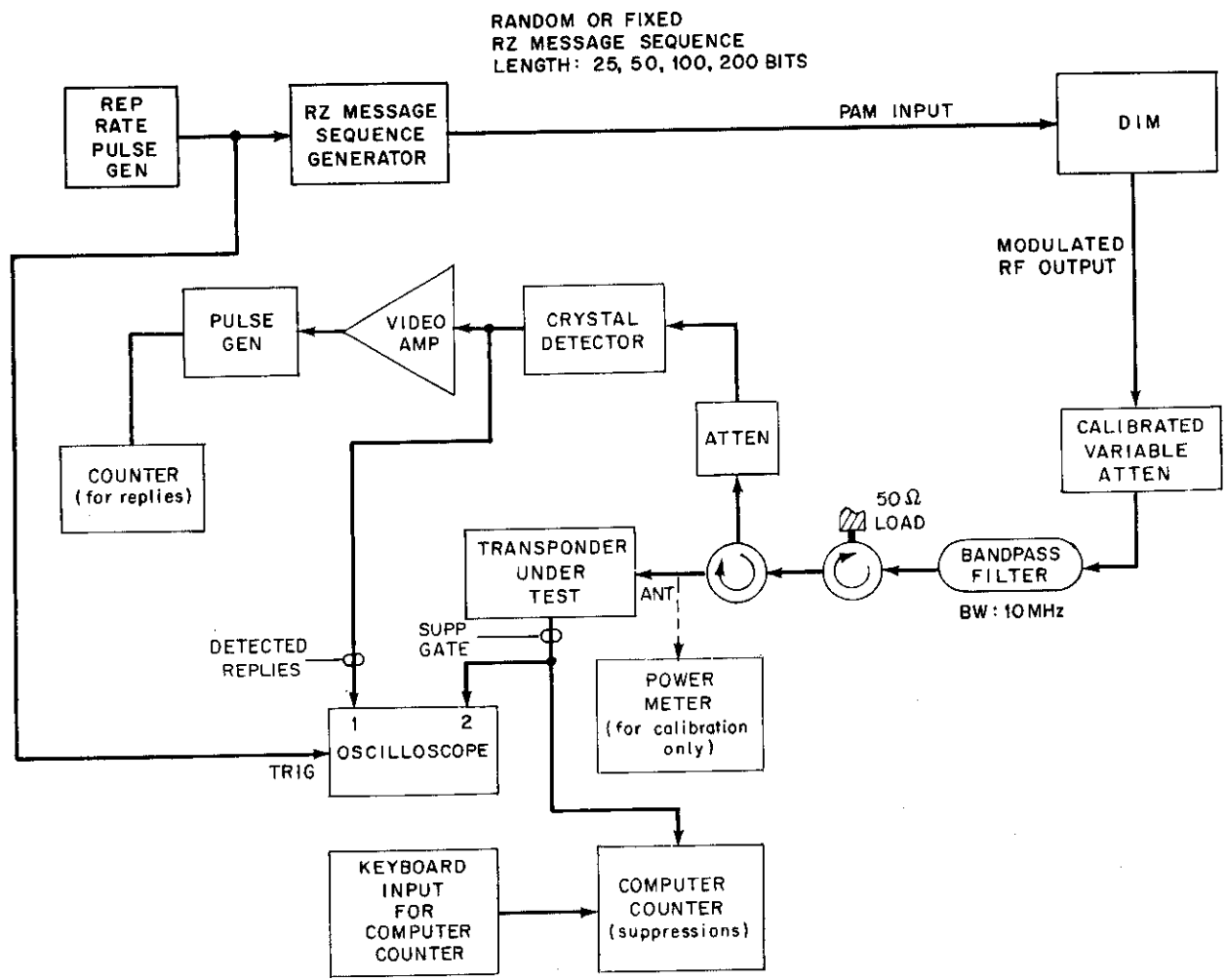
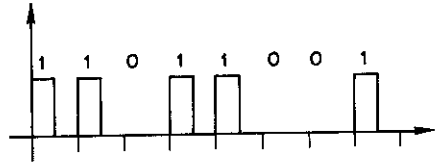
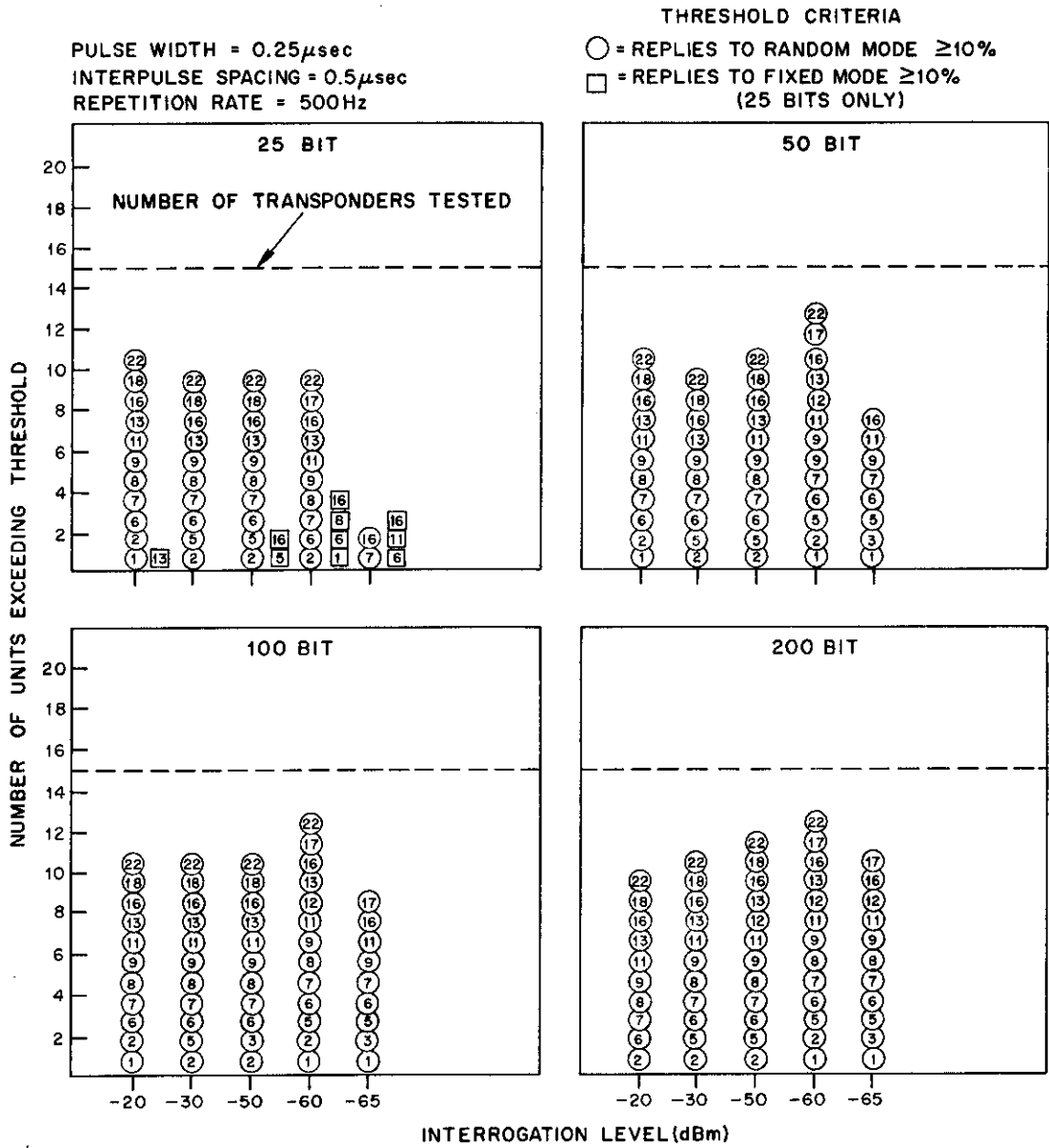
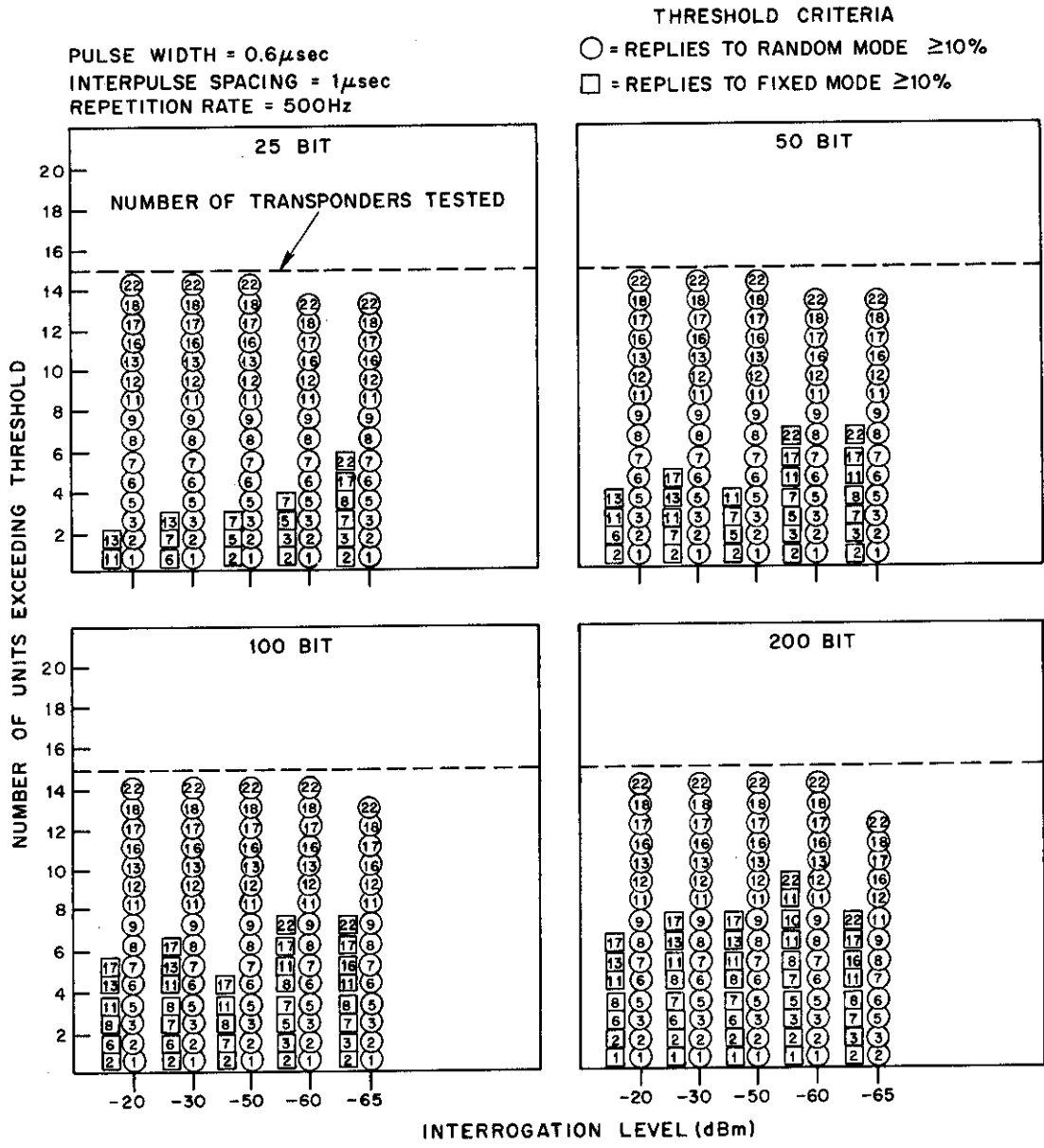


Fig. 14. Block Diagram of Test Configuration - Response to PAM (RZ).



UNITS NOT TESTED - 4, 10, 14, 15, 19, 20, 21

Fig. 15. Response to Short-Pulse PAM.



UNITS NOT TESTED - 4, 10, 14, 15, 19, 20, 21

Fig. 16. Response to Long-Pulse PAM.

For a fixed message sequence of the same length and data rate, only 20% of the transponders exhibited an average reply rate exceeding 10% at the -50 dBm interrogation level.

A general trend which is not readily apparent from the bar circle charts is the increase in reply rates as the message length is extended. This effect may be noted (slightly) in the fixed mode data of Figure 16.

4.1.3. Response to CW-PSK

The purpose of this set of tests was to examine the response of ATCRBS transponders to CW-PSK modulation. These tests were conducted for random 25, 50, 100, and 200 bit message sequences at interrogation levels of -20, -30, -40, -50, -60, and -65 dBm, and the bit duration was $0.25 \mu\text{sec}$. (Block diagram, Figure 17.) Figure 18 illustrates the results of these tests. It was not expected that PSK would be invisible to ATCRBS transponders due to the finite phase transition which can be translated to amplitude modulation by the filters in the transponders. This expectation was borne out by experiment in that approximately 40% of the transponders tested replied to more than 10% of the interrogations for 50 bit messages ($12.5 \mu\text{sec}$ in length) at the -50 dBm interrogation level. It is seen that PSK modulation has a slight advantage over PAM in terms of invisibility for a comparable message length. The effect of increased reply rates with increased message length is again noted in Figure 18 in terms of a greater number of transponders exceeding the 10% threshold at the longer message lengths.

4.2 ATCRBS SUPPRESSING SCHEMES

The Preliminary DABS Tests examined ATCRBS transponder response to the three basic types of modulation. These tests indicated that none of the

