Project Report
ATC-9

Final Report:
Transponder Test Program

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16. Abstract

Performance parameters of transponders installed in aircraft were measured to determine their degree of compliance with current specifications. A mobile van was outfitted with electronic test equipment which simulated the transmitter and receiver sections of a ground interrogator and which allowed measurement of transponder parameters. A horn antenna located near the aircraft under test was used to couple signals to and from the transponder.

The results of measurements on 504 transponders installed in general aviation aircraft, 17 transponders installed in military aircraft, and 28 transponders installed in air carrier aircraft are reported. Of these, 31 general aviation, 2 military, and one air carrier transponders were inoperative. The results of measurements of reply frequency, squitter, delay, Mode C operation, dead time, P2/P1 ratio required for suppression, suppression time, framing pulse spacing, power output and sensitivity are included.

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I. PROGRAM FORMULATION AND IMPLEMENTATION

A. Introduction

1. Historical Background[1]

The Air Traffic Control Radar Beacon System (ATCRBS), commonly referred to as secondary surveillance radar (SSR), was adapted from the basic Mark X system developed by the military in World War II for identifying aircraft as friend or foe (IFF). Although the SSR was not designed to replace the primary radar, it did greatly enhance the detection capability of the surveillance system and, over a period of time, has become the major source of surveillance data.

Early in 1961, the FAA adopted the first of a series of National Standards[2] which described the characteristics of components for the use in the ATCRBS system. The standard has been subsequently upgraded to include the addition of side-lobe suppression, altitude reporting, and a 4096 code capability. The system has been extensively deployed, and will become the primary source of identity, altitude and position information in the automated ATC system now being implemented.

The FAA has planned and implemented continuing improvements in the ATCRBS system throughout its existence, and these have been reflected in revisions to the National Standard. The Radio Technical Commission for Aeronautics (RTCA) has published a document outlining the Minimum Operational Characteristics (MOC) desired in airborne transponders.[3] Neither the National Standard nor the RTCA document had any binding power at the time this program was initiated, and no mechanism existed for insuring that transponders then in service met either the letter or spirit of the Minimum Operational Characteristics. Very little data was available on the performance of units then in operation.

In view of the growing volume of air traffic and the known capacity limits of the present ATCRBS system, a program was sponsored by the FAA to make field measurements of existing transponders to provide data which could be used both in evaluating the present system operation and in planning future developments.*

2. Description of the Present System

Transponder-equipped aircraft are interrogated by a secondary surveillance radar located with the primary radar on the ground. For ease of data synchronization, the SSR antenna is located on top of the primary radar antenna and rotates with it. The SSR interrogation waveform consists of an RF pulse pair transmitted on a frequency of 1030 MHz. The mode of interrogation is identified by the spacing between the two pulses transmitted from the ground. Civil aviation transponders in use in the United States utilize only two modes of operation: Mode 3/A, the identity reporting mode, and Mode C, the altitude reporting mode. The interrogations for these two modes consist of RF pulse pairs with spacings of 8 and 21 microseconds, respectively. In addition to recognizing these pulse pairs, the transponder also must detect the presence of a side-lobe-suppression (SLS) pulse.

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*Rule making is in progress to require that all transponders manufactured after February 1973 comply with a Technical Standard Order.

The SLS pulse is transmitted from an omni-directional antenna two microseconds after the first pulse of an interrogation train is transmitted from the directional antenna. If a transponder receives a second pulse that is comparable to or larger in amplitude than the first received pulse, it recognizes the existence of an interrogation due to radiation from a side-lobe and does not reply.

Upon detection of a Mode 3/A interrogation, assuming a side-lobe condition is not detected, the transponder replies with its identity code. This reply is transmitted at a frequency of 1090 MHz and consists of two framing pulses with up to twelve code pulses between them. The Mode C reply is similar, the difference being that in Mode 3/A, the code is set manually by the pilot operating the unit control box, while in Mode C, the code is set automatically by the encoding altimeter. If no encoding altimeter is provided, the unit replies with framing pulses (assuming Mode C is selected on the control box).

At present, the surveillance system is operated by experienced controllers who perform target acquisition and identification through continued observation of displays. With the implementation of the NAS/ARTS program, automation will be introduced which will include computer processing of transponder replies. It is expected that such processing equipment will have less tolerance to signal anomalies than do the present operators.

In order to provide a basis for the evaluation of the adequacy of the present generation of transponders for operation in the automated system, it was deemed desirable to determine the operating characteristics of a significant sample of such units installed and operating in their natural environment.

B. Program Formulation

1. General

This program was undertaken to provide a measure of the primary characteristics of the transponders operating *in situ* in a random sample of aircraft. It was planned to indicate in general terms the degree to which representative operational transponders meet the current Minimum Operational Characteristics. The test program was not intended as either a comprehensive evaluation of all transponder characteristics or as a competitive evaluation of units of different manufacture.

The tests were performed on private and business aircraft as they became available, resulting in a random selection of aircraft and transponder types. In addition to the tests on general aviation units, measurements were also made on a limited number of transponders installed in military and air-carrier aircraft.

As a compromise between the most realistic possible measurements, which would involve a highly instrumented and extensive flight test program, and the desire to minimize cost and time duration, the tests were performed with the aircraft parked on a suitable run-up pad and the mobile test van parked nearby. The aircraft's engine and radio/navigation equipment were operated during the 10 to 15 minutes required to test the transponder. Coupling between the equipment located in the van and the aircraft under test was accomplished through the use of a horn antenna as illustrated in Figure 1.

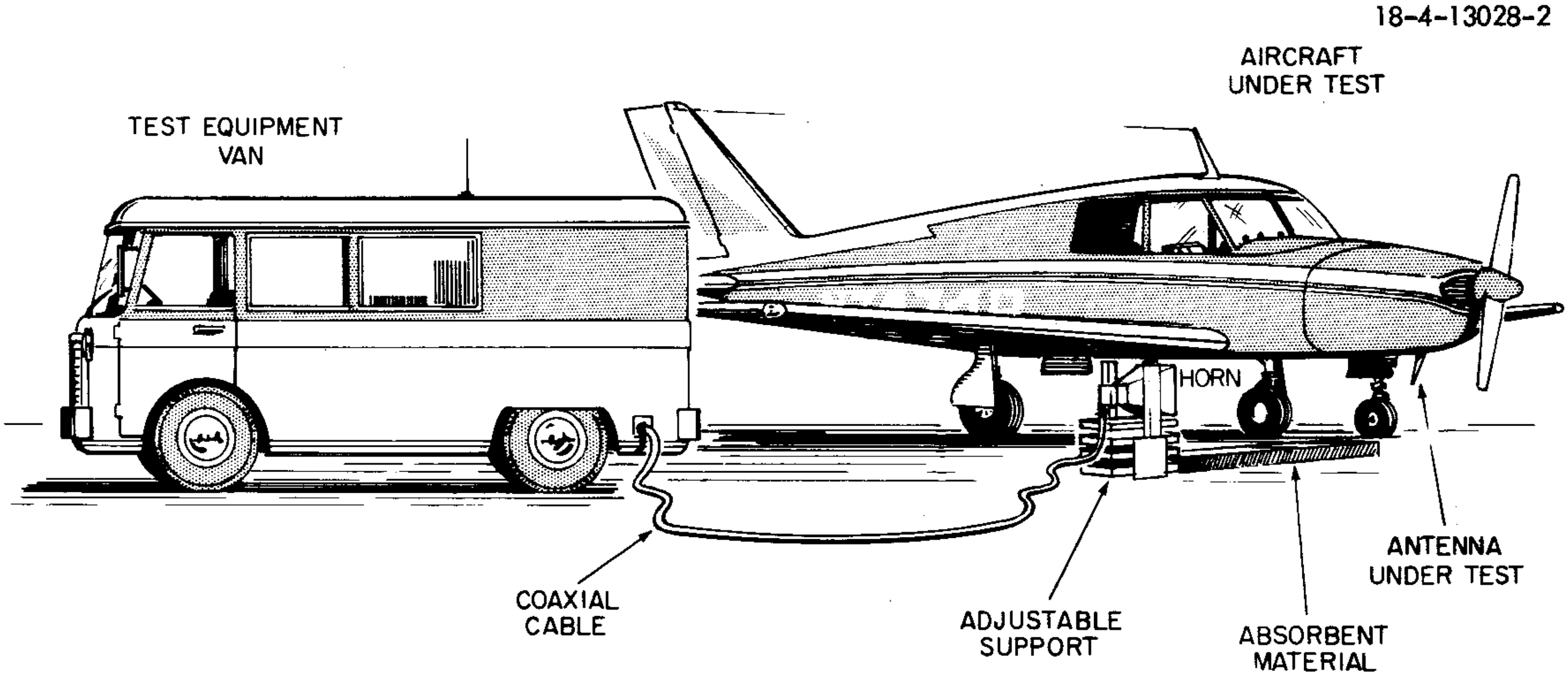

Fig. 1. Typical test setup.

2. Parameters Measured

The transponder parameters measured were: transmitter frequency, squitter, delay, Mode C operation, framing pulse spacing, P2/P1 ratio required for suppression, dead time, suppression time, power output and sensitivity. General definitions of these parameters are given in the following paragraphs.[2,3]

Transmitter Frequency is the center frequency of the reply spectrum. The specification value is 1090 ±3 MHz.