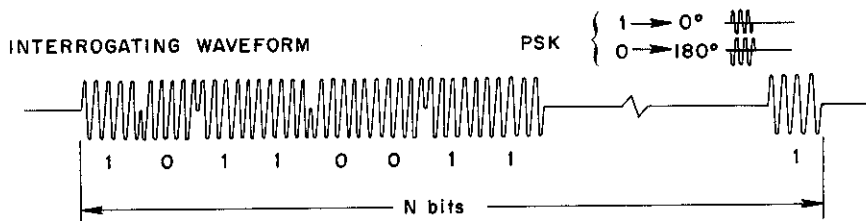
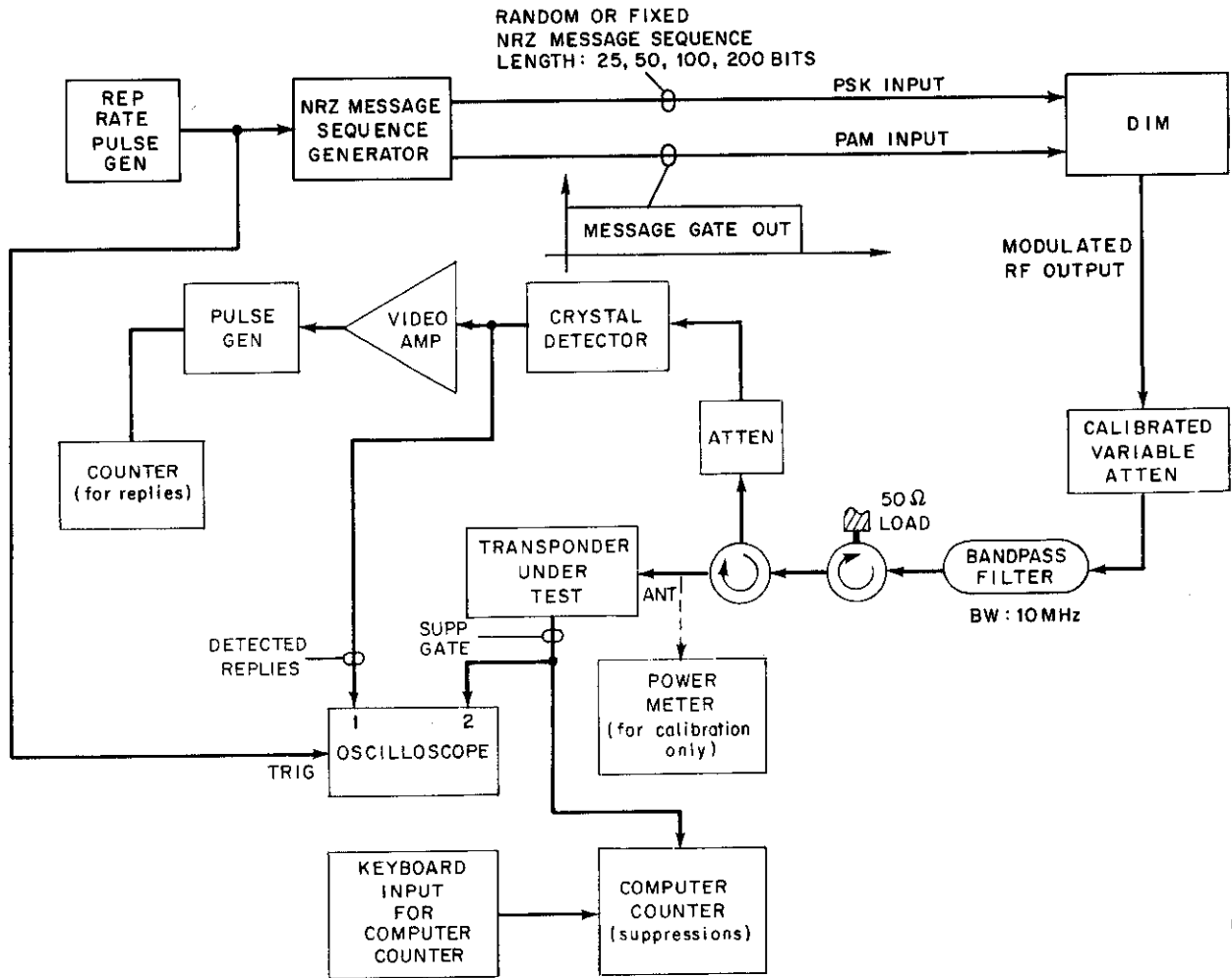
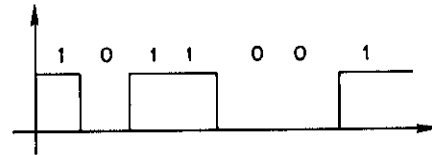
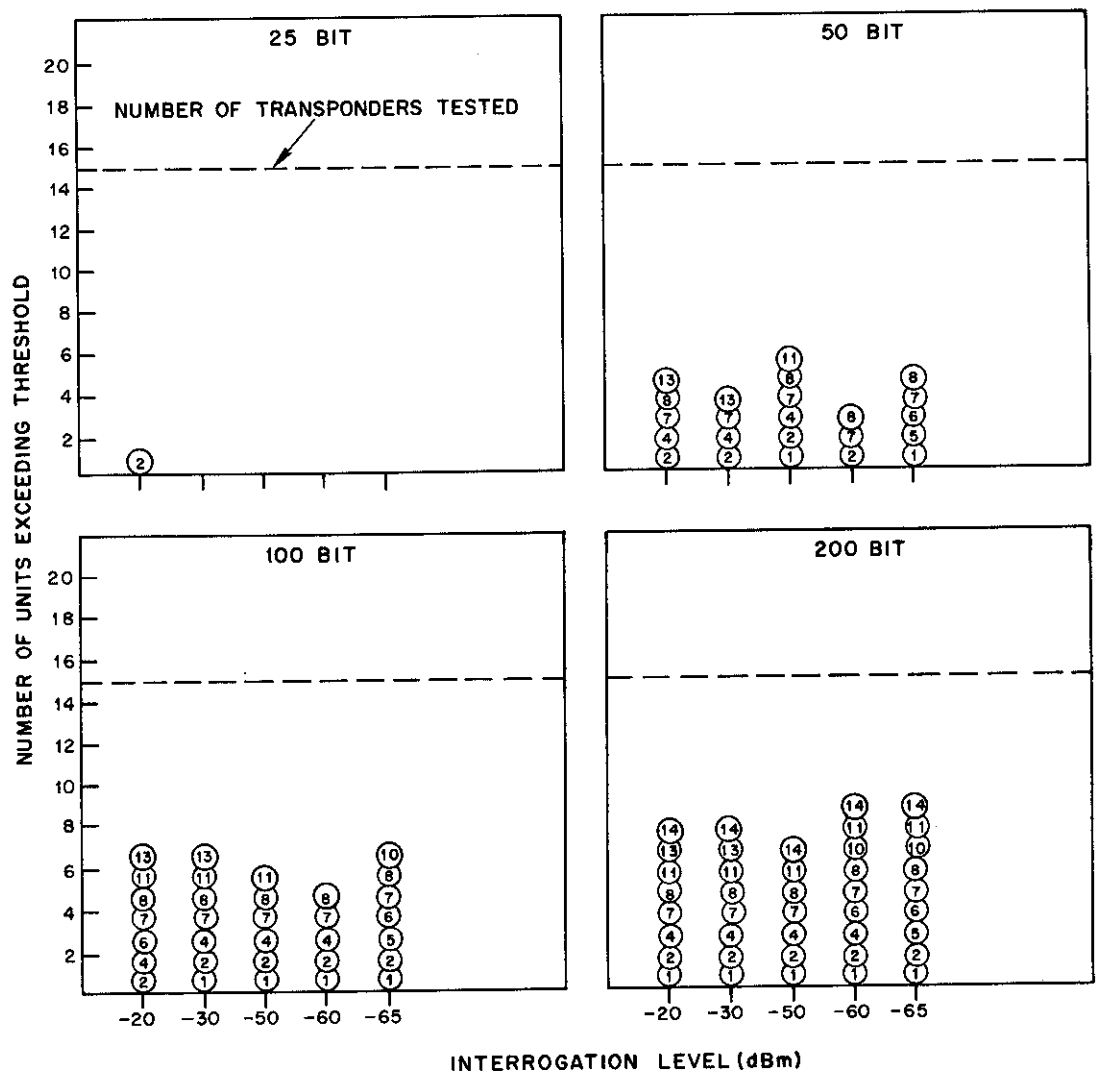


Fig. 17. Block Diagram of Test Configuration - Response to CW-PSK.

BIT DURATION = 0.25 μ sec
 INTERPULSE SPACING = —
 REPETITION RATE = 500Hz

THRESHOLD CRITERIA
 ○ = REPLIES TO RANDOM MODE \geq 10%



UNITS NOT TESTED — 15, 16, 17, 18, 19, 20, 21

Fig. 18. Response to CW-PSK.

basic modulation types are invisible to ATCRBS transponders, and thus DABS cannot rely on invisibility alone to prevent replies from ATCRBS transponders. Subsequent testing examined specific uplink transmissions which were designed on the basis of these preliminary results.

The alternative is to intentionally suppress ATCRBS transponders with an SLS sequence in the preamble to the DABS message and rely on: a) short message duration, b) partial invisibility, or c) resuppression capabilities of the particular DABS uplink waveform, to prevent the ATCRBS transponders from replying to the DABS uplink message following the end of the initial suppression interval. To this end, tests were conducted with an ATCRBS suppressing preamble followed by PAM, NRZ-PAM, and PSK messages. (FSK was not considered since it offers no advantages over PAM or PSK and requires more bandwidth.)

4.2.1 Response To PAM With ATCRBS Suppressing Preamble

These tests examined the transponder response to fixed and random sequences of long and short-pulse PAM messages following a standard ATCRBS SLS suppression sequence. The separation between the trailing edge of the P_2 pulse and the beginning of the message sequence was $1.0 \mu\text{sec}$. These tests were conducted for 25, 50, 100, and 200 bit messages at interrogation levels of -20, -30, -40, -50, -60, -65, -70 and -75 dBm. (Block diagram, Figure 19). The data from these tests are presented in the bar-circle charts, Figures 20 through 23, using a 10% criterion for replies.

The results indicate that the suppression pair suppresses the transponders initially, but that messages which extend beyond the initial suppression period elicit substantial replies (even fixed messages sequences fail

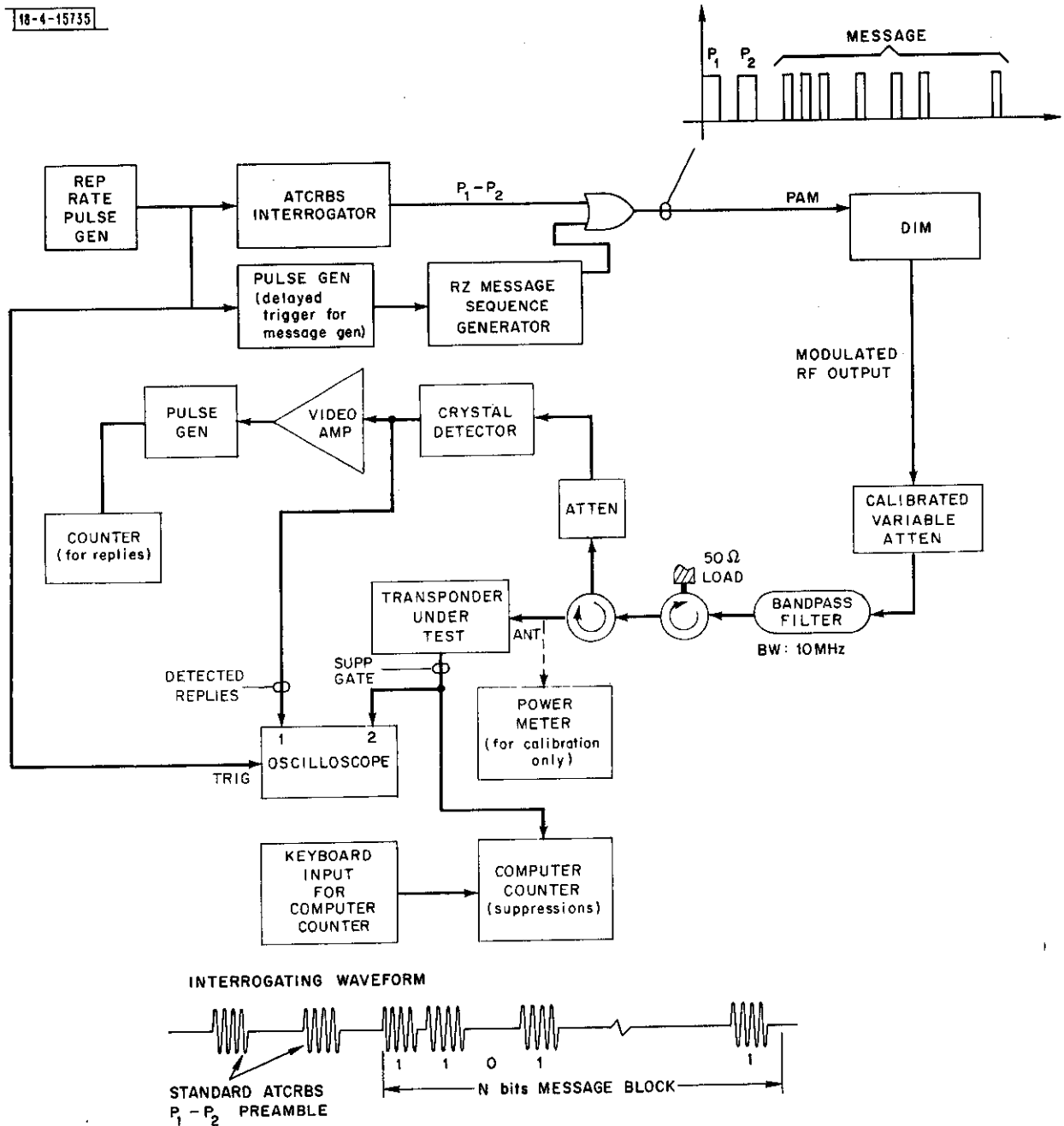
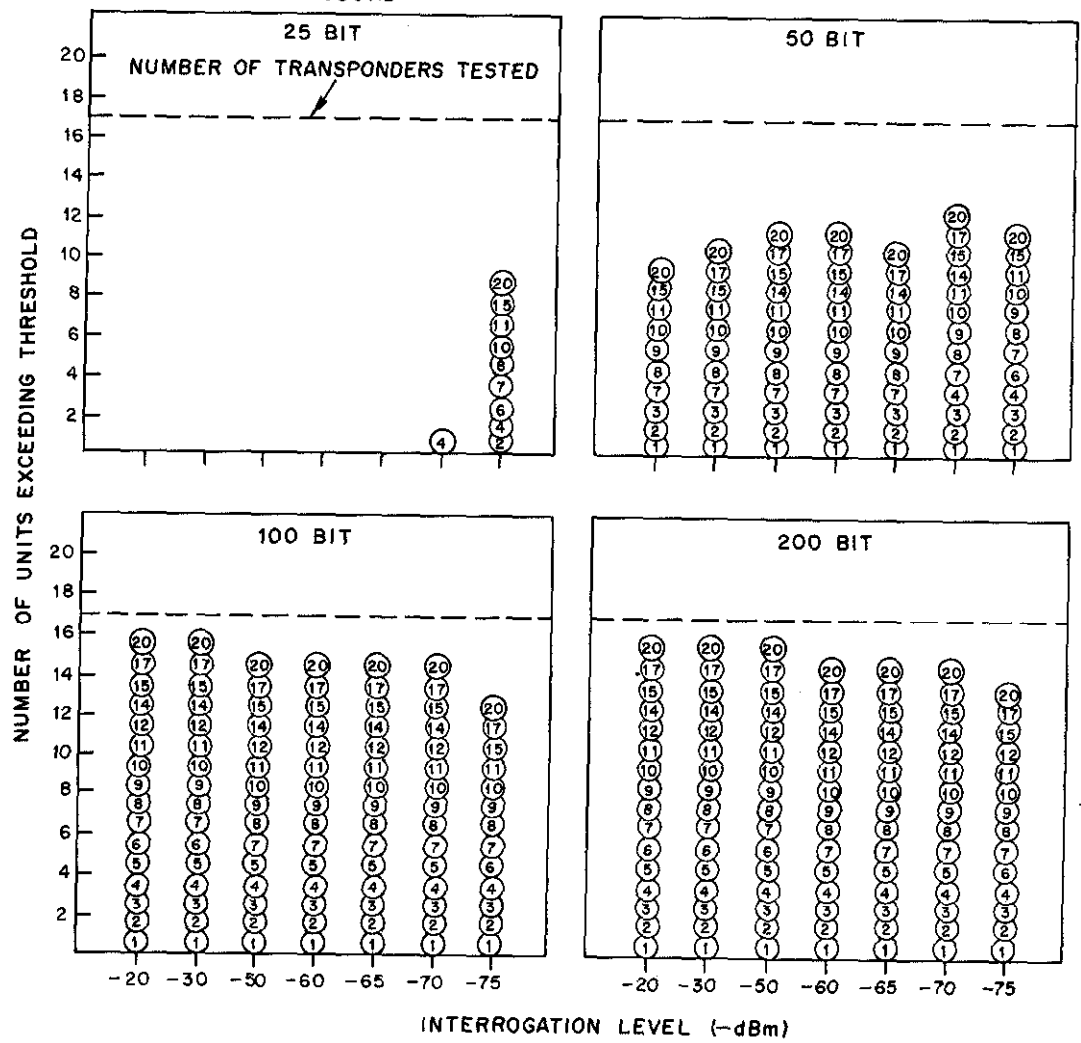


Fig. 19. Block Diagram of Test Configuration - Response to PAM with ATCRBS Suppressing Preamble.

PULSE WIDTH = 0.6 μ sec
 INTERPULSE SPACING = 1.0 μ sec
 REPETITION RATE = 500Hz

THRESHOLD CRITERIA
 ○ = REPLIES TO RANDOM MODE $\geq 10\%$

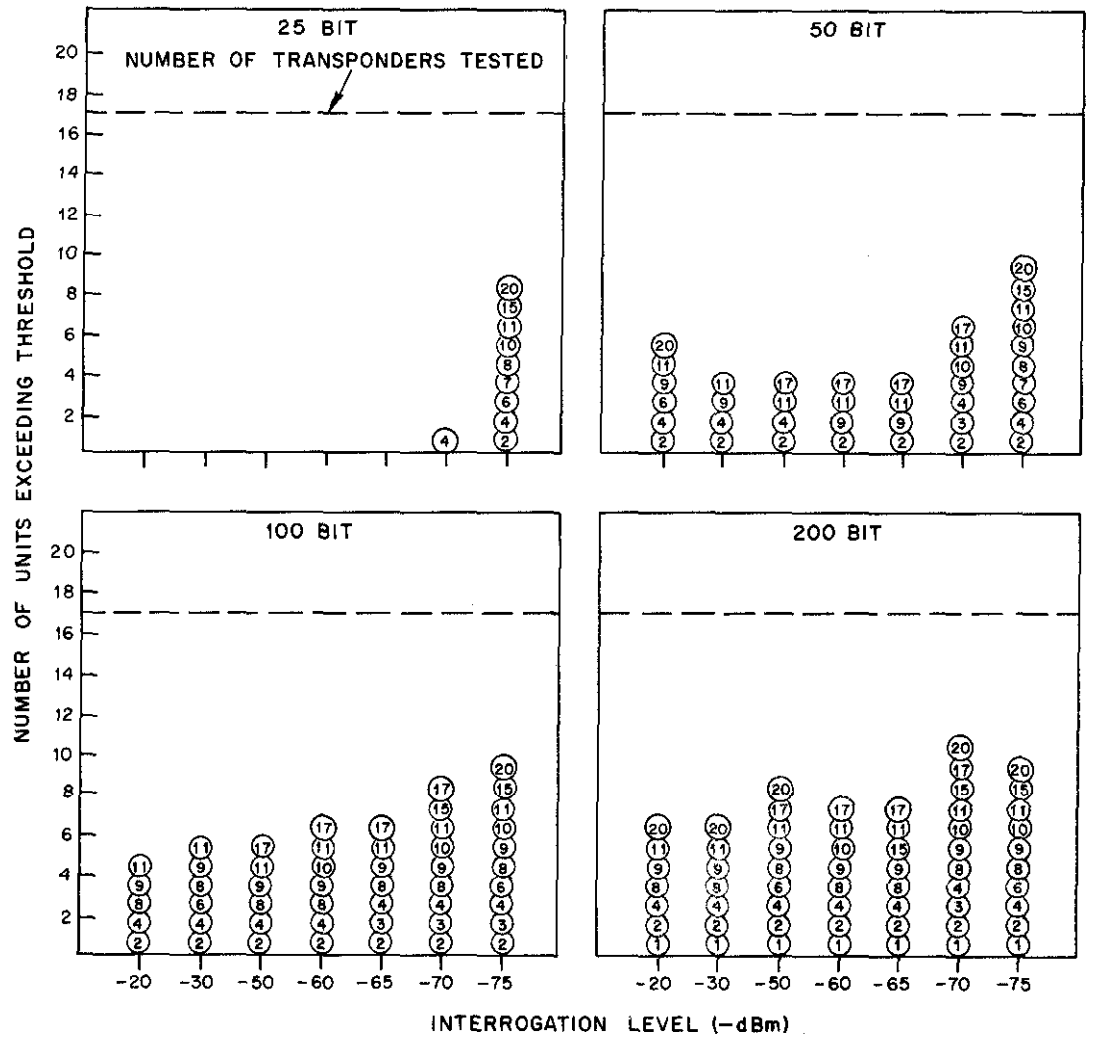


UNITS NOT TESTED - 16, 18, 19, 21, 22

Fig. 20. Response to Random Long-Pulse PAM With Suppression Pair.

PULSE WIDTH = 0.6 μ sec
 INTERPULSE SPACING = 1.0 μ sec
 REPETITION RATE = 500Hz

THRESHOLD CRITERIA
 ○ = REPLIES TO FIXED MODE \geq 10%

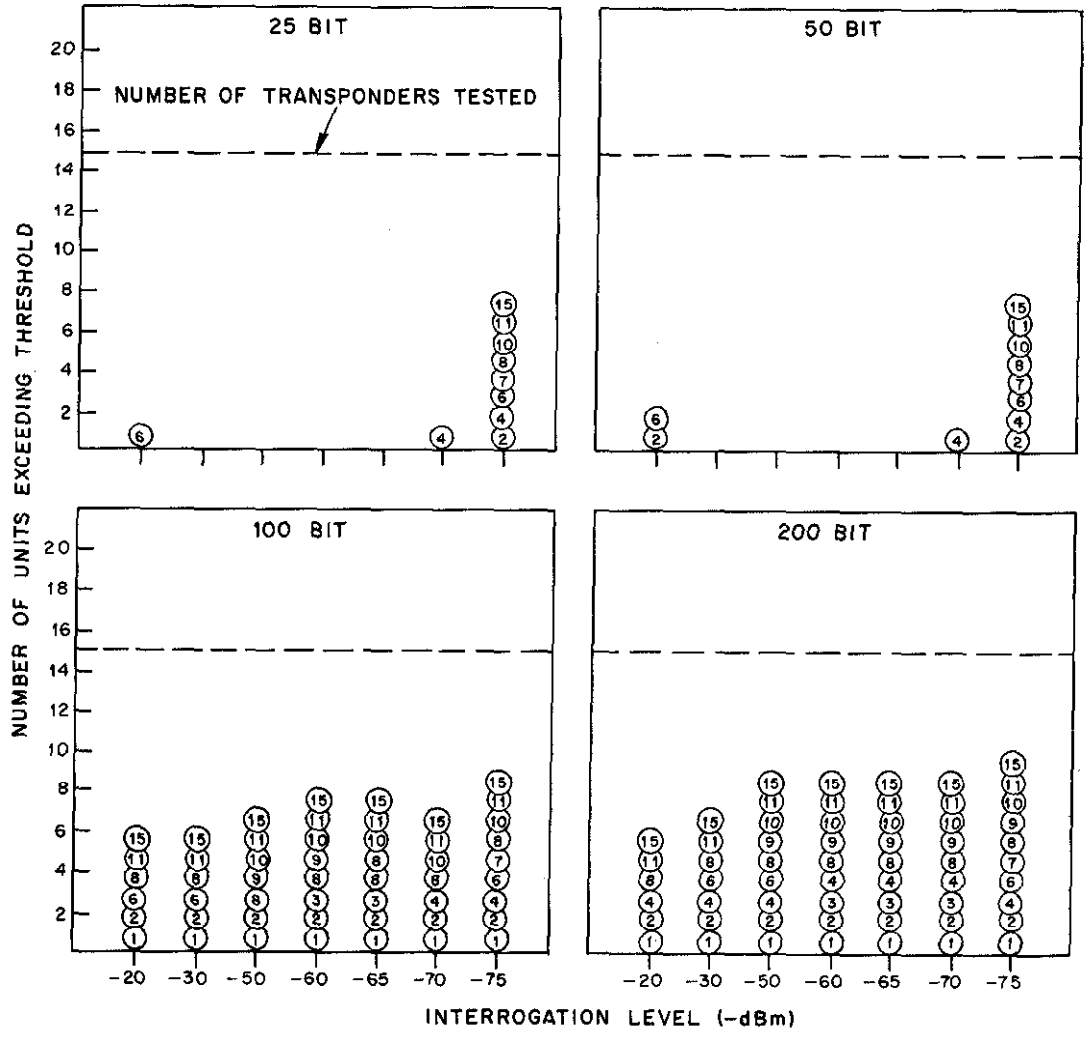


UNITS NOT TESTED - 16, 18, 19, 21, 22

Fig. 21. Response to Fixed Long-Pulse PAM With Suppression Pair.

PULSE WIDTH = 0.25 μ sec
 INTERPULSE SPACING = 0.5 μ sec
 REPETITION RATE = 500Hz

THRESHOLD CRITERIA
 ○ = REPLIES TO RANDOM MODE \geq 10%



UNITS NOT TESTED - 16, 17, 18, 19, 20, 21, 22

Fig. 22. Response to Random Short-Pulse PAM With Suppression Pair.

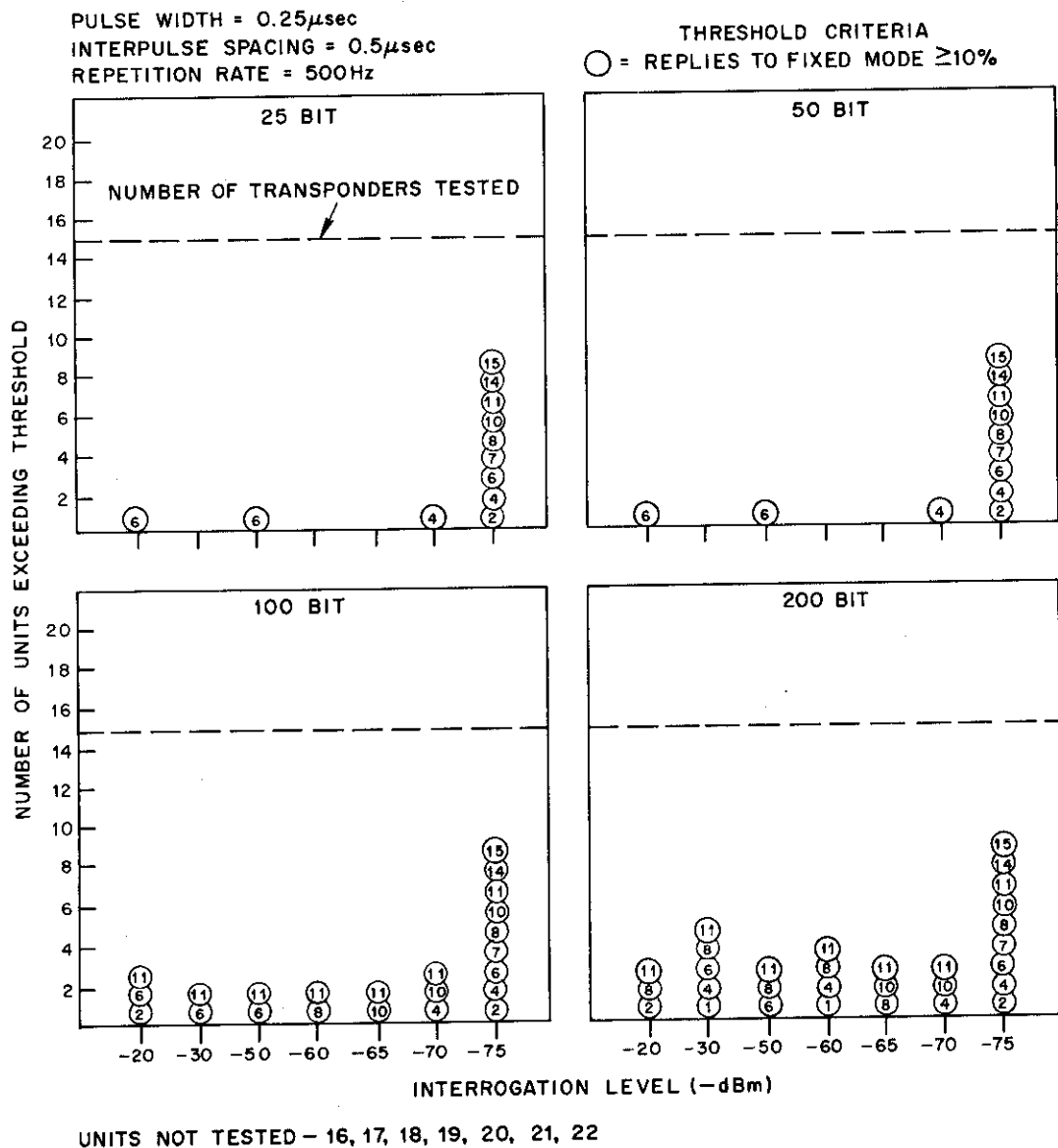


Fig. 23. Response to Fixed Short-Pulse PAM With Suppression Pair.

to resuppress a significant fraction of the transponders). The fact that transponders cannot be reliably suppressed at interrogation levels around MTL is indicated by the height of the bar-circles at -75 dBm for all message lengths. Again, it is noted that the fixed message sequences elicit fewer replies than the random message sequences.

4.2.2 Response To PSK With ATCRBS Suppressing Preamble

In these tests, the transponder response to random PSK messages following an SLS suppression sequence was examined. The tests were conducted for 25, 50, 100, and 200 bit, 4Mb/s PSK messages at interrogation levels of -20, -30, -40, -50, -60, -65, -70, and -75 dBm. (Block diagram, Figure 24,) The data are plotted in Figure 25. The significant increase in the number of transponders replying at the 200 bit message length is due to the extension of the DABS message beyond the initial suppression period of the transponders. It was again evident that the transponder suppression circuitry failed to operate reliably at interrogation levels around MTL for all message lengths. Compared with the PAM data, it is seen that PSK has a slight advantage in terms of fewer transponders replying (> 10%) to a given message length and data rate.

4.2.3 Response To NRZ-PAM With ATCRBS Suppressing Preamble

The purpose of these tests was to examine the transponder response to NRZ (non-return-to-zero) PAM messages following an SLS preamble. The difference between RZ-PAM and NRZ-PAM used in the context of these tests is illustrated in Figure 26 for an arbitrary message sequence. This NRZ format was investigated because it requires less bandwidth for a given data rate than its RZ-PAM counterpart. (Block diagram, Figure 27.)