Squitter is the transmission of false reply signals in the absence of valid interrogations. The maximum squitter rate allowed by the specification is 30 false replies per second.

Delay is the length of time from the leading edge of a received P3* pulse to the leading edge of the first reply pulse. Delay is specified to be 3 ±0.5 microseconds.

Mode C Operation is checked by interrogating the transponder with a Mode C pulse pair (P1 - P3 spacing of 21 microseconds) and observing the Mode C reply, if any. All transponders should reply with a pair of framing pulses if no encoding altimeter is connected.**

Framing Pulse Spacing is measured by determining the time interval from the

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* The two pulses of a normal interrogation are referred to as P1 and P3 pulses. The side-lobe suppression pulse, which occurs between P1 and P3 is referred to as the P2 pulse.

** The most elementary reply, as it exists when a 0000 code is set into the transponder on Mode A, or when no altimeter is connected on Mode C, consists of a pair of pulses called "framing pulses."

start of the first framing pulse to the start of the second framing pulse. The time interval is specified to be 20.3 ±0.1 microsecond.

P2/P1 Ratio Required for Suppression Suppression of a transponder should occur upon receipt of a P2 pulse equal to, or greater than, the corresponding P1 pulse. Suppression should not occur if P2 is more than 9 dB below P1.

Dead Time After reception of a proper interrogation, the transponder shall not reply to any other interrogation at least for the duration of the reply pulse train. This dead time shall end no later than 125 microseconds after the transmission of the last reply pulse of the group.

Suppression Time is the interval between the start of a P2 pulse sufficient to cause suppression and the start of the earliest subsequent interrogation which can cause the transponder to reply. The suppression time is specified to be 35 ±10 microseconds.

The Peak Power Output is specified to be between +21 dBW and +27 dBW for aircraft designed to operate above 15,000 feet, and between +18.5 dBW and +27 dBW for aircraft operating below 15,000 feet.

The Sensitivity of the transponder receiving system is specified to be between -69 and -77 dBm as measured at the antenna terminals.

3. Sites

Tests on general aviation aircraft were conducted at airports in the following states: (See Figure 2.)

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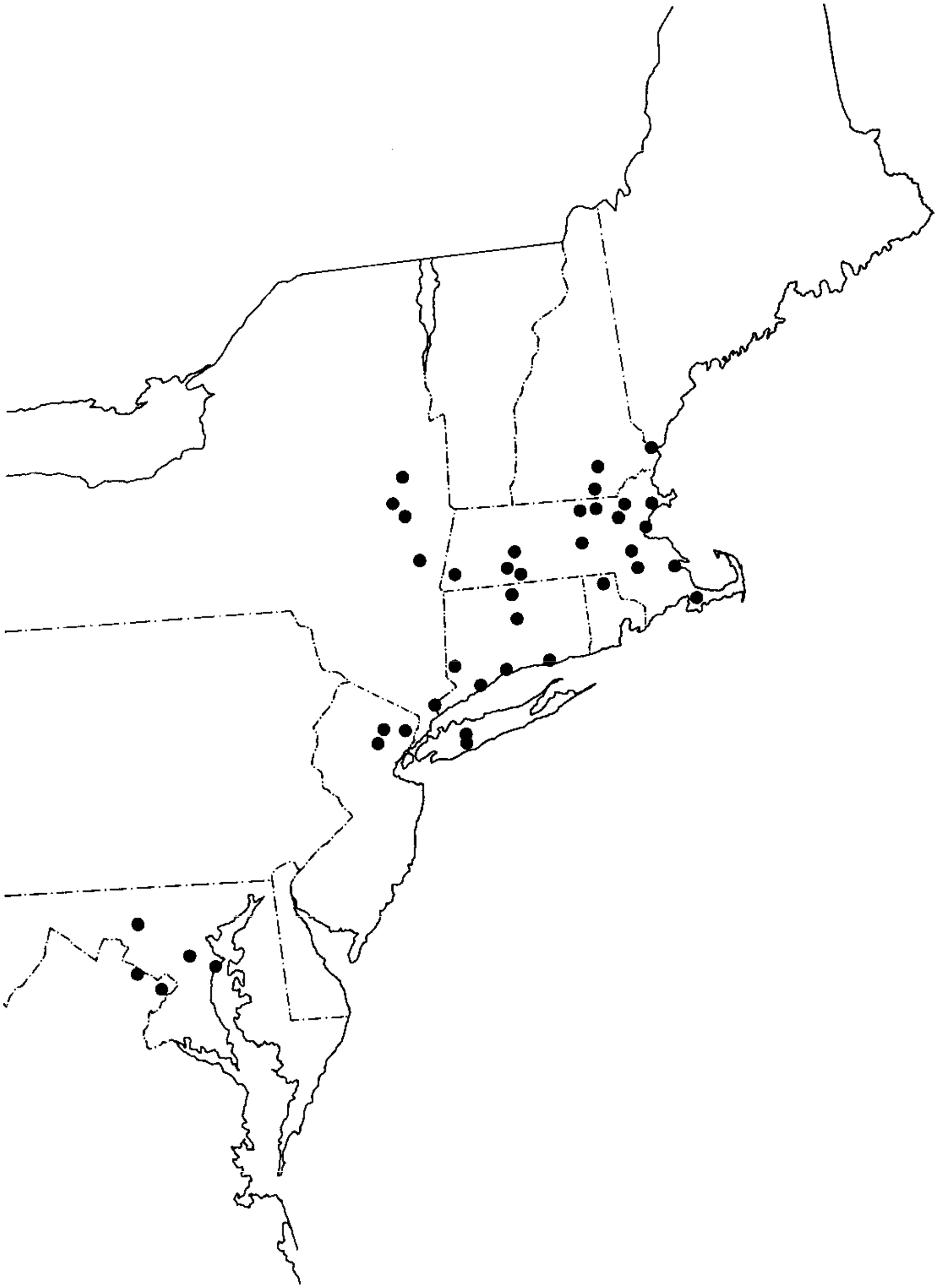

Fig. 2. Airport test sites.

State	No. of Airports
New Hampshire	2
Massachusetts	13
Rhode Island	1
Connecticut	6
New York	7
New Jersey	3
Maryland	3
Virginia	2

Tests on air carrier transponders were conducted at Logan Airport, Boston. Tests on military aircraft were conducted at Hanscom Field, Ft. Devens, and Otis AFB in Massachusetts, and at Pease AFB in New Hampshire.

4. Schedule

The project was initiated in mid-May 1971. The required equipment was obtained and installed in the van and the field tests started by mid-June. The initial field test ended following the test of unit number 96 in mid-July. Prior to the publication of the interim report in late September, the scope of the measurement program was extended to include tests on a total of 500 general aviation transponders. The extended field testing was performed between mid-October 1971 and the end of February 1972.

C. Implementation

1. General

In view of the short time period allowed for the initial phase of the program, equipment was taken from a previously existing transponder test bench setup, installed in a van, and used for this program.

A photograph of the test instrumentation installed in the van is shown in Figure 3. This equipment simulated the transmitter and receiver portions of an ATCRBS ground interrogator. Coupling to the transponder antenna was accomplished by means of a test horn antenna which was connected to the test equipment in the van by a coaxial cable.

2. Transmitter

A block diagram of the instrumentation is shown in Figure 4. The RF Signal Generator served as the RF source for the transmitter. The nominal output of this generator was 1 milliwatt with the attenuator in the zero decibel position, and attenuation of over 100 dB was available. This generator was operated at a constant frequency of 1030 MHz. The output of the generator was connected to a power divider and used to drive the two modulators. The first modulator was used to generate the P1 and P3 RF pulses. A logic box driven by a pulse generator provided the video input to the modulator. The second modulator was used to generate the P2 RF pulse. The P2 logic signal from the logic timing box was either fed directly to the P2 modulator driver or through a divide-by-two countdown circuit which only passed every other P2 pulse. The countdown mode, which was controlled by a switch on a control panel, was used in the suppression time tests.

The P1-P2-P3 Logic Box was driven by the output from a pulse generator operating at a PRF of 500 Hertz. For most tests, the pulse generator was operated on the single pulse mode; however, for the dead time and suppression time tests, the generator was operated in the double pulse mode. The delay control on the pulse generator was used to vary the spacing between pairs of interrogation pulse trains used for the dead time and suppression time tests.