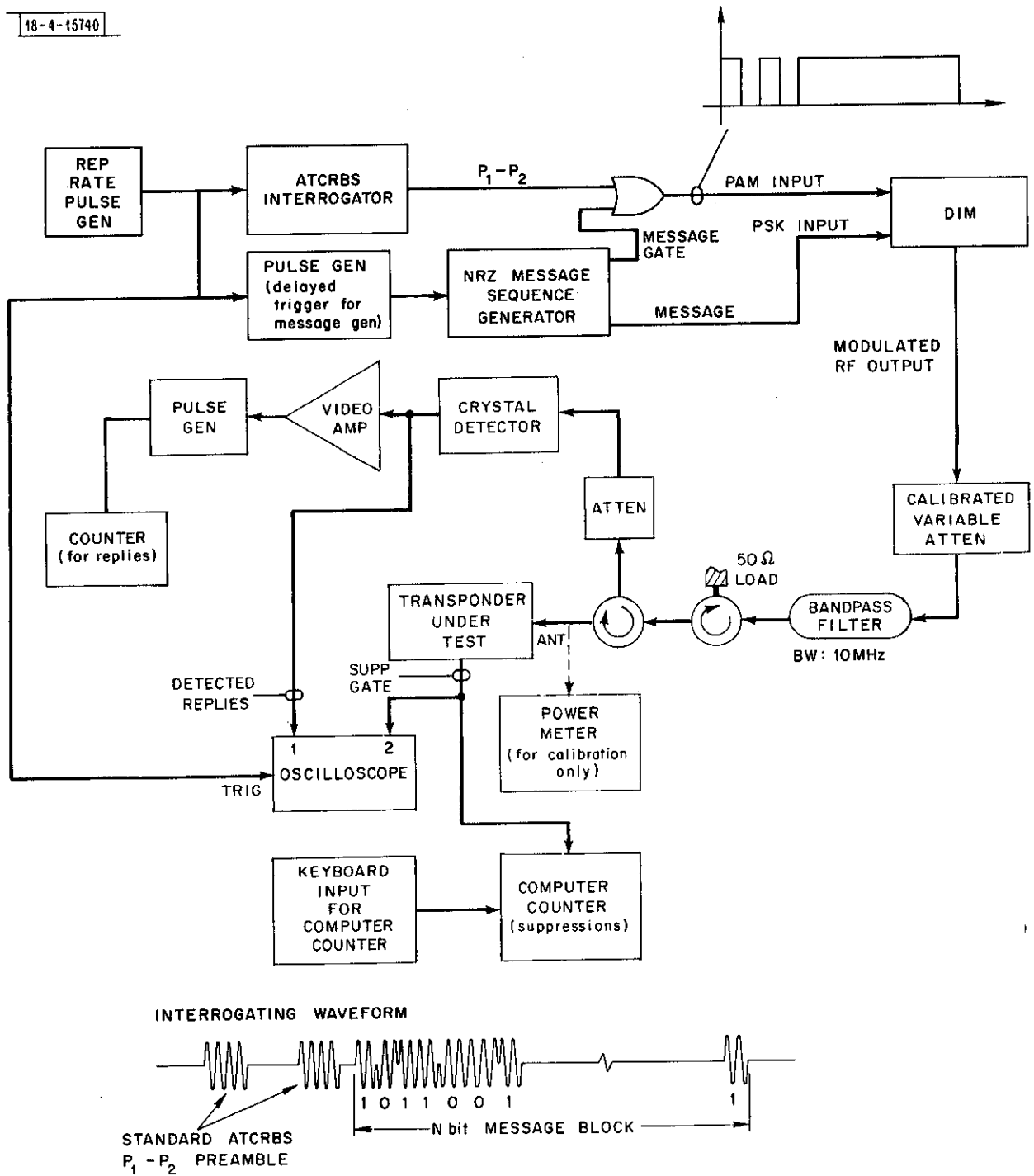
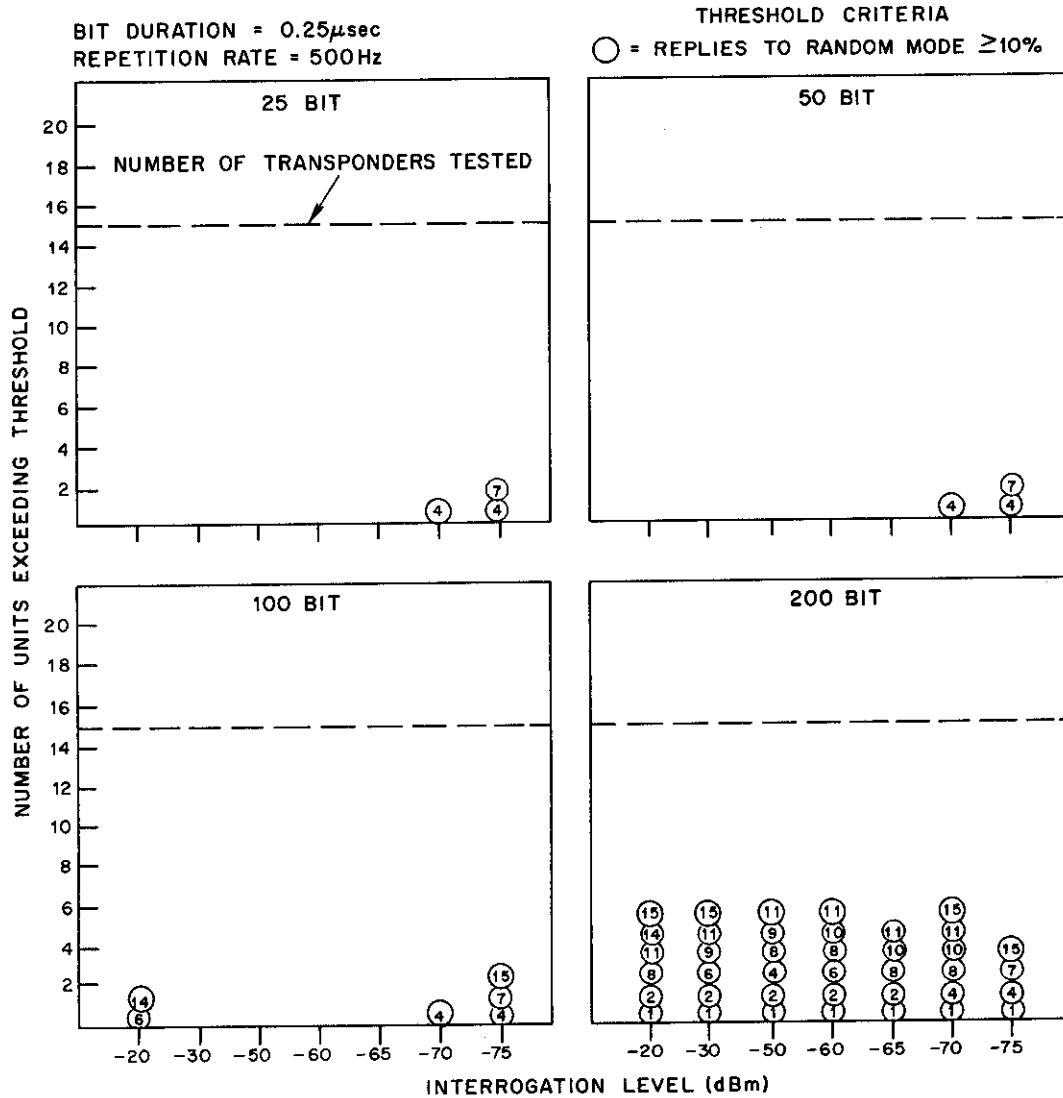
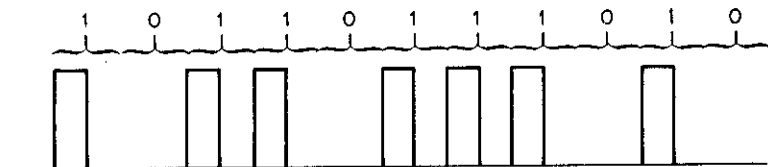


Fig. 24. Block Diagram of Test Configuration - Response to PSK with ATCRBS Suppressing Preamble.

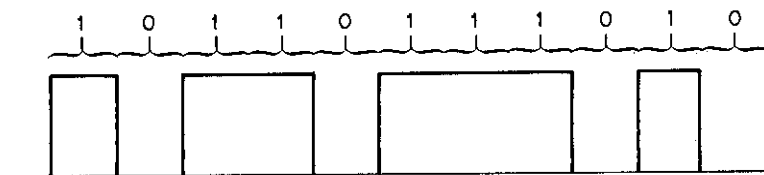


UNITS NOT TESTED - 16, 17, 18, 19, 20, 21, 22

Fig. 25. Response to 4 Mb/s PSK With Suppression Pair.



(a)



(b)

Fig. 26. Pulse Coding of 10110111010 Message Sequence.

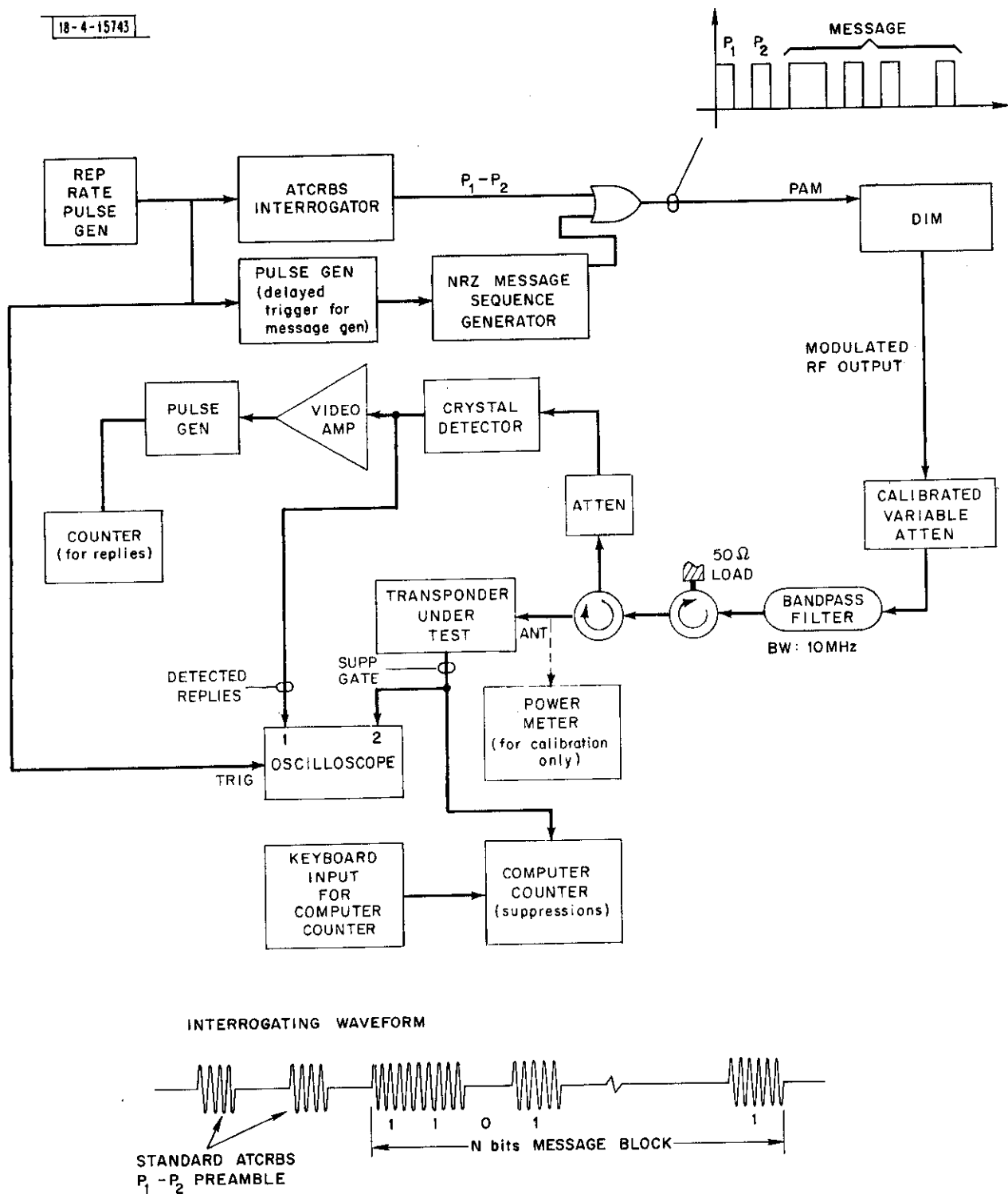


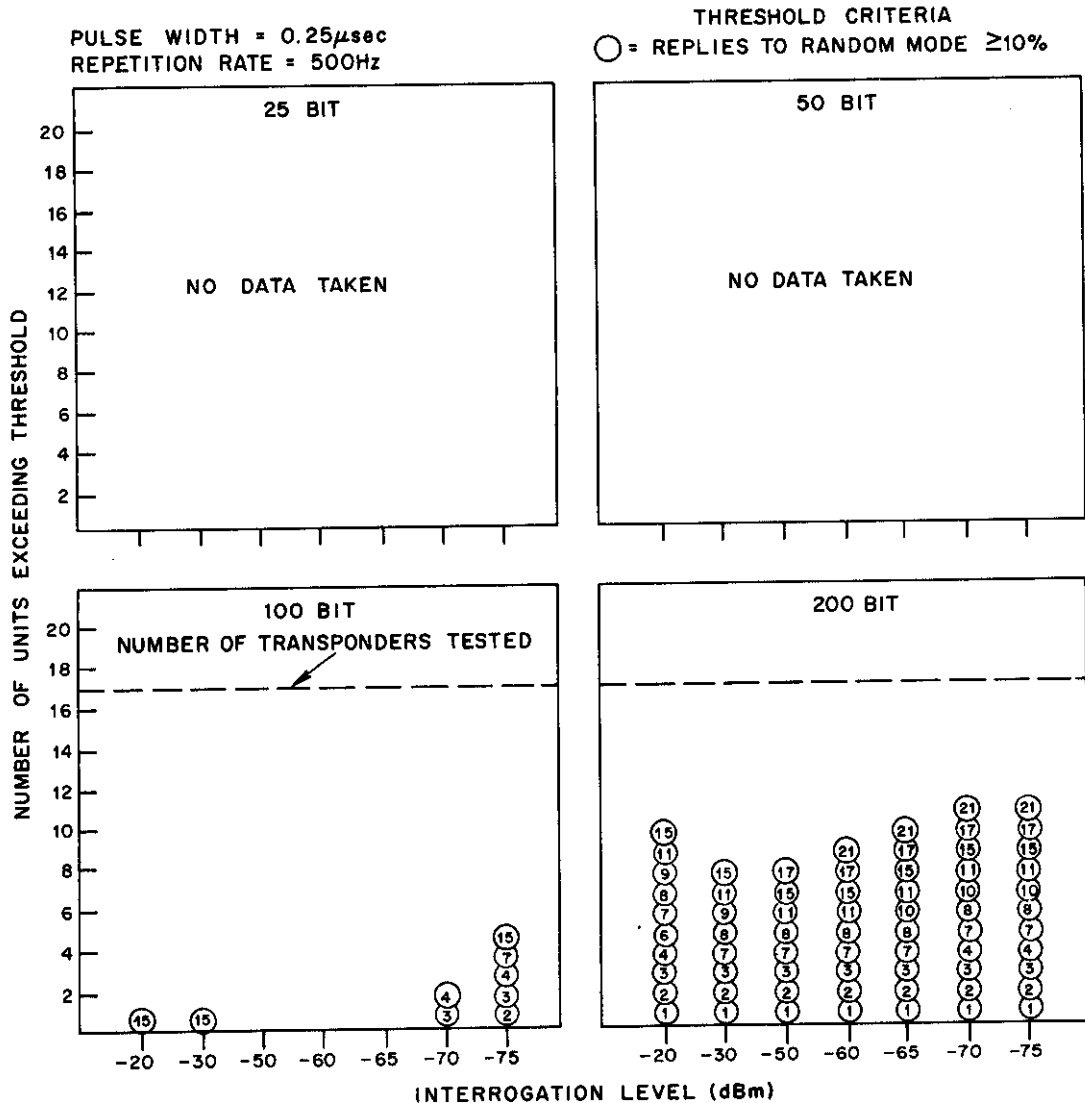
Fig. 27. Block Diagram of Test Configuration - Response to NRZ-PAM With ATCRBS Suppressing Preamble.

This test interrogated the transponder with a suppressing preamble followed by 100 or 200-bit random NRZ-PAM messages with a bit duration of $0.25 \mu\text{sec}$. The spacing between the trailing edge of the P_2 pulse and the beginning of the message was varied between $0.25 \mu\text{sec}$ and $1.0 \mu\text{sec}$ with no significant change in response observed. The bar circle charts for this test are presented in Figure 28. Again, the transponders replied to the 200-bit messages due to the extension of the message beyond the initial suppression period. It is also noted that the response to NRZ-PAM is comparable to the response to RZ-PAM for a given message length, although NRZ-PAM messages have twice the data rate of the RZ messages.

4.2.4 Transponder Response as a Function of DABS Message Length Following an ATCRBS Suppressing Preamble

Previous testing indicated that ATCRBS transponders which had been intentionally suppressed by an SLS sequence in the DABS preamble were susceptible to interrogation from a DABS message extending beyond the initial suppression period. It was also determined that the longer the duration of the DABS message, the higher the probability of eliciting a reply from an ATCRBS transponder. It was concluded that the DABS messages may have to be limited to the $25 \mu\text{sec}$ minimum specified suppression period. The tests in this section were intended to examine the variations in response to messages ranging from $25 \mu\text{sec}$ to $50 \mu\text{sec}$ in length.

In these tests, the transponders were interrogated with 2 Mb/s NRZ-PAM messages preceded by a $P_1 - P_2$ SLS sequence, at interrogation levels of -30 , -50 , and -65 dBm . These tests investigated the reply characteristics (number of replies per interrogation) of ATCRBS transponders as the message length



UNITS NOT TESTED - 16, 18, 19, 20, 22

Fig. 28. Response to NRZ-PAM With Suppression Pair.

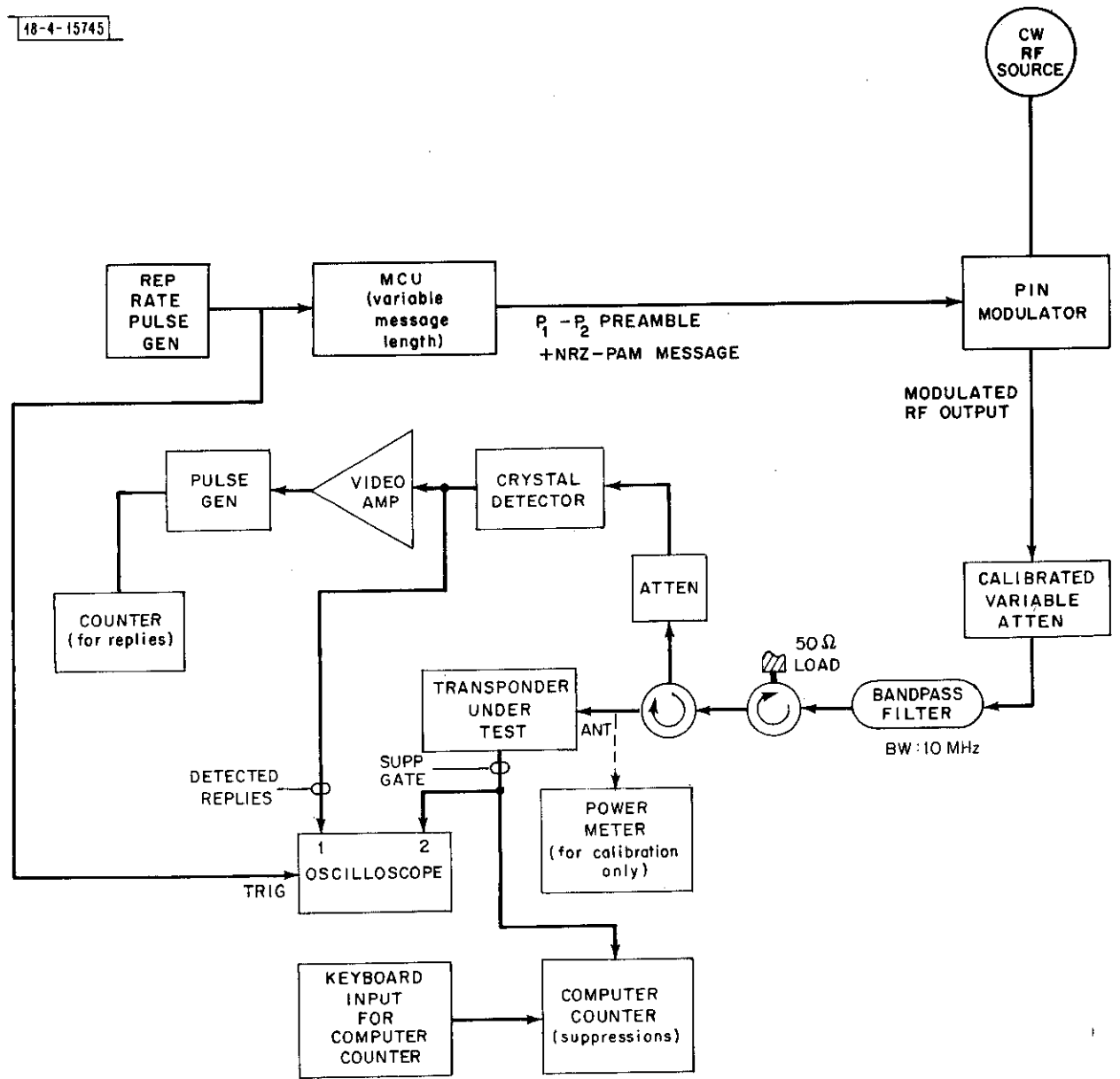
was increased in 5 μ sec increments beyond the 25 μ sec minimum specified suppression period. (Block diagram, Figure 29.)

Transponder reply rates as a function of message length for four typical transponders at the -50 dBm interrogation level are illustrated in Figure 30. The measured suppression period of each of the transponders is also indicated on the graph, and the overall average reply rate of the 14 transponders in the sample is plotted as a function of message length. The results from the individual transponder measurements indicate a strong correlation with the measured suppression period; following the 8 μ sec time interval beyond the measured suppression period, most transponders exhibit a significant increase in average reply rate. This increase is reasonable, since the earliest a transponder should reply following the end of a suppression period is 8-10 μ sec, at least sufficient time for a valid Mode A interrogation. Additional time is required to attain a substantial reply rate (>10%) because of the random coding of the message and the possibility that the random waveform could re-trigger the suppression circuitry.

Although the responses varied somewhat over the 35 dB test range, none of the transponders replied significantly (>1%) at either the high or low interrogation levels within the 8 μ sec threshold.

The results of these tests indicate that the DABS message may be extended to approximately 33 μ sec without eliciting a significant number of replies from civilian ATCRBS transponders*. The 33 μ sec interval is the sum of the 25 μ sec minimum suppression period plus the 8 μ sec required for a Mode A interrogation.

*In these experiments, the transponders (including the military unit, APX-72) were capable of only Mode-A or Mode-C operation. Military transponders which are enabled for Mode-2 (P₁ - P₃, 5 μ sec spacing) can start replying 5 μ sec following the end of a suppression period. A more conservative restriction on the maximum length of a DABS message following a suppressing preamble is thus 30 μ sec.



INTERROGATING WAVEFORM

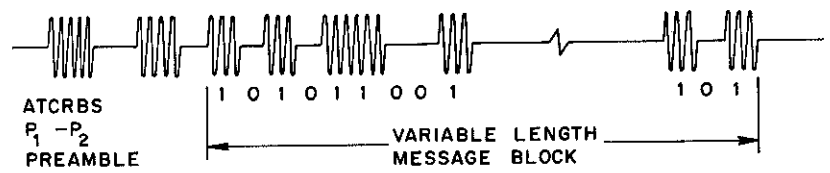


Fig. 29. Block Diagram of Test Configuration - Response as a Function of Message Length Following an ATCRBS Suppressing Preamble.

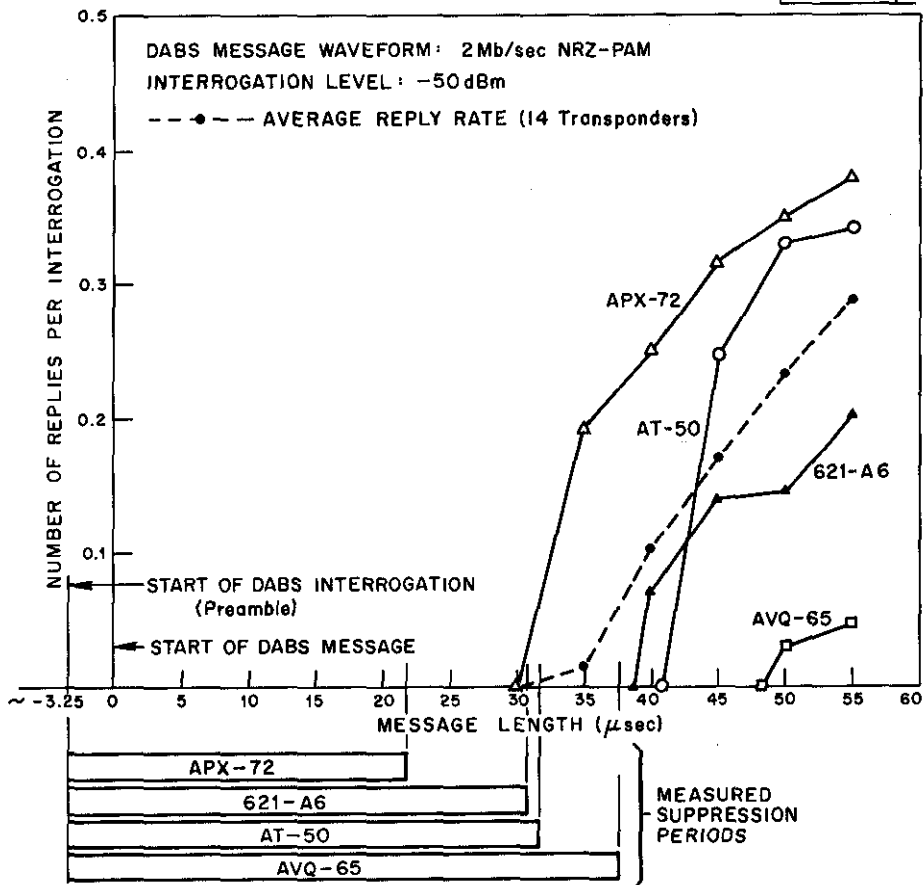


Fig. 30. Reply Rate Per Interrogation vs DABS Message Length Following an ATCRBS Suppressing Preamble.

4.2.5 Improvement In Reliability of Suppression at Interrogation Levels Near MTL when the Transmitted Peak Power of the Preamble is Increased Relative to the Message

It was observed that almost every transponder in the sample failed to suppress reliably at interrogation levels near MTL when an ATCRBS suppressing preamble was included in the DABS interrogation waveform. In all previous testing with intentionally suppressing schemes, the peak power of the P_1 - P_2 preamble was equal to the peak power of the message. The purpose of these tests was to determine if an improvement in the reliability of suppression at interrogation levels near MTL is obtained when the transmitted peak power of the preamble is increased relative to the transmitted peak power of the message.

These tests investigated two preamble modulation schemes: 1) with the transmitted peak power of both P_1 and P_2 increased relative to the message, and 2) with the transmitted peak power of P_2 increased relative to P_1 and the message. The tests were conducted with 4 Mb/s PSK messages 30 μ sec in length and with ratios of preamble peak power to message peak power of 0, 1, 2, and 3 dB. The range of interrogation levels (referred to the peak power of the message) was -30 dBm to -90 dBm. The data recorded in these tests were the range of interrogation levels over which replies were obtained and the maximum reply rate within that range. (Block Diagrams, Figures 31 and 32.)

The results of these tests are plotted in Figures 33 and 34. With the increased power of the preamble, two effects on the response of ATCRBS transponders are observed: 1) a downward shift occurs in the sensitivity range and/or 2) a reduction occurs in the maximum observed reply rate within the range. It

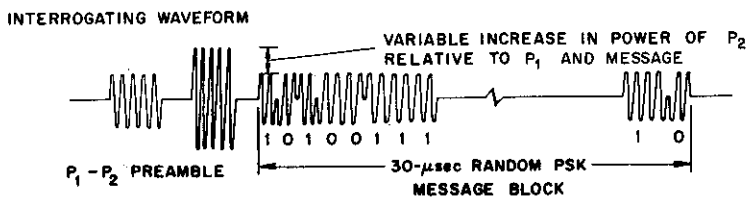
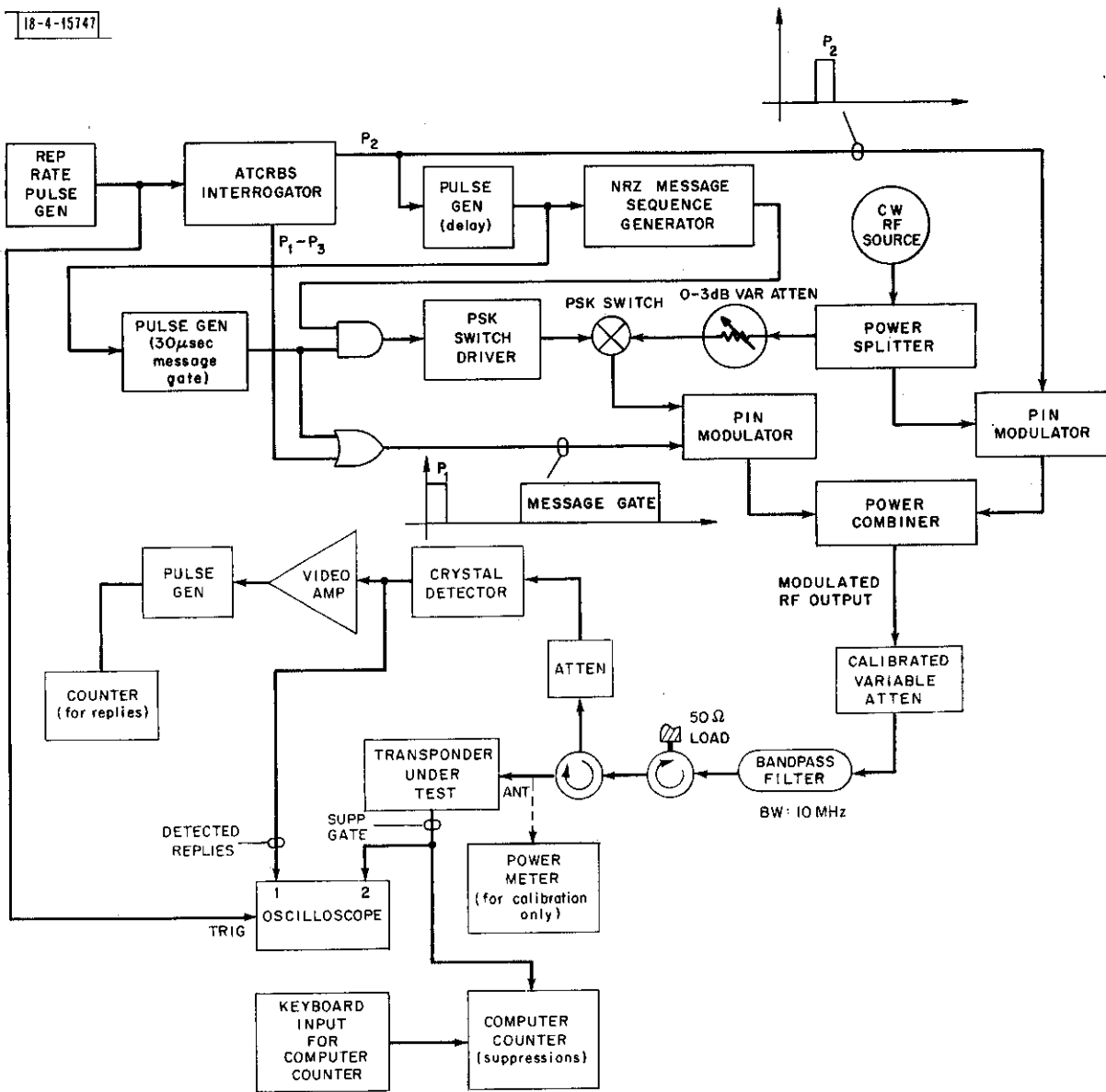


Fig. 31. Block Diagram of Test Configuration - Improvement in Reliability of Suppression When Power of P_2 is Increased Relative to P_1 and Message.