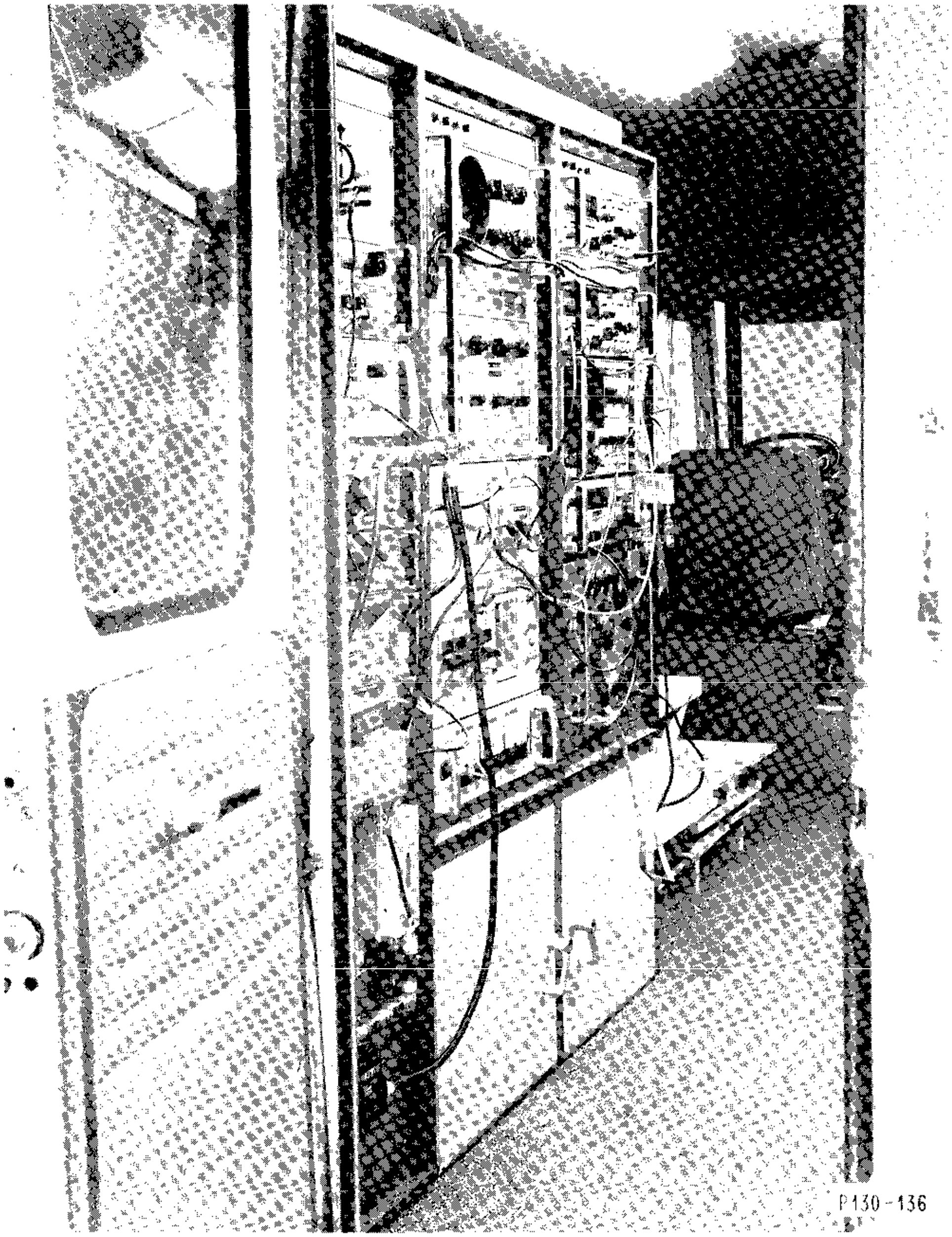

Fig. 3. Test instrumentation in van.

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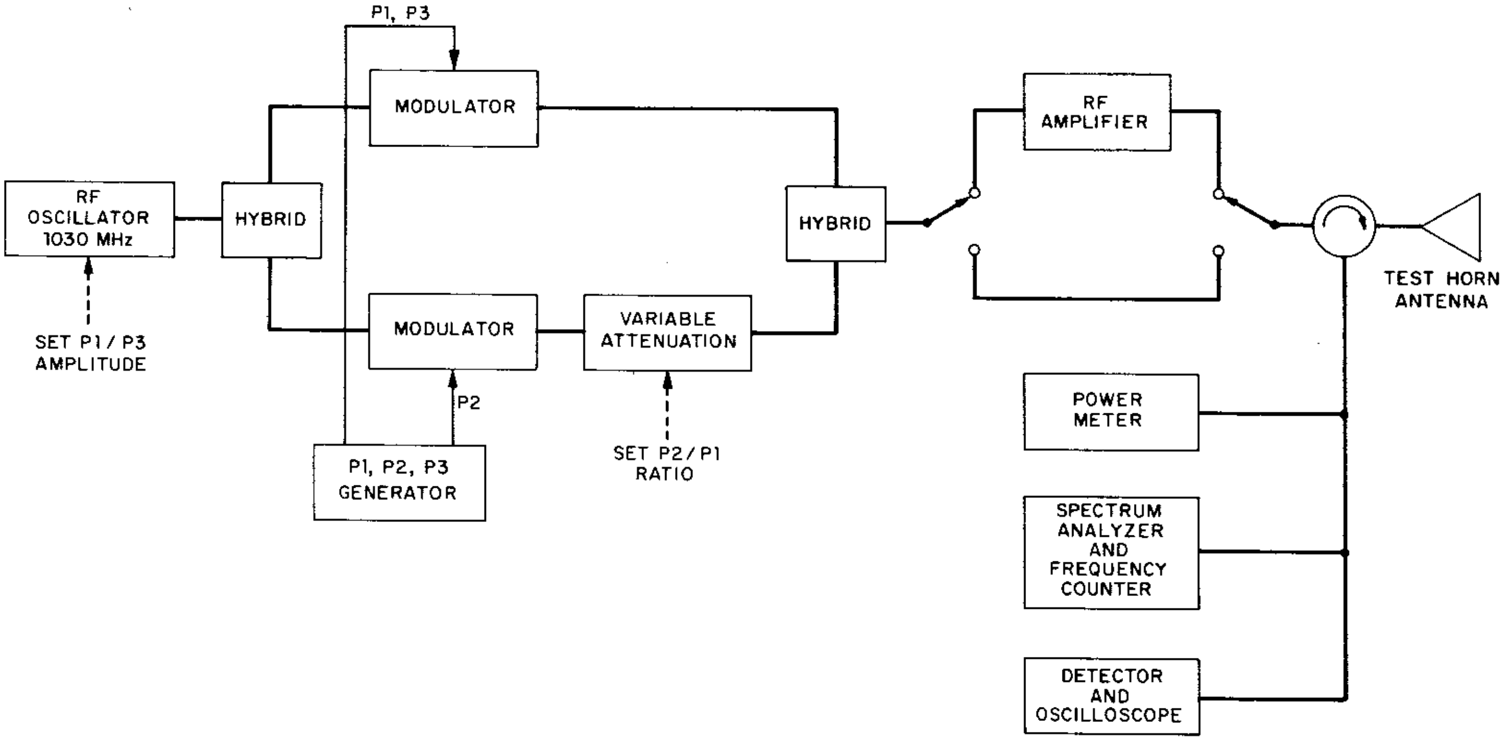

Fig. 4. Instrumentation block diagram.

The P1-P2-P3 Logic Box contained provision for control of the P1-P3 spacing. P1-P2 spacing was fixed at 2 microseconds. P1-P3 spacing was 8 microseconds when the spacing control switch was in the Mode A position. When this switch was in the Mode C position, the spacing was a nominal 21 microseconds with provision for varying this spacing by plus or minus 2 microseconds from the center value.

The P2 pulse from the modulator was fed through a fixed and a variable attenuator. The fixed attenuator was used to balance system losses. The variable attenuator allowed the operator to vary the amplitude of P2 relative to the P1-P3 pair. Note that P1 and P3 were always of the same amplitude. All three pulses were combined in a hybrid, and the output fed to either the circulator or an RF amplifier chain consisting of a solid state amplifier and a traveling wave tube amplifier. The amplifier chain was used in all tests except for sensitivity (where it was important to know the exact magnitude of the transmitted signal) and the squitter test, when no transmitter signal at all was radiated. It was found necessary to shut off the TWT amplifier during the squitter test to prevent leakage signals or noise from being amplified and triggering the transponder. A pair of coaxial switches was provided to control the amplifiers.

3. Receiver

Signals arriving from the horn antenna were passed through the circulator to a hybrid which directed the input signal to the various receiver channels. One half the power went to a variable attenuator and thence to a peak reading power meter.

The remainder of the received signal was coupled to two spectrum analyzers, operated in parallel, and to a crystal detector and video amplifier. The output of the detector was displayed on an oscilloscope. During the squitter test, the video amplifier output was fed to a frequency counter and the rate of false replies measured.

Two spectrum analyzers were used for convenience. One was outfitted with a camera used to photograph the display of the frequency spectrum. The second analyzer was used in the measurement of frequency. This was accomplished by varying the frequency of a reference generator until its output signal appeared to be in the middle of the transponder output frequency spectrum displayed on the analyzer. The generator frequency was then determined using the frequency counter.