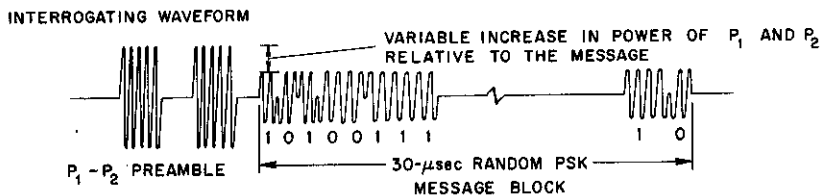
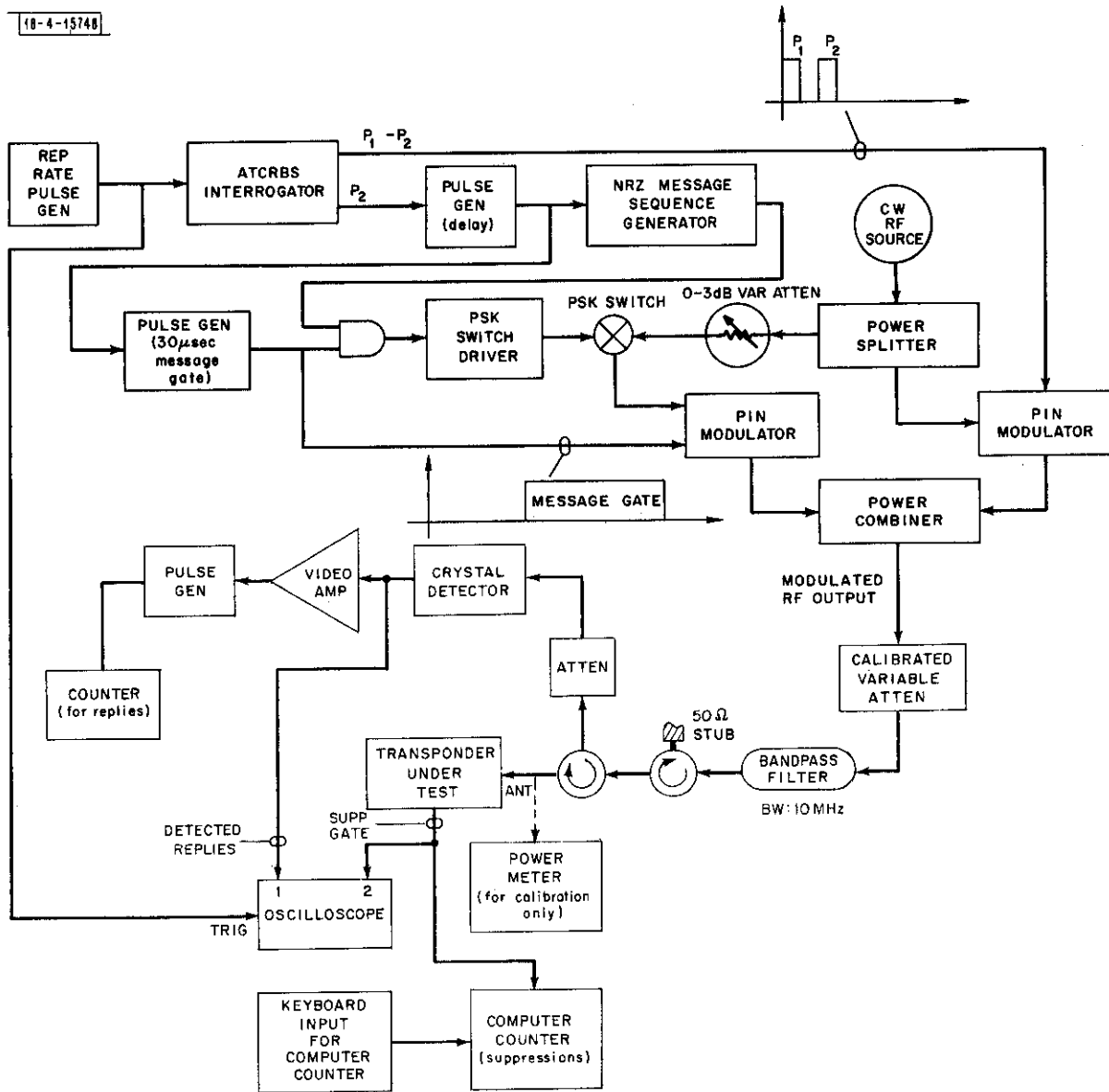


Fig. 32. Block Diagram of Test Configuration - Improvement in Reliability of Suppression When Power of P_1 and P_2 is Increased Relative to the Message.

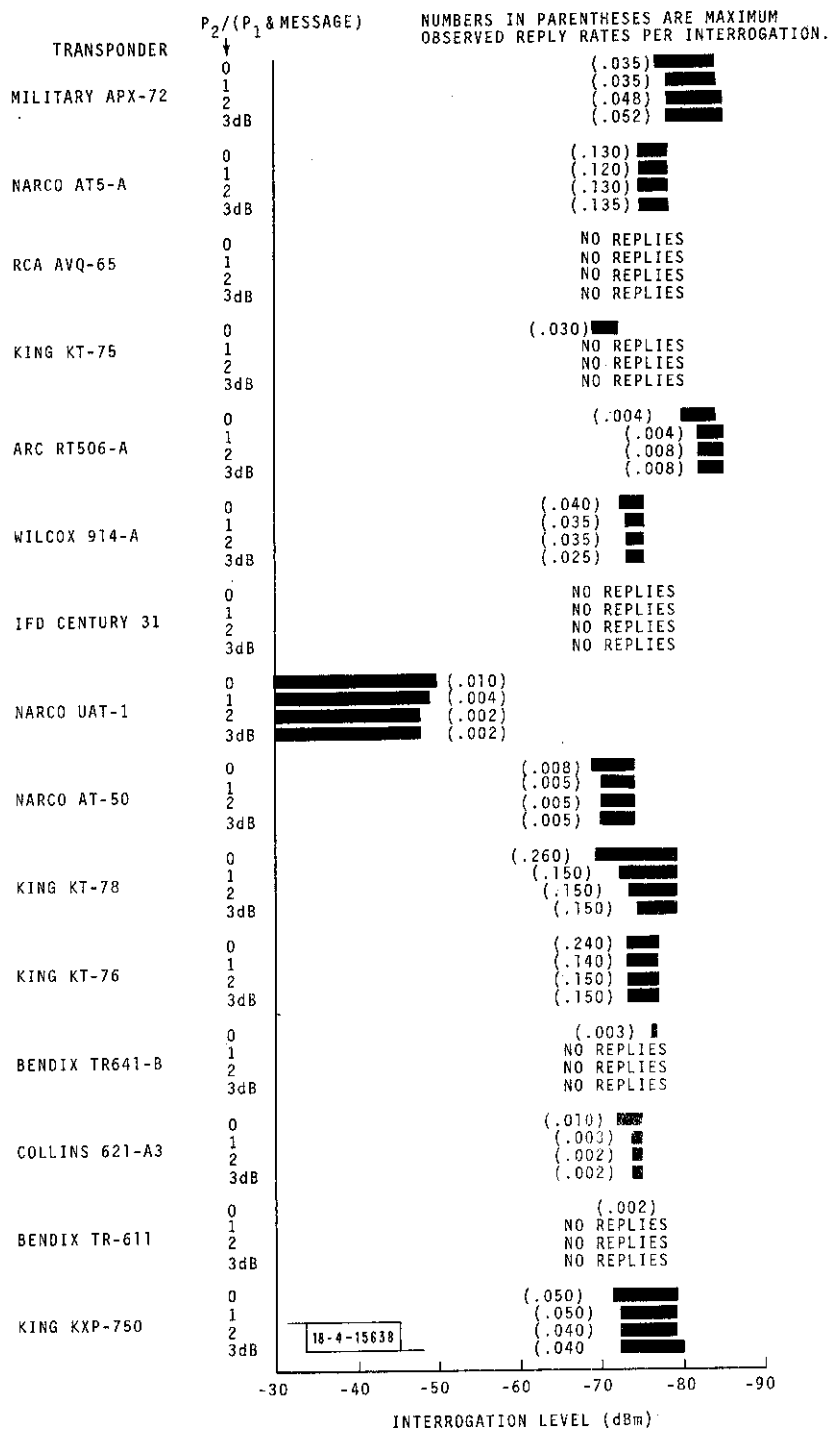


Fig. 33. Range of Interrogation Levels Over Which Replies Are Obtained and Maximum Observed Reply Rate Within That Range Showing the Variation in Reliability of Suppression When The Transmitted Power of P_2 is Increased Relative to P_1 and Message.

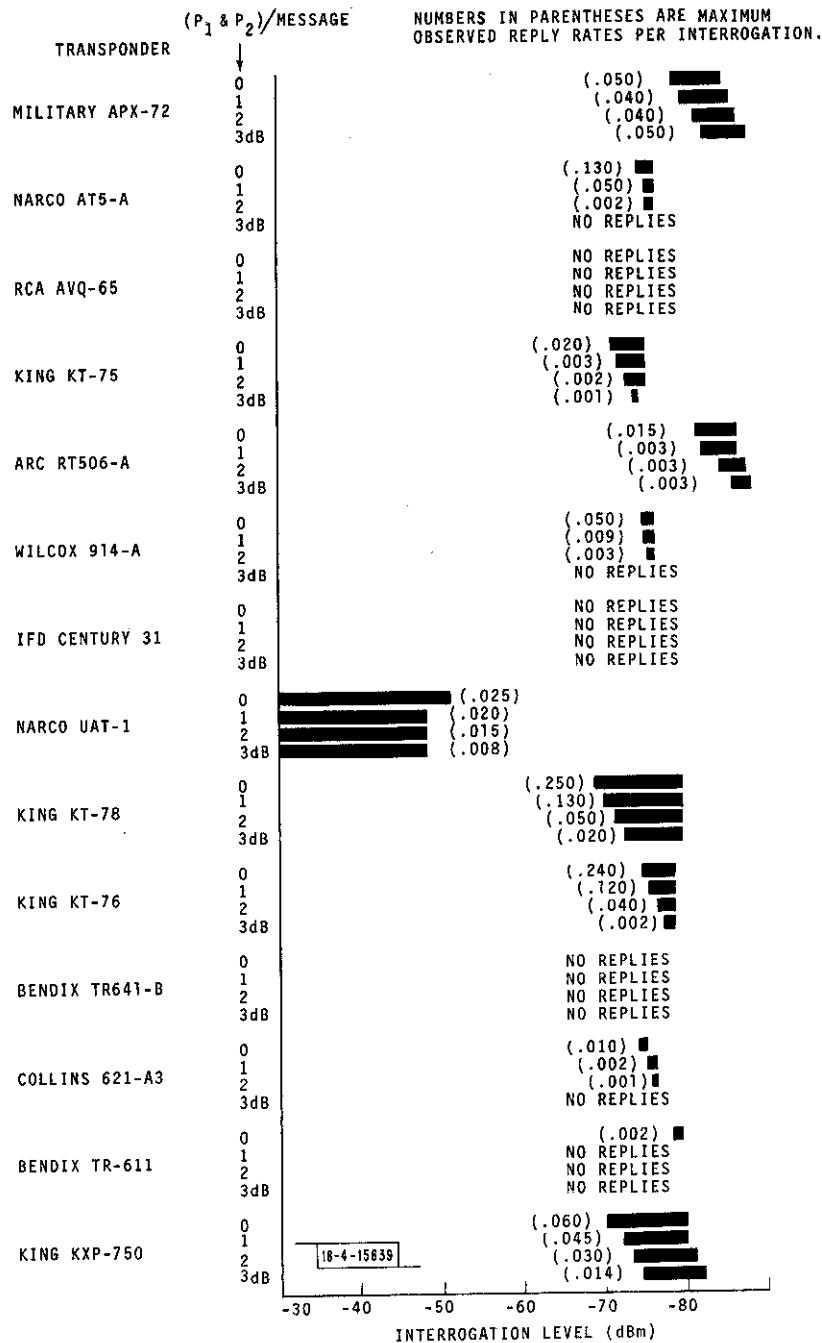


Fig. 34. Range of Interrogation Levels Over Which Replies are Obtained and Maximum Observed Reply Rate Within that Range Showing the Variation in Reliability of Suppression When the Transmitted Power of P_1 and P_2 is Increased Relative to the Message.

is likely that the downward shift in the sensitivity range would be less significant in the system than a reduction in the maximum reply rate, even though the shift is often accompanied by a reduction in the range of signal power over which replies are obtained. If one is interested in making DABS interrogations invisible to ATCRBS transponders, the most significant measure of performance is the maximum reply rate recorded over any range.

Figure 35 is a comparison of the effects of preamble power level increases on the maximum reply rates exhibited by the tested transponders. It can be seen that only the first dB increase in the level of P_2 over the level of P_1 and the message effects a reduction in the maximum reply rates. No further improvement was obtained by a 2 or 3 dB increase in the level of P_2 alone. When both P_1 and P_2 are increased relative to the message, each dB increase in the level of the preamble effects a further reduction in the maximum reply rates. With a 3 dB increase in the preamble level, only one transponder exhibits a maximum reply rate of greater than 0.02 replies per interrogation (i. e., it replies to more than 2% of the interrogations, but only in a small range of interrogation levels near MTL), while half of the transponders exhibit no replies.

With the DABS message restricted to 30 μ sec following the end of the suppression pair preamble, it was not expected that any ATCRBS transponder exhibiting at least the minimum specified suppression period of 25 μ sec, would reply to a DABS interrogation at interrogation levels much above MTL. As can be seen in Figures 33 and 34, one transponder did reply to 30 μ sec messages at higher interrogation levels (very low maximum reply rate of less than 2.5% at -30 dBm). This transponder was also found to reply infrequently to PSK

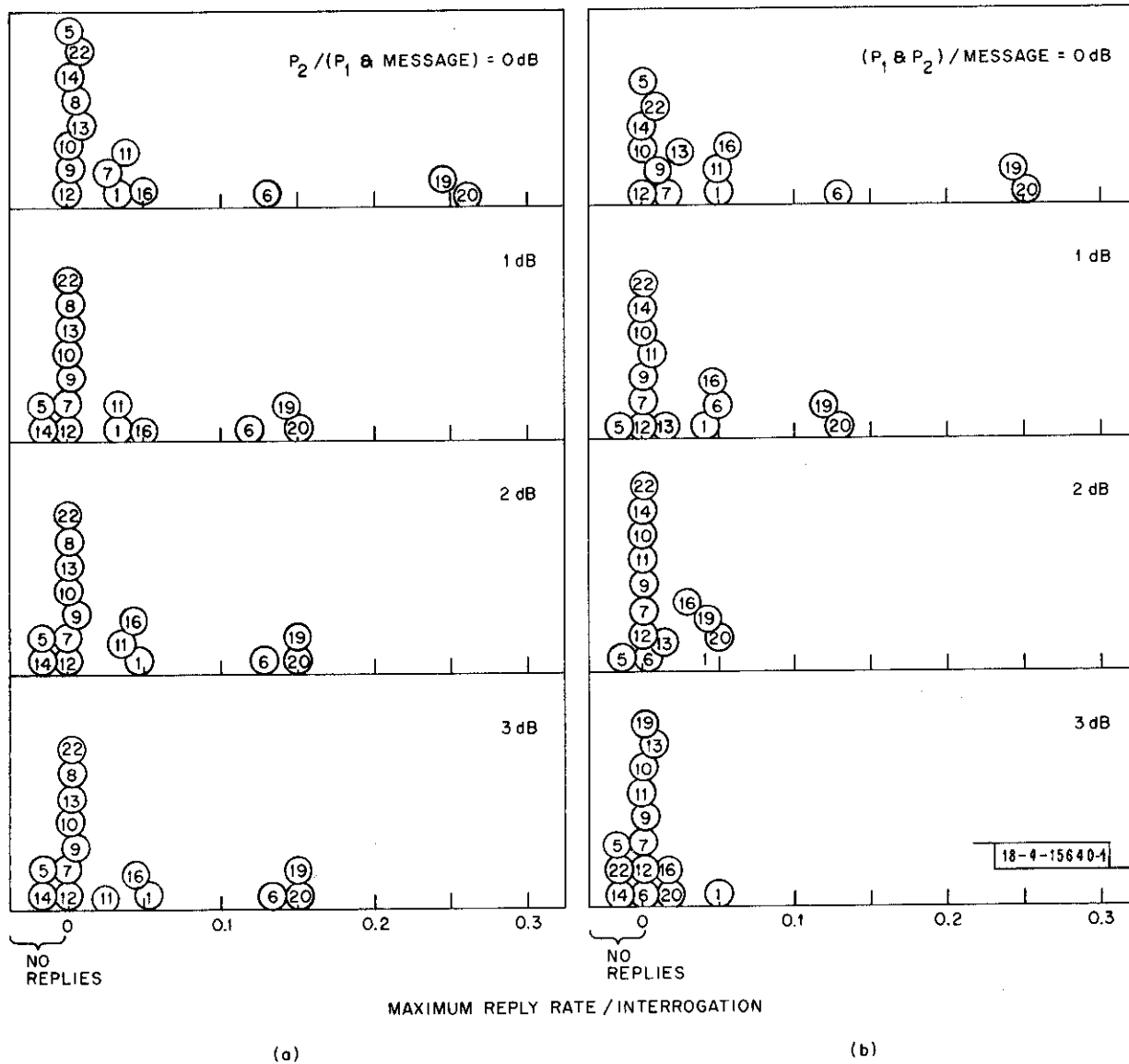


Fig. 35. Comparison of Maximum Observed Reply Rates Per Interrogation When the Transmitted Peak Power of the Preamble is Increased Relative to the Message by 0, 1, 2, and 3 dB.

messages as short as 8 μ sec at high interrogation levels. No explanation for this behavior was pursued, although it was noted that the measured suppression period of this transponder did fall within the ATCRBS specification.

Additional tests were conducted with the level of P_2 varied with respect to the level of P_1 and the message for 35 and 40 μ sec messages. These tests confirmed our conclusion that the DABS messages should be limited to 30 μ sec for a low probability of triggering replies from ATCRBS transponders. Compared with the data taken for 30 μ sec messages where only one transponder replied very lightly to such a short DABS message, four transponders replied to 35 μ sec messages at interrogation levels above MTL (two replied with maximum rates of $>10\%$ at some interrogation level above MTL), and eight transponders replied to 40 μ sec messages (five of the eight exhibited maximum reply rates $>10\%$). It was further found that with the longer messages of 35 and 40 μ sec, each additional dB increase in the level of P_2 alone reduced the maximum reply rates exhibited by about one third of the transponders tested. In some of these transponders, this increase in the level of P_2 reduces the number of replies due to the combined effects of extended message length and unreliable suppression at interrogation levels near MTL, but the replies due to extended message length keep the lowest maximum reply rate above the 1% level. This result is of little significance if the DABS messages are limited to 30 μ sec for maximum invisibility to ATCRBS transponders.

4.2.6 Transponder Response as a Function of DABS Interrogation Rate

The purpose of this test was to determine the effect of variations in the interrogation rate on the response of ATCRBS transponders to DABS waveforms. In these tests, the DABS waveforms used were 2 Mb/s PSK messages of lengths

20, 30, 40 and 50 μ sec following an ATCRBS suppressing preamble of peak power equal to that of the message. The tests were conducted at rates of 100, 250, 500, and 1000 DABS interrogations per second, and at each message length the response was checked at interrogation power levels of -30, -50, and -65 dBm. These tests were conducted on a limited sample of six ATCRBS transponders which had previously been found to reply to the PSK messages. (Block diagram, Figure 36.

The test results indicated that for DABS interrogation rates of 100, 250, and 500 per second, no variations in response (number of replies per interrogation) were observed at any message length or power level. At a DABS interrogation rate of 1000 per second, the response of one transponder (the military APX-72) was found to differ from its response recorded at the lower repetition rates. The variation in response of this transponder was examined and was attributed to the ATCRBS reply rate limiting circuitry. With standard ATCRBS interrogations ($P_1 - P_3$), this transponder was found to lose sensitivity due to reply rate limiting at an ATCRBS interrogation rate of 1200 per second, as specified in the ATCRBS National Standard. With the DABS waveforms, the possibility exists of triggering both a suppression and a reply or two suppressions in response to one interrogation. The APX-72 limits on the sum of replies and suppressions and exhibits ATCRBS-type reply rate limiting at a DABS interrogation rate of 600 per second.

The deviation from the general results at 1000 Hz was not considered a serious problem, since in the proposed DABS system the maximum DABS up-link transmission rate at any point in space will be well below 600 per second and the message length will be kept short enough so that the average reply rate per interrogation will be much less than unity.

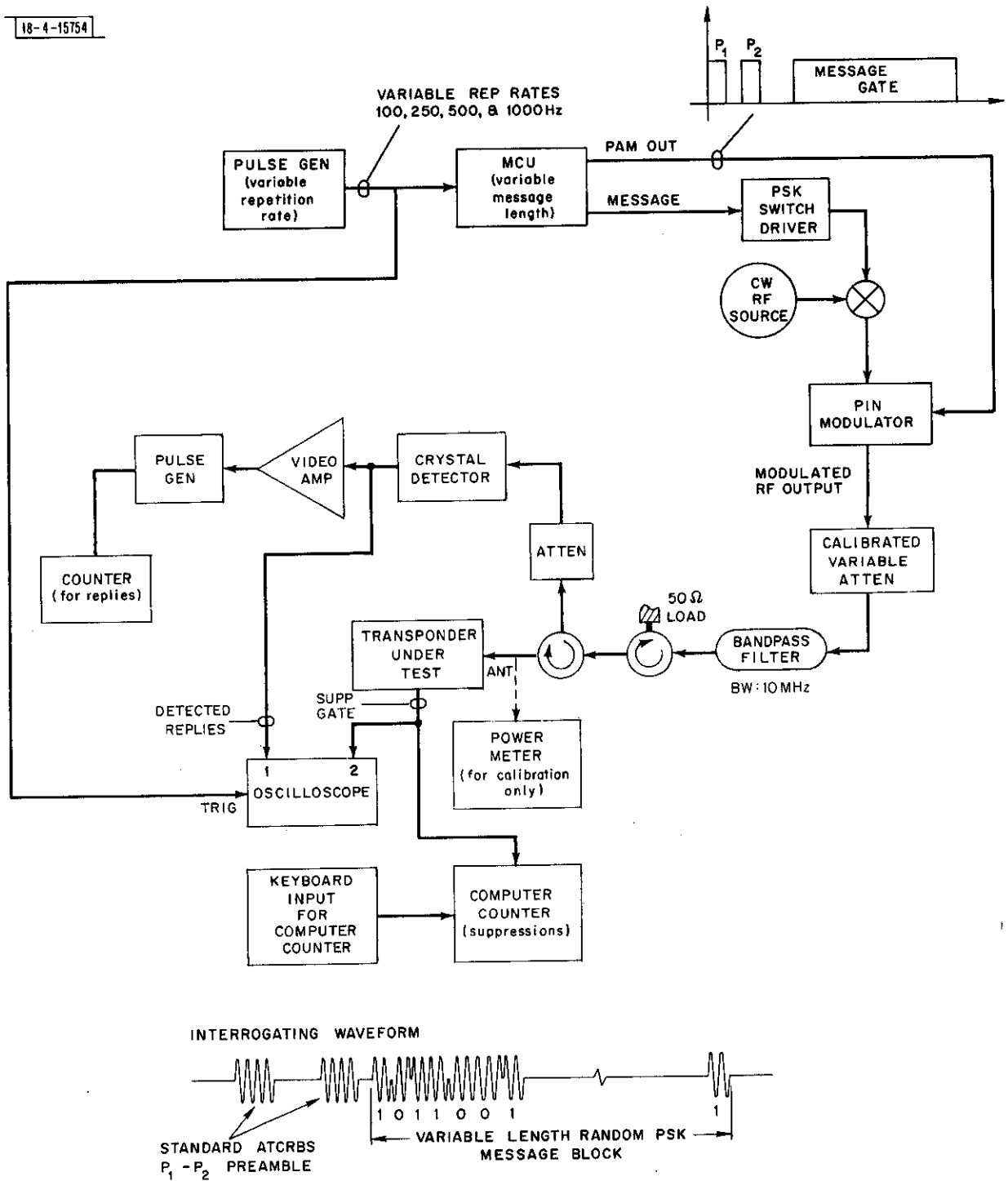


Fig. 36. Block Diagram of Test Configuration - Response as a Function of DABS Interrogation Rate.

4.3 TWO SCHEMES FOR DABS/ATCRBS DISCRIMINATION

One of the required interrogation modes in the proposed DABS system is the All-Call acquisition mode in which previously unidentified DABS transponders are requested to respond with their DABS identification. An efficient way to schedule All-Call interrogations is to include them with every conventional ATCRBS Mode A interrogation by the addition of some special characteristic to the ATCRBS interrogation to identify it as a transmission from a DABS interrogator. This additional characteristic must not alter the response of standard ATCRBS transponders to the interrogation, and it must indicate that the interrogation is a DABS All-Call early enough to allow sufficient time for the DABS transponder to inhibit an ATCRBS reply before transmitting the proper DABS acquisition response. The tests in this section investigated the response of ATCRBS transponders to two candidate DABS All-Call acquisition mode transmissions. Two schemes were investigated for adding the All-Call capability to the ATCRBS Mode A interrogation: 1) introduction of 180° phase reversals within P_1 and P_3 , and 2) transmission of an extra pulse (P_4).

4.3.1 PSK Within Standard ATCRBS Pulses

The object of this experiment was to determine the effect on ATCRBS transponders of including a 180 degree phase reversal within the ATCRBS pulses for the DABS All-Call mode.

In this test, the transponders were interrogated with standard ATCRBS Mode-A and Mode-A with SLS pulse sequences with a 180 degree phase reversal occurring within each of the standard pulses. In the initial tests, the phase reversal

occurred 0.4 μ sec after the start of the pulse (at the midpoint of the standard pulse). Reply and suppression counts were measured at interrogation levels of -30, -50, -65, -75, -80, and -85 dBm. In the tests which included an SLS pulse, the range of interrogation levels over which the suppression failed, and the maximum reply rate within this range were also recorded. (Block diagram, Figure 37.)

Almost every transponder in a sample of fifteen was affected to some extent by the introduction of the phase reversals at the midpoint of standard ATCRBS pulses. In about two-thirds of the transponders tested this effect was limited to a reduction in sensitivity (MTL) to Mode-A and/or Mode-A with SLS interrogations of 3 dB or less. In the remaining third of the transponders, the effects included complete loss of suppression capability over some range of interrogation levels, erratic suppression over the 55 dB test range, and up to 9 dB loss in sensitivity to Mode-A and/or Mode-A with SLS interrogations.

Further experiments were suggested by these initial observations. The sensitivity of the transponders was measured as a function of the position of the phase reversal within the pulses. These tests were performed on a limited sample of six transponders, including those transponders which were most adversely effected by the phase change at the midpoint of the pulses. The position of the phase reversal was varied in increments of 0.1 μ sec relative to the leading edge of the pulses, and the sensitivity data were recorded at each position. The tests were conducted for both SLS and Mode A interrogations. The MTL sensitivity measurement was based on a reply or suppression efficiency of at least 90%. Figure 38 illustrates the results of the measurements of sensitivity versus position of phase reversal for four transponders responding

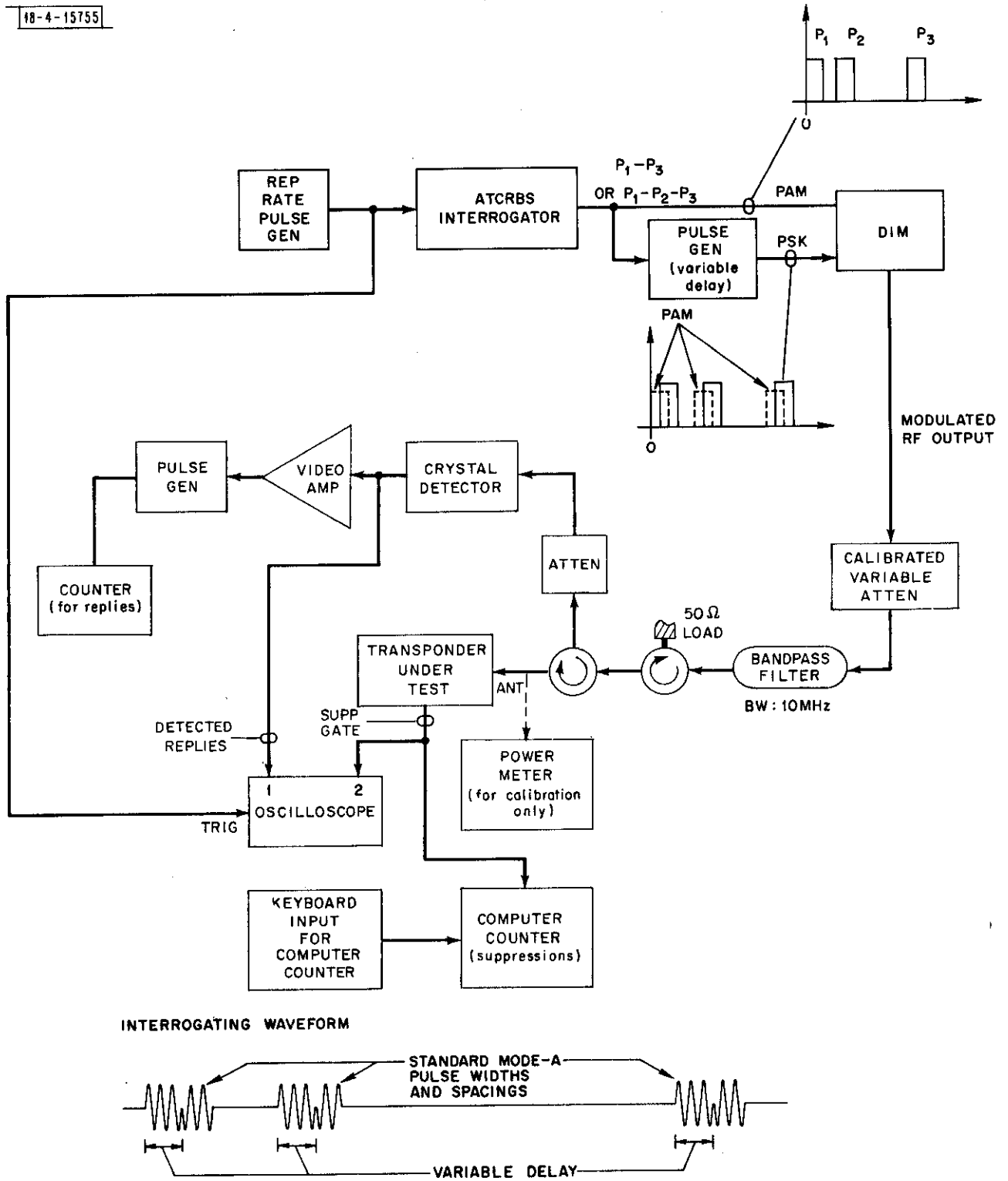
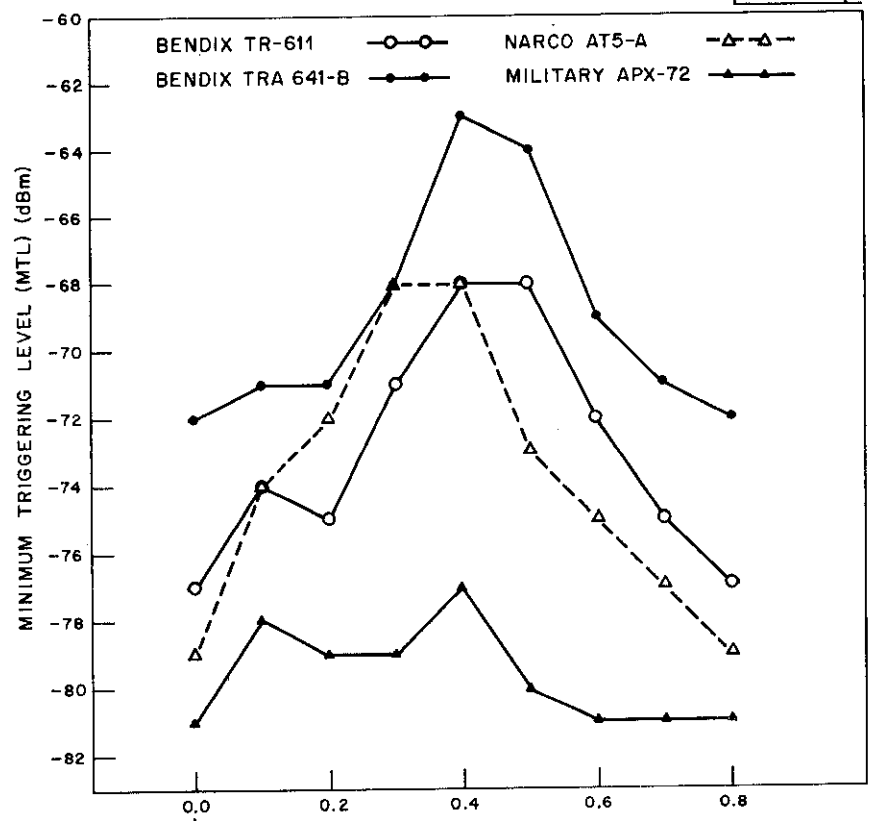


Fig. 37. Block Diagram of Test Configuration - PSK Within Standard ATCRBS Pulses.