4. Antenna

An L-band horn antenna was used to couple signals between the test setup and the transponder antenna (see Figure 5). This horn was mounted on a special fixture with absorbing material on the ground immediately in front of the horn. Provisions were made for inserting various shims to raise the horn to the desired height. The fixture was located so that the front edge of the horn was always 70 inches from the antenna and the top of the horn 5 inches above the center of the antenna under test. The horn was coupled to the van by means of a 43-foot coaxial cable. Early in the program, consideration was given to the possibility of using either direct coupling to the transponder or a coupling hood which would be positioned over the antenna under test. It rapidly became apparent, however, that access to the transponder was not

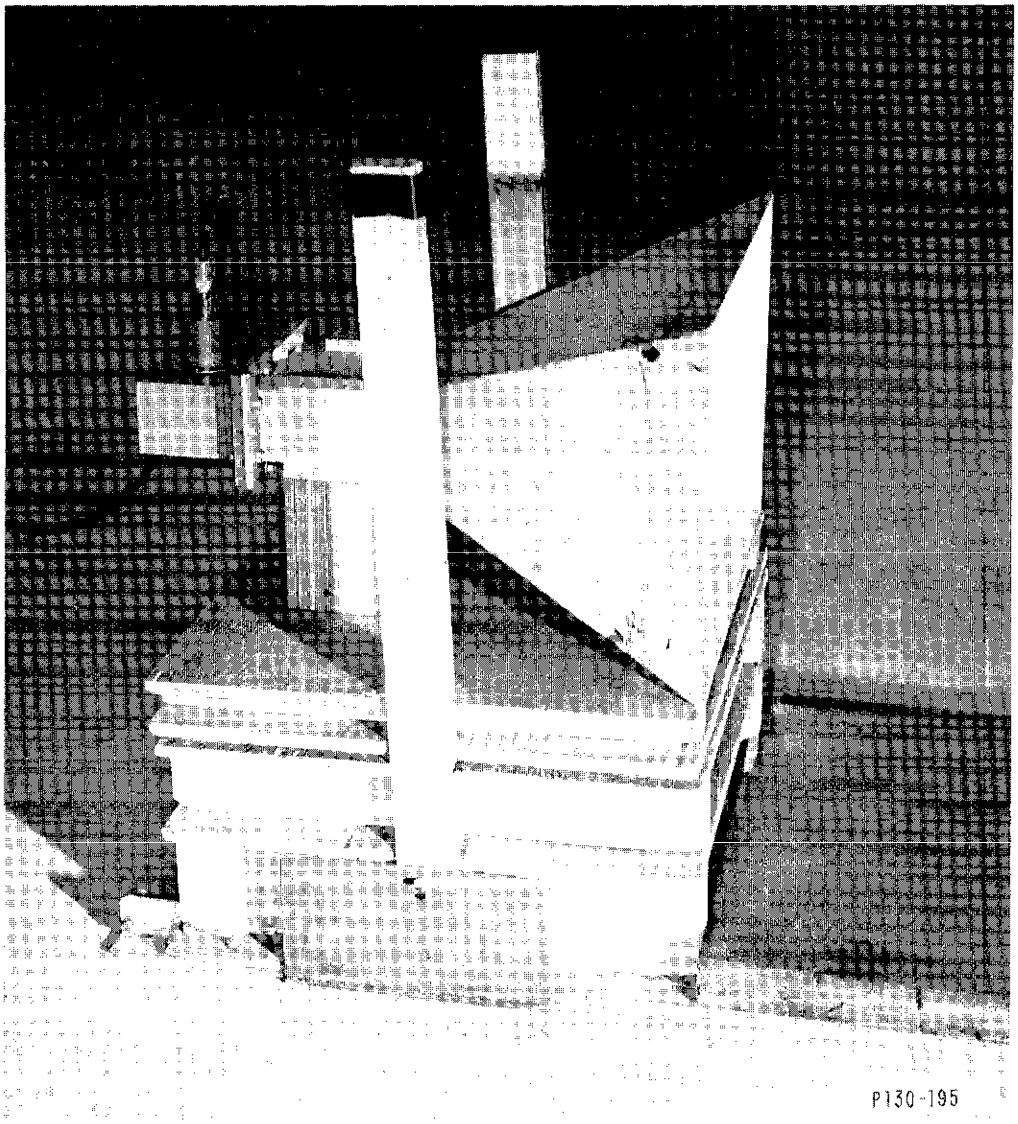
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Fig. 5. Test horn antenna.

feasible in most cases. The use of a coupling hood was equally infeasible due to the location of many antennas in close proximity to landing gear or other aircraft structural parts.

The coupling loss between the horn and various typical antennas mounted on a ground plane was measured and found to be of the order of 26 dB. A variation of coupling loss with height for the test setup was determined and incorporated into a calibration curve. This curve was used to correct the raw data for effects of ground multipath.*

5. Test Procedure

A detailed test procedure/data sheet was evolved which was used throughout the test program. Upon arrival of the aircraft to be tested, two members of the test crew would position the horn antenna and check the test setup. The third member of the crew would record aircraft and transponder type data and instruct the pilot in the method of conducting the test.

The pilot was then asked to start the engine, turn on all radio/ nav equipment, and operate the transponder on Mode A, Code 1777. As soon as the operators detected reply signals from the transponder, the test routine outlined in Table I was started. The test was accomplished in approximately 13 minutes if no unusual circumstances were encountered.

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*A discussion of the derivation of the coupling calibration curve is contained in Appendix A.

TABLE I

TEST PROCEDURE

	Action		Measurement
1.	Set Mode A Code 1777		Frequency
2.	Switch to Code 1200, turn off interrogation		Squitter
3.	Turn on xmtr, set interrogator	3 db above MTL*	Delay
		10 db above MTL	Delay
		50 db above MTL	Delay
	Switch to Mode C; Set interrogator to Mode C		Delay
4.	Set code to 0000; Interrogator to Mode A		Framing pulse spacing
5.	Set code to 1200		
	Set interrogator	3 db above MTL	P2/P1 Ratio for Suppression
		10 db above MTL	P2/P1 Ratio for Suppression
		50 db above MTL	P2/P1 Ratio for Suppression
6.	Set interrogator 10 db above MTL		Dead Time
7.	Set interrogator 10 db above MTL		Suppression Time
8.	Set interrogator 10 db above MTL		Power Output
9.	Set interrogator to MTL		Sensitivity

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* MTL = Minimum Triggering Level

II. DETAILED DISCUSSION OF DATA

The following section describes the sample population of the transponders tested by manufacturer, model, and end use. For reporting purposes, the units have been segregated into three categories: general aviation, military, and air carrier. The classification was made on the basis of end use, not on the basis of transponder model. The second section reports the results of the field tests.

A. Transponder Distribution

Transponders in general aviation aircraft were located, and arrangements made for testing, by working through an intermediary with extensive contacts at the particular airport. The intermediary was generally an aircraft dealer, maintenance shop operator, flight school manager, or free lance instructor. No preselection was made and transponders were tested in the order in which they became available.

In the following graphs and tables, the test results of individual units are identified by test numbers to allow further analysis as desired. A cross reference between test number, which relates to the order in testing, and transponder model is given in Appendix C.

Figure 6 shows the distribution of transponders tested by manufacturer and model type. It is reasonable to assume that the distribution is typical of general aviation transponder population in at least the geographic areas in which testing was performed.

The distribution of ownership of the general aviation aircraft tested is presented in Table II.

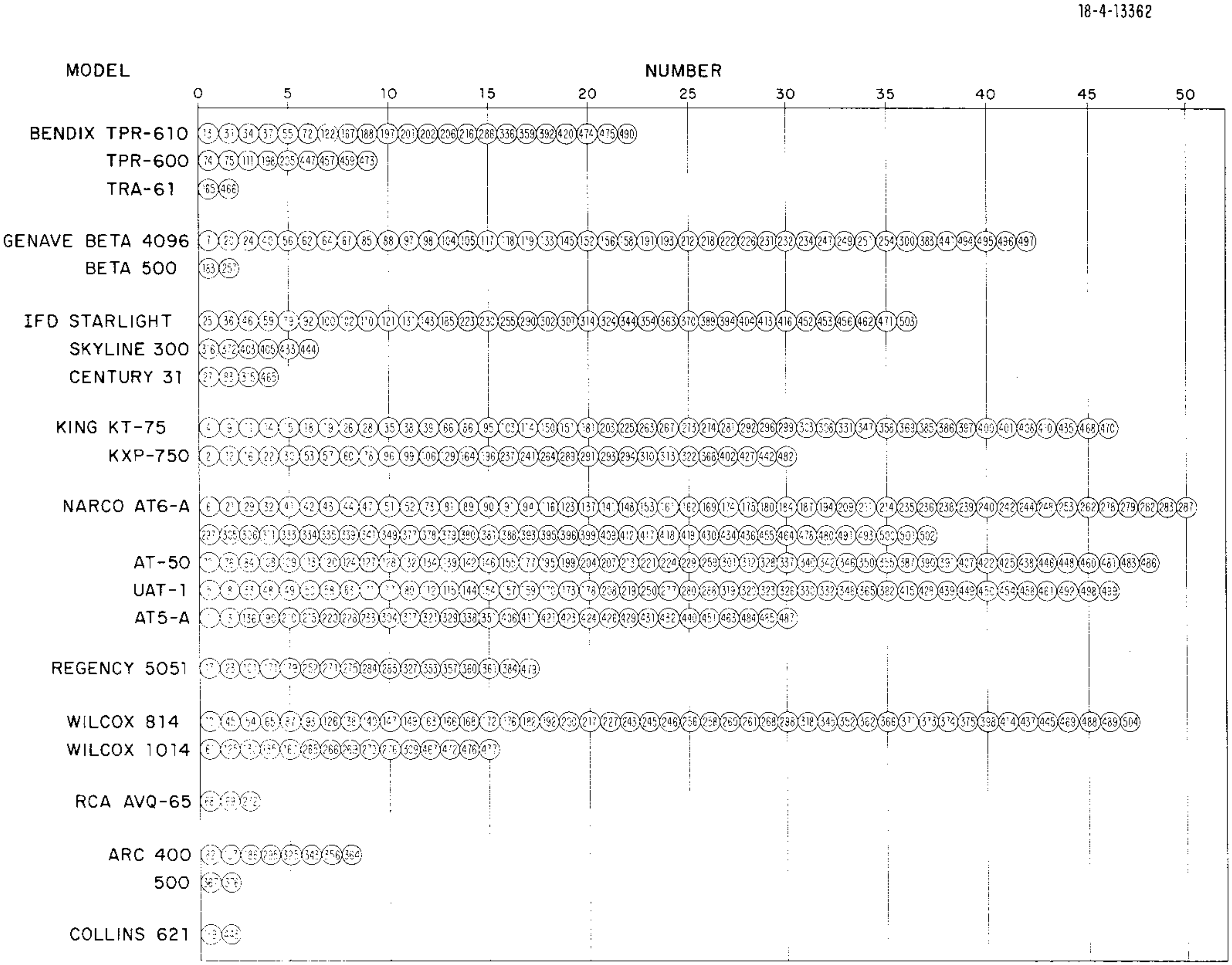

Fig. 6. Distribution of general aviation transponders tested by model. (Numbers inside circles refer to the order in which the units were tested; i.e. 13 was the thirteenth unit tested.)

TABLE II

OWNERSHIP OF GENERAL AVIATION TRANSPONDERS TESTED

Type Owner	Quantity Owned
Private Individuals	202
Corporations & Businesses	107
Dealers	88
Flying Schools, Air Charter	43
Clubs	21
Unidentified	43
Total Tested	504

Arrangements for tests of transponders in military aircraft were made through the base operations offices. Tests were made at Air Force installations at Pease AFB, Otis AFB, and Hanscom Field, and at the Army installation at Fort Devens. Arrangements for tests of air carrier aircraft were made through direct contact with maintenance personnel of two scheduled air carriers with maintenance facilities at Logan Airport. The distribution of military and air carrier transponders tested by model type is shown in Table III.

B. Test Results

1. Inoperable Units

The units listed in Table IV were found to be inoperative and consequently do not appear in the data plots. In general, the operators appeared to be unaware that the transponders were not working properly.

TABLE III

DISTRIBUTION OF MILITARY & AIR CARRIER TRANSPONDERS TESTED BY MODEL

	MODEL	TEST NUMBER
Military		
	AN/APX-25	1, 2, 3, 4, 11, 14, 15, 16, 17
	AN/APX-44	5, 6, 9
	AN/APX-64	12
	AN/APX-72	7, 8
	Narco AT6-A	10, 13
Air Carrier	Collins 621A	1, 17, 21, 22, 23, 24, 25, 26, 27, 28
	Wilcox 914A	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20

TABLE IV

INOPERATIVE TRANSPONDERS

	TEST NUMBER						
General Aviation	32	154	194	271	373	413	477
	36	157	199	278	377	424	
	43	183	208	305	384	434	
	93	185	247	361	398	450	
	139	191	254	369	402	458	
Military	7	9					
Air Carrier	20 (one unit of a dual installation)						

2. Reply Frequency

The results of the transponder reply frequency measurements are shown in Figures 7 and 8. Of the 473 operable general aviation transponders tested, seventeen were above the specification upper limit, and thirty-four were below the specification lower limit. Military unit number six had a reply frequency of 1085.8 MHz; otherwise, all other units were within specification limits.

3. Squitter

Squitter was found to be present in a total of 47 transponders. Of these, six were located at airports with interrogators which made accurate squitter measurements difficult. Of the remaining forty-one units, as shown in Figure 9, thirty-two units had squitter rates below the specification limit of 30 false replies per second, four units had squitter rates between 30 and 100 false replies per second, and five units had squitter rates over 100 false replies per second. The highest squitter rate found was 2209 false replies per second.

No squitter was detected in military or air-carrier transponders.

4. Delay

The delay is the time between the arrival at the transponder of the second interrogation pulse (P3) and the transmission of the first framing pulse of a reply. The times were measured at the 50 percent amplitude points. Before plotting, the raw data was corrected for a total instrumentation circuit delay of 0.50 microsecond. It was known that delay varied with signal level; therefore, the test was conducted with interrogation levels of 3, 10 and 50 dB above the minimum triggering level.

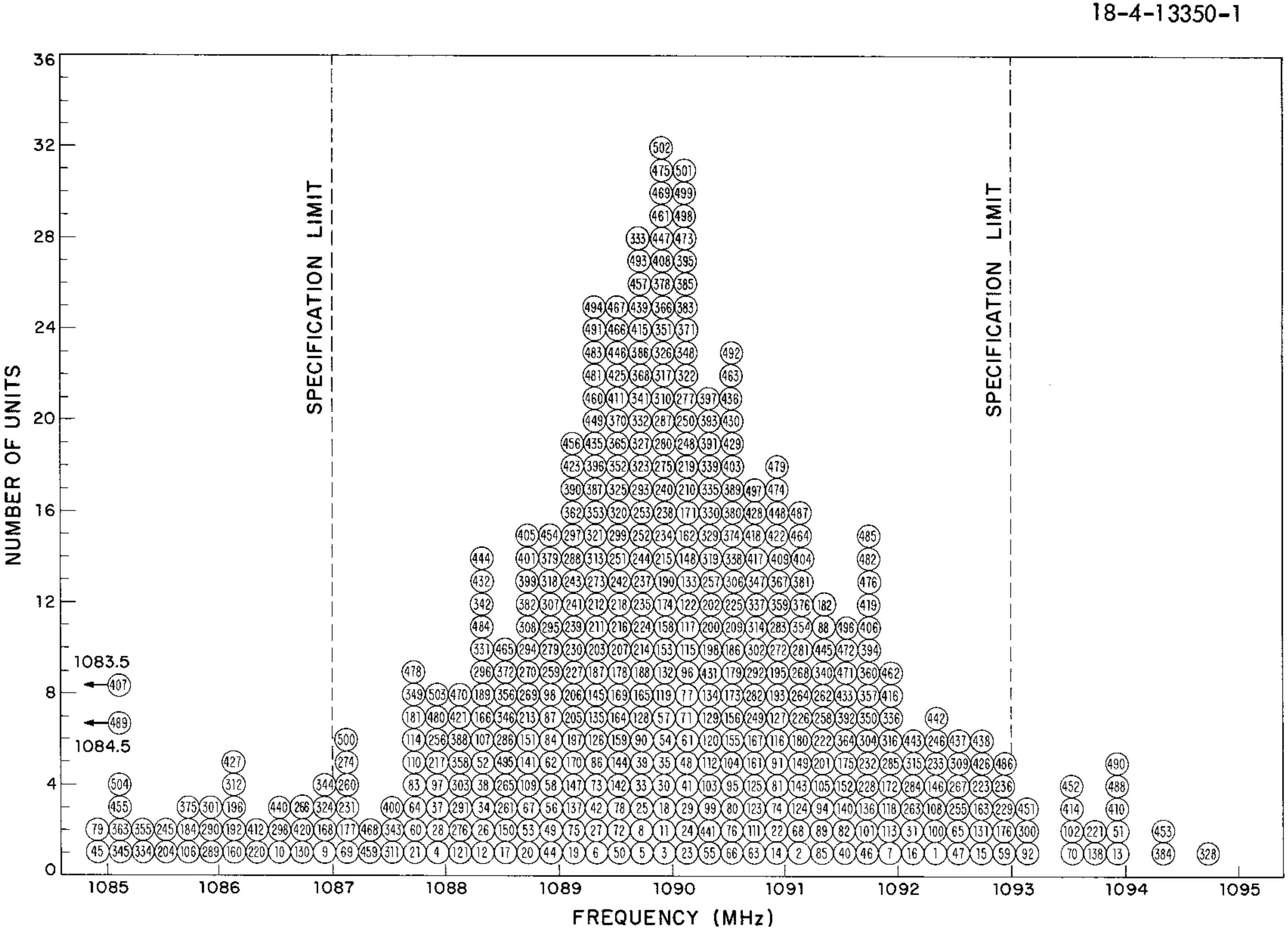

Fig. 7. Reply frequency - general aviation transponders.