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CORRESPONDS TO STANDARD MODE-A INTERROGATION WITHOUT PHASE REVERSAL

POSITION RELATIVE TO LEADING EDGE (μsec)

Fig. 38. Variations in Sensitivity (MTL) to Mode A Interrogations vs Position of 180° Phase Reversal Relative to Leading Edge of P₁ and P₃.

to Mode-A interrogations. The "0" position corresponds to the standard interrogation without phase reversal. These results indicated that the phase reversal could be effected towards the end of the pulses without changing the sensitivity of the transponders by more than a few dB.

These experiments were repeated with 1.0 μ sec pulses and the position of the phase reversal was varied in increments of 0.25 μ sec relative to the leading edge of the pulses.* The results indicate that the response of the transponders is affected the least if the phase reversal occurs at the 0.75 μ sec position. However, some transponders exhibit up to a 3 dB reduction in sensitivity with the phase reversal at this position.

Although the concept indicated some degree of feasibility, the scheme was dropped from further consideration since it was judged inadvisable to alter the basic ATCRBS waveform in any manner which results in a degradation of ATCRBS performance.

4.3.2 Transponder Response as a Function of the Position of P_4 Pulse Added to Mode-A Interrogations

Another possible DABS acquisition transmission consists of a Standard ATCRBS Mode-A sequence with an additional pulse (P_4) located on either side of the P_3 pulse. The detection of this additional pulse by a DABS transponder would trigger a DABS All-Call reply, while ATCRBS transponders would reply in the normal way (unless intentionally inhibited). The purpose of these tests was to determine the effect of the position of the P_4 pulse on the response of ATCRBS transponders. In these tests, a P_2 pulse was not transmitted. To simulate anti-

*This interval is convenient if the uplink waveform is based on a 4 Mb/s data rate.

icipated DABS timing, the P_1 and P_3 pulses were $0.98 \mu\text{sec}$ wide with the P_4 pulse $0.48 \mu\text{sec}$ wide. The position of the leading edge of the P_4 pulse was varied over a range from $5 \mu\text{sec}$ preceding the leading edge of P_3 to $3 \mu\text{sec}$ following the leading edge of P_3 . (Block diagram, Figure 39.) As the position of the P_4 pulse was varied, the reply and suppression counts were observed. Within the $5 \mu\text{sec}$ to $2 \mu\text{sec}$ range preceding the P_3 pulse, most transponders replied normally. As the P_4 pulse was brought closer to the P_3 most transponders exhibited a range of pulse positions where no replies occurred. In some cases, this condition existed until the P_4 pulse overlapped the P_3 pulse, when the transponders replied normally again. The variations in this dead range exhibited by the sample of transponders at the -50 dBm interrogation level are illustrated in Figure 40. This figure is characteristic of the response exhibited by the transponders over a 35 dB test range, from -30 to -65 dBm . It was found that the P_4 pulse could be located at any position following the P_3 pulse (including the cases in which the pulses overlapped) without affecting the response of ATCRBS transponders.

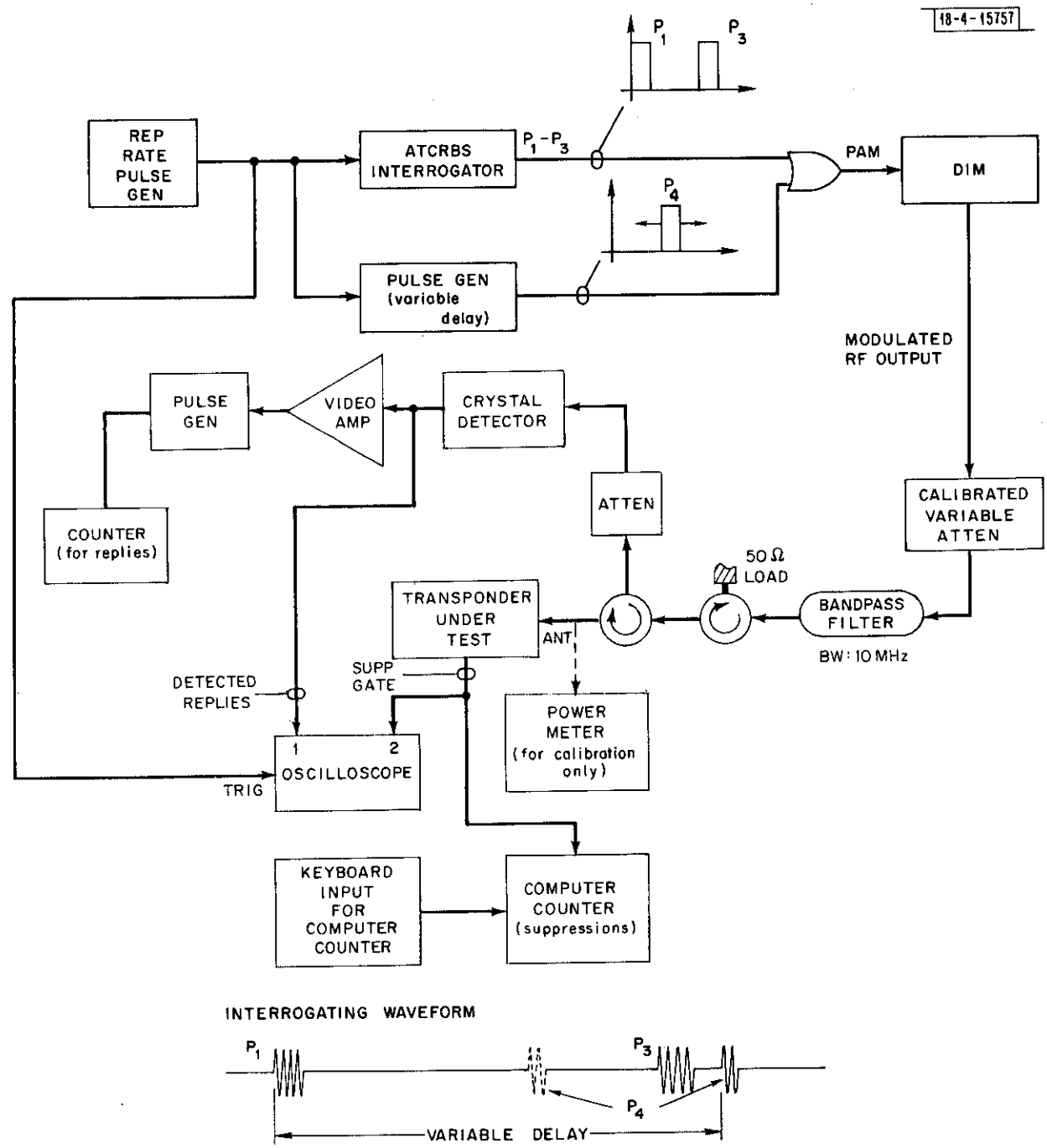


Fig. 39. Block Diagram of Test Configuration - Response as a Function of P_4 to Mode A Interrogations.

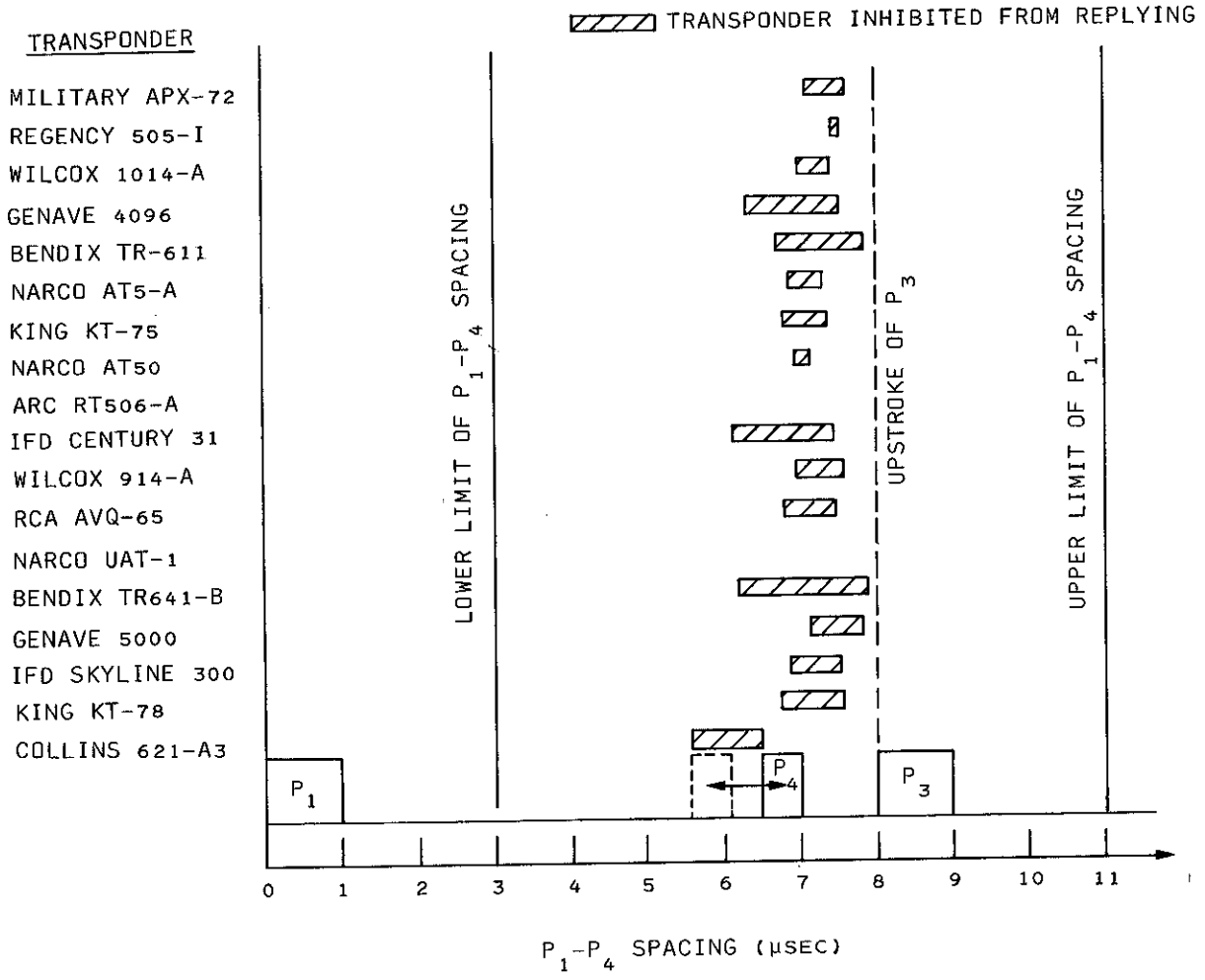


Fig. 40. Range of Position of P_4 Resulting in No Replies From ATCRBS Transponders When P_4 is Added to a Mode A Interrogation.

5.0 SUMMARY OF RESULTS

These tests determined that none of the FSK, PAM, or PSK modulation types used are completely invisible to ATCRBS transponders. The tests further determined that the actual transponder tolerances for pulse widths and spacings are wide enough that none of the PAM pulse widths or spacings tried were invisible to ATCRBS transponders (at a usable data rate).

Since it has been determined that DABS cannot rely on invisibility alone to prevent replies from ATCRBS transponders, the most reasonable transmission is a DABS message preceded by an SLS preamble which suppresses all ATCRBS transponders and relies on: a) short message duration, b) partial invisibility, or c) resuppression capabilities of the particular DABS uplink waveform, to prevent the ATCRBS transponders from replying to DABS uplink messages extending beyond the end of the initial suppression period.

For maximum invisibility to ATCRBS transponders, the allowable DABS message duration following a suppressing preamble is restricted by the 25 μ sec minimum specified suppression period, to insure that ATCRBS transponders with short suppression periods would not be interrogated or suppressed falsely by the end of the DABS message waveform. The DABS message can actually be extended to a maximum length of about 30 μ sec without eliciting a significant number of replies from existing ATCRBS transponders. The 30 μ sec value is the sum of the 25 μ sec minimum suppression period plus the 5 μ sec required for a valid Mode-2 (military) interrogation. This is a direct restriction on the message duration, not on particular waveform used.

It was also determined that: 1) short-pulse waveforms appear to be partially invisible to ATCRBS transponders (particularly at lower interrogation levels), 2) PSK has a slight advantage over PAM in terms of invisibility to ATCRBS transponders, and 3) ATCRBS transponders exhibit fewer replies to fixed message sequences than to random message sequences due to the suppression and resuppression capabilities of fixed pulse waveforms.

The minimum allowable spacing of DABS interrogations with an ATCRBS suppressing preamble is about 50 μ sec, enough time to allow ATCRBS transponders with the longest resuppression time to be reliably resuppressed (i.e., for long DABS messages requiring multiple interrogations). DABS interrogations with messages exceeding the 30 μ sec limit stated above, can generate multiple ATCRBS "interrogations" (i.e., two suppressions or one suppression and one Mode-A interrogation per DABS interrogation). For messages which are slightly longer than 30 μ sec, e.g., 35 or 40 μ sec, the reply rate limiting operation of some ATCRBS transponders imposes 600 Hz as an upper limit on the DABS interrogation rate at any point in space.

Of the two methods investigated for DABS/ATCRBS discrimination (DABS All-Call), PSK within standard ATCRBS interrogation pulses is not recommended since it reduced the sensitivity of a large fraction of the transponders, some by as much as 9 dB. The scheme using an additional pulse (P_4) following the P_3 pulse caused no observable effect on the performance of ATCRBS transponders.

It was also observed that almost every transponder in the sample failed to suppress reliably at interrogation levels near MTL when an ATCRBS suppressing preamble was included in the DABS interrogation waveform, and that although the DABS messages were limited to 30 μ sec, replies were obtained

from many transponders at these interrogation levels . It was shown that the reliability of the intentional suppression at interrogation levels near MTL could be improved by increasing the transmitted peak power of the preamble relative to the message. Whether the transmitted peak power of both P_1 and P_2 was increased relative to the message or the transmitted peak power of only P_2 was increased relative to P_1 and the message, a 1-dB increase in the transmitted peak power of the preamble resulted in the same improvement in suppression reliability. Further improvements in suppression reliability could be obtained only when the level of both P_1 and P_2 was increased by more than 1 dB relative to the message. Increasing the level of both preamble pulses by 3 dB resulted in only one transponder exhibiting a maximum reply rate greater than 0.02 replies per interrogation (i. e. , it replies to more than 2% of the interrogations only in a small range of interrogation levels near MTL), and half of the transponders tested exhibited no replies at all.

6.0 CONCLUSION

It is concluded from the results of this test program, that the DABS uplink interrogation which minimizes interference to ATCRBS transponders is a PSK-modulated DABS message, of duration less than 30 μ sec, preceded by a PAM preamble which intentionally suppresses ATCRBS transponders and whose transmitted peak power (both P_1 and P_2) is 3 dB greater than the transmitted peak power of the message.

The value to the system of the 3-dB increase in the transmitted power of the preamble has not been established. The resulting improvements would be applicable only to a narrow range of interrogation levels near MTL. It is recommended that the DABS uplink interrogations be specified with the peak power of the preamble equal to that of the message until flight tests clearly show the need for an increase in the transmitted power of the preamble.

The DABS All-Call transmission with an additional pulse (P_4) following a standard ATCRBS Mode-A (or Mode-C) interrogation will not degrade the performance of ATCRBS transponders of the ATCRBS system.

The measurements reported here provide a necessary input into the determination of a recommendation for the DABS uplink transmissions.

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