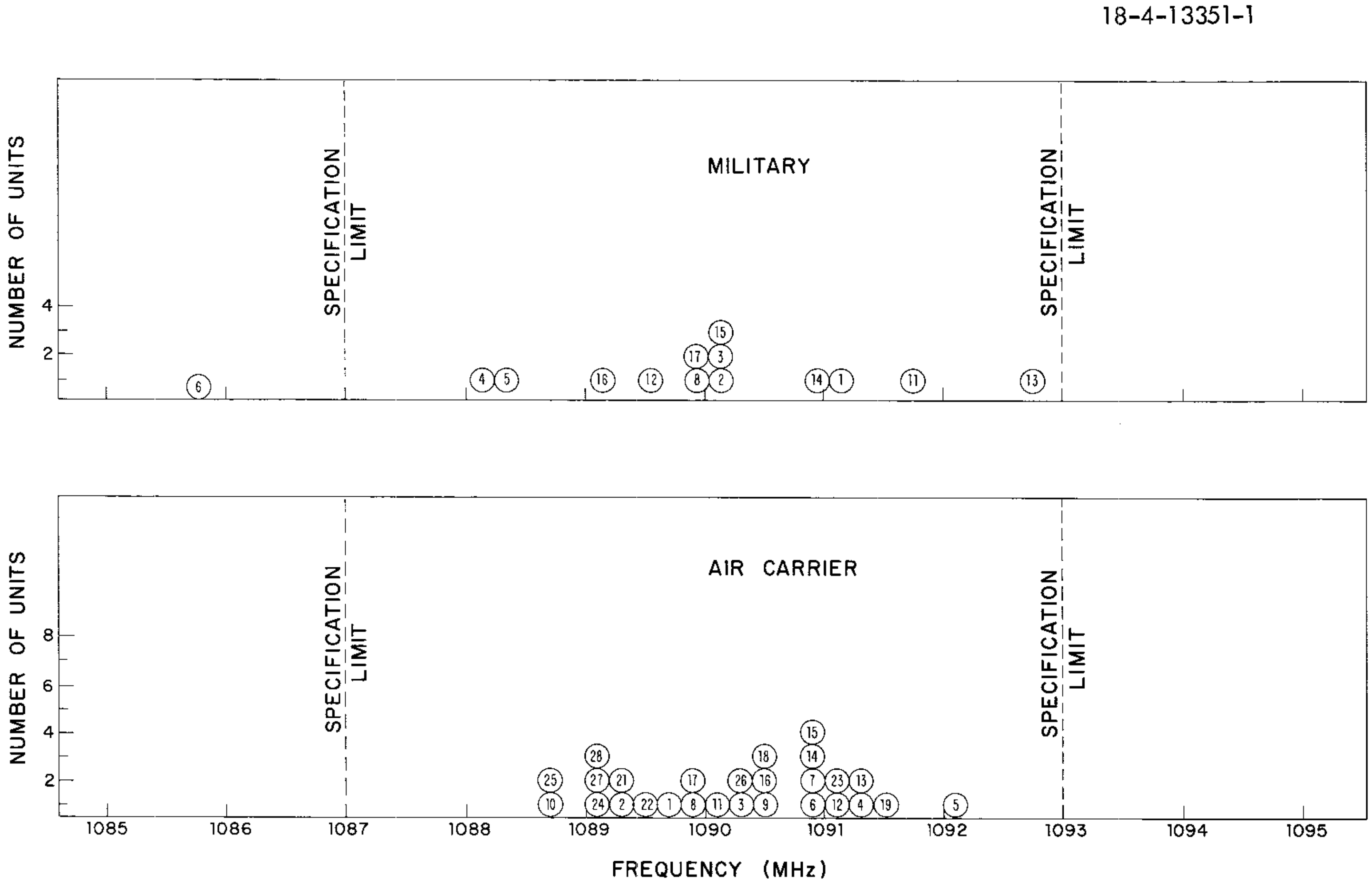

Fig. 8. Reply frequency - military and air carrier transponders.

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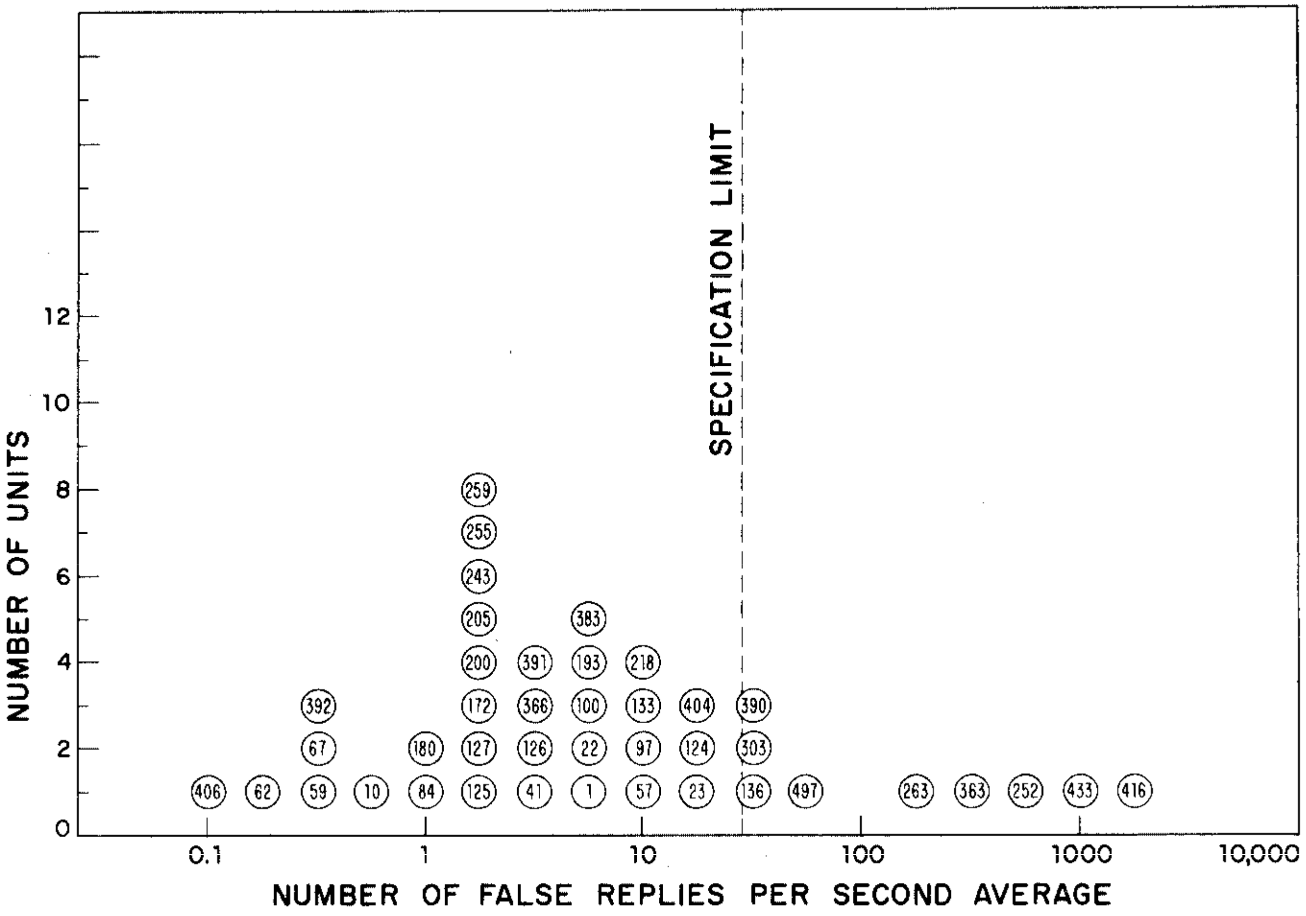

Fig. 9. False reply rates (SQUITTER) – general aviation transponders.

A plot of the results of the delay measurement on general aviation aircraft is shown in Figure 10. The results for military and air carrier transponders are similar. All such units tested were within specification for transponder delay.

5. Mode C

Following the delay test, the pilot was instructed to switch his transponder to Mode C (ALT). The transponder was then interrogated with a signal level of 10 dB above the minimum Mode A triggering level. The delay on Mode C was then measured, and was found to be generally consistent with the Mode A results for the same interrogation level.

Whenever a unit was found which did not reply to a Mode C interrogation, a member of the test crew checked the aircraft's control panel to ensure that the transponder was set for this mode of operation. The P1 - P3 spacing was then varied over the range from 19 to 22 microseconds. Units that did not reply to the nominal pulse spacing of 21 microseconds did not reply for any pulse spacing within the test range.

The distribution of units which did not reply to a Mode C interrogation is given in Table V. A large fraction of the NARCO AT6-A transponders were deliberately inhibited from responding to the Mode C interrogation; the manufacturer has indicated that this practice has been discontinued.

6. Dead Time

The dead time was measured using two Mode A interrogations and the data was reduced to conform to the RTCA specification of test procedures.

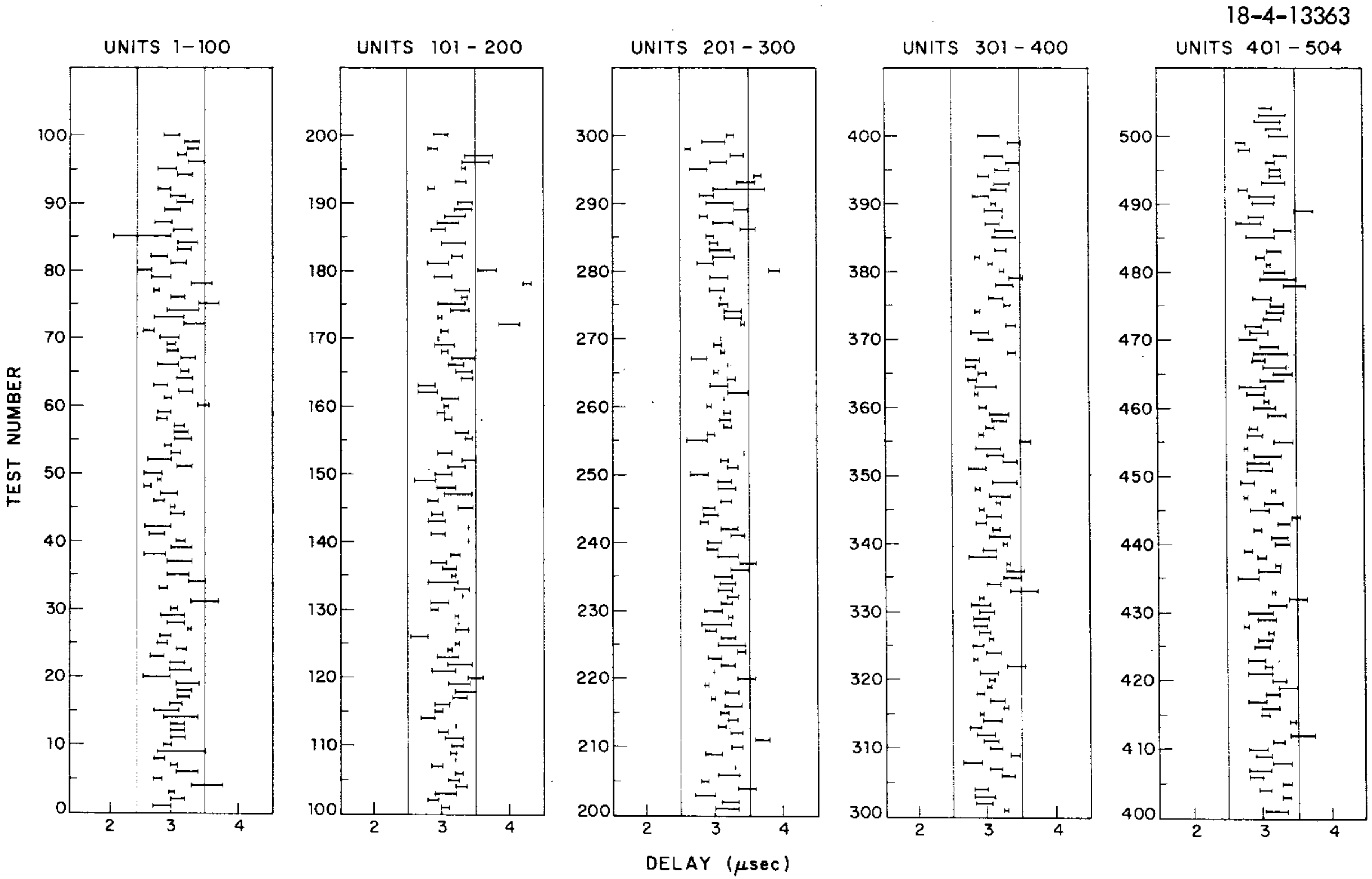

Fig. 10. Transponder delay - general aviation transponders.

TABLE V

TRANSPONDERS FAILING TO REPLY TO MODE C INTERROGATION

Manufacturer	Model	Number With No Replies*	Total Number Tested
ARC	400	1	8
BENDIX	TRA-61	2	2
	TPR-610	1	22
COLLINS	621	1	2
GENAVE	Beta 4096	2	42
IFD	Starlight	1	36
	Skyline 300	1	6
KING	KT-75	1	46
	KXP-750	1	30
NARCO	AT6-A	66	87
	UAT-1	18	46
RCA	AVQ-65	1	3
REGENCY	5051	1	17
WILCOX	814	13	47
	1014	1	15
	Total	111*	

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* Does not include units which were inoperative in all modes.

Results of the measurements on general aviation aircraft are given in Figure 11 and the results for military and air carrier transponders in Figure 12. Specification limits are zero and 125 microseconds.

A total of 32 transponders had measured dead time longer than allowed by the specification. Of these, 25 had dead time longer than 300 microseconds. The distribution of these 32 units is as follows:

TABLE VI

UNITS NOT MEETING DEAD TIME SPECIFICATION

Manufacturer	Model	Number	Total Tested
IFD	Starlight	29	36
	Skyline 300	1	6
	Century 31	1	4
WILCOX	1014	1	15

The dead time clustered around 33 microseconds. Analysis of the entire dead time distribution shows 90 percent of the operating general aviation transponders tested had dead times between 27 and 70 microseconds. Seventy percent of the units tested were between 28 and 41 microseconds.

7. P2/P1 Ratio Required for Suppression

The amplitude of the P2 pulse relative to the amplitude of the P1 and P3 pulses required to produce essentially complete suppression was measured for P1 and P3 signal levels of 3, 10, and 50 dB above the minimum triggering level.

An analysis of data taken during the early part of the project, and described in the interim report, showed two models of transponders to be

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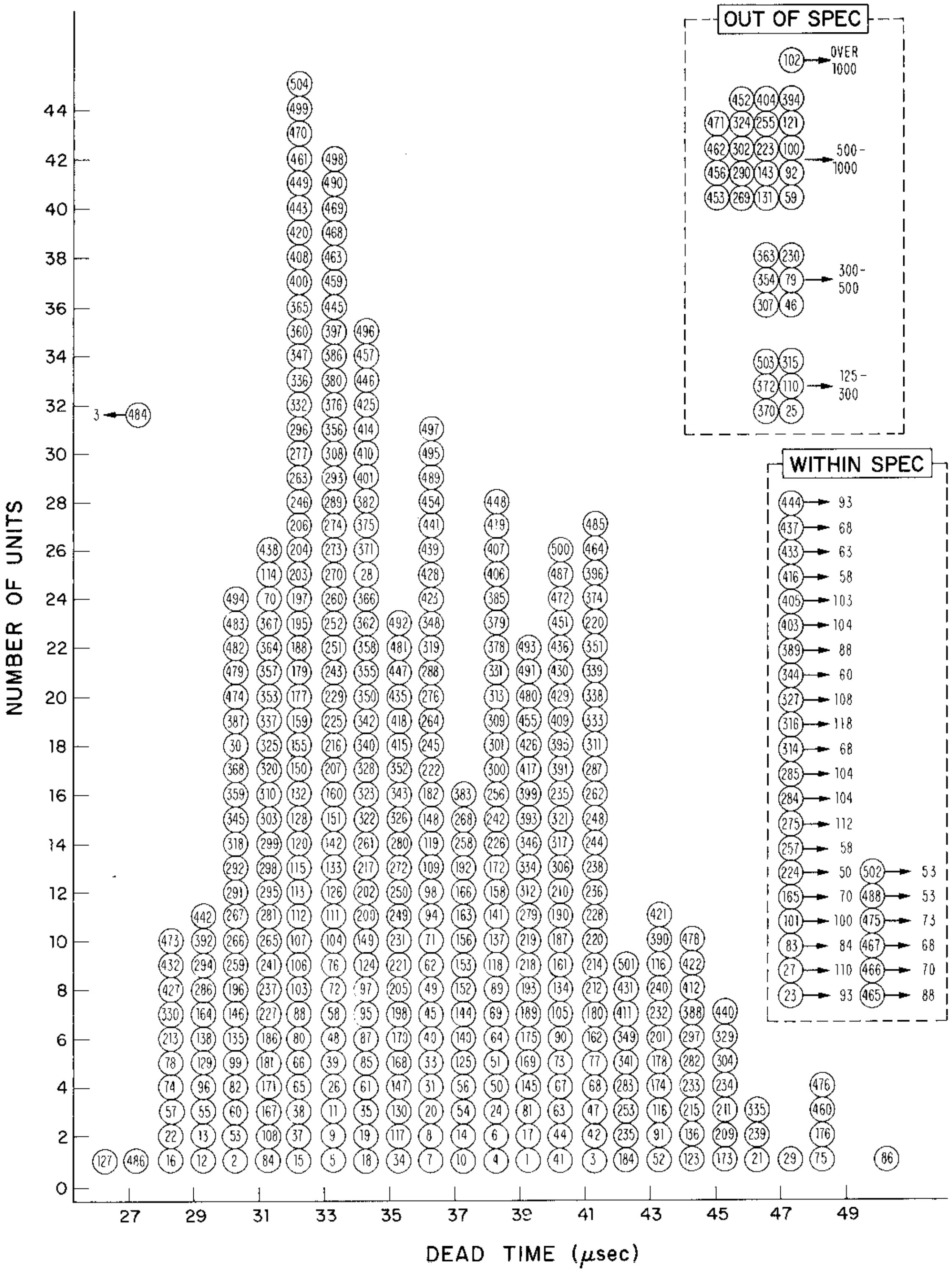

Fig. 11. Dead time – general aviation transponders.

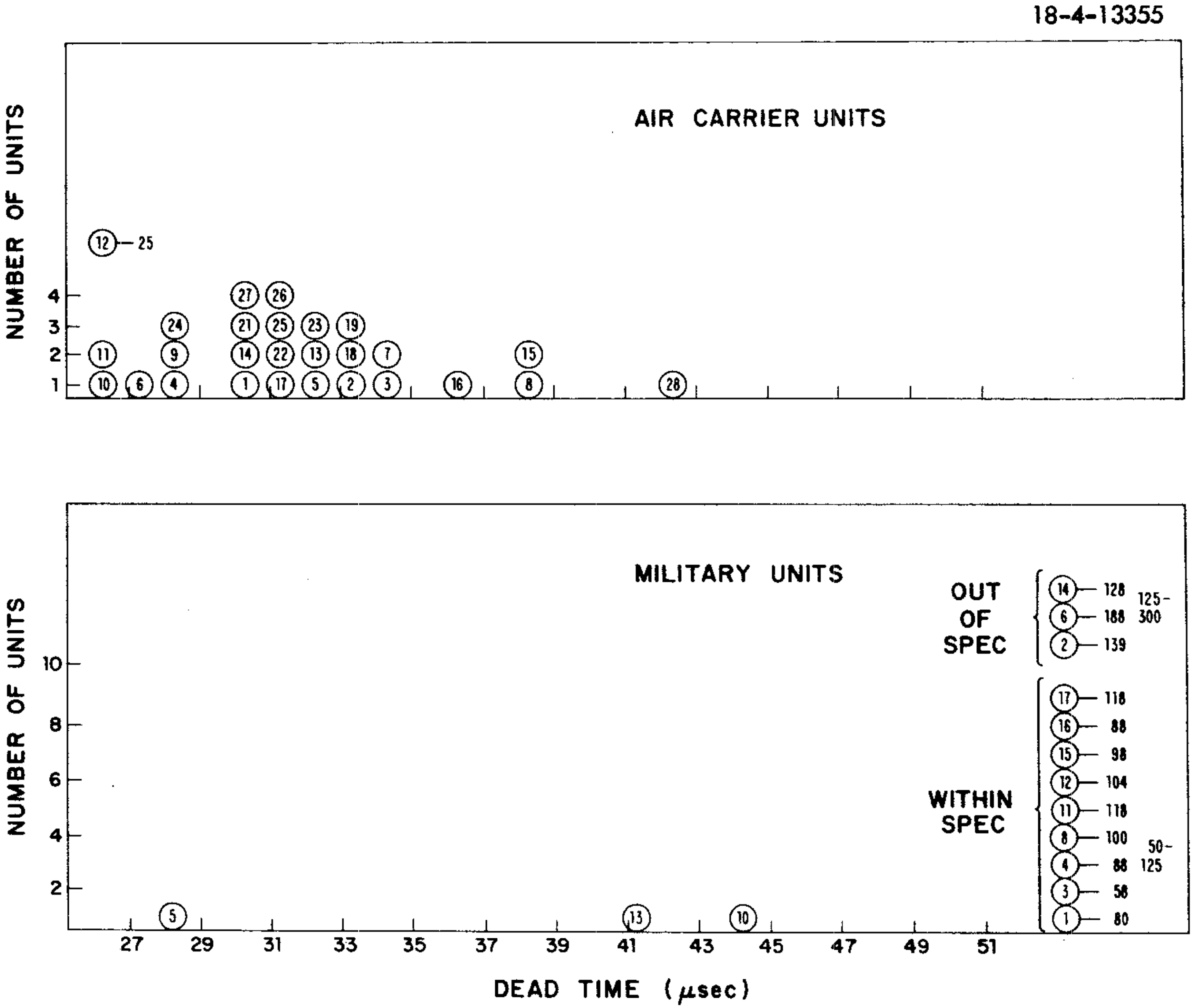

Fig. 12. Dead time - military and air carrier transponders.

consistently yielding results which were at variance with the specifications. An investigation into possible causes of such results indicated CW RF leakage signals at relatively low levels could interfere with suppression action in some models of transponders.*

Two sources of leakage were identified during the investigation. A low level constant-amplitude RF leakage signal was apparently present in the test setup during the period in which the first 96 units were tested. Such a signal would cause the poor suppression action of the King KXP-750 found at low signal levels. A second leakage signal, resulting from an improperly functioning P2 modulator driver, apparently existed during the testing of the first 416 transponders. The amplitude of this leakage signal was a function of the interrogation signal level, and therefore its influence became more significant at the higher signal levels. It caused the lack of suppression action at 50 dB interrogation level observed in the case of the Bendix TPR-610 transponders.

Following the investigation, the sources of the leakage were eliminated from the test setup. Units tested after number 416 were not exposed to leakage signals. As shown in Figure 13, of the 83 operable units in this test sample, 14 were more than 3 dB outside of specification limits. A breakdown of these results by model is given in Table VII. The fourteen units represent ten different models by six different manufacturers.

The results of the complete P2/P1 ratio-for-suppression measurements are plotted in Figure 20, in Appendix B. Results on Bendix TPR-610 units prior to test number 417 and King KXP-750 units prior to test number 97 have been omitted from the chart because of the doubtful validity of the measurement due

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* A complete discussion of the RF leakage investigation and findings is given in Appendix B.

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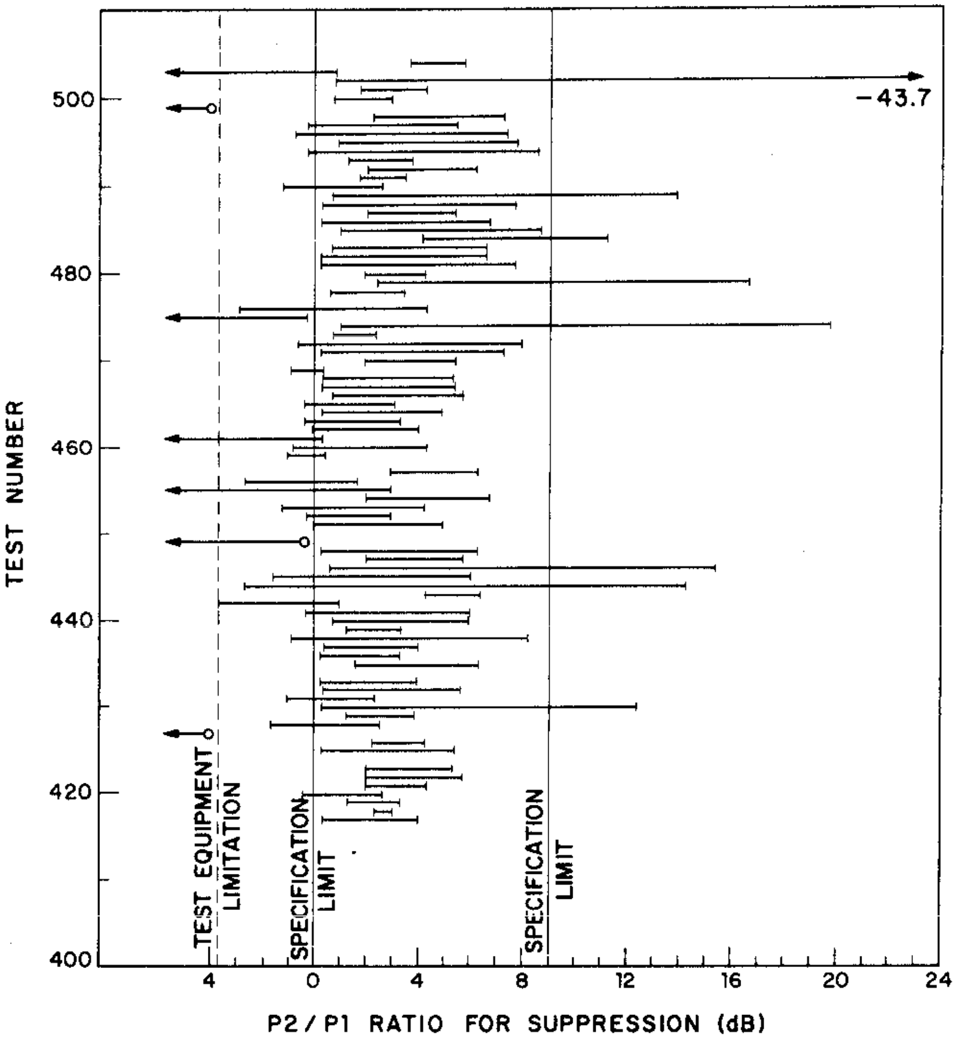

Fig. 13. P2/P1 ratio for suppression - general aviation transponders.

TABLE VII

P2/P1 SUPPRESSION RATIO PROBLEMS

Manufacturer	Model	Number More Than 3dB Over Spec	Total Number In Sample
Bendix	TPR-610	1	4
	TRA-61	1	1
IFD	Starlight	1	6
	Skyline	1	2
King	KXP-750	2	3
Narco	AT6-A	3	12
	AT-50	1	9
	UAT-1	2	10
Regency	505I	1	1
Wilcox	814	1	6

to the possible influence of leakage. Bench and field tests of the CW leakage susceptibility of other makes and model transponders have not indicated any performance degradation when subjected to leakage levels of the magnitude revealed in the aforementioned investigation.

Of the fifteen operating military transponders tested, nine were AN/APX-25's which do not have side-lobe suppression circuitry. Tests on the other six units revealed one unit to have no suppression action at any signal level (military unit number 6) and two units to have suppression action at the 50 dB above minimum triggering level (MTL) test signal level for P2/P1 ratios of -12.3 and -18.4 dB, respectively (military unit numbers 5 and 12).

One air carrier transponder tested did not suppress at any signal level (air carrier unit number 3) and one unit suppressed at the 50 dB above MTL test signal level for a P2/P1 ratio of -11.6 dB (air carrier unit number 10). Otherwise, all units were within specification for all test signal levels.

8. Suppression Time

The suppression time was measured with a signal level 10 dB above the minimum triggering level with a P2 pulse equal in amplitude to P1, or higher if required, to produce suppression. The test results for general aviation units are shown in Figure 14.

One military unit exhibited a suppression time of 22 microseconds (military unit number 8) and one air carrier (unit number 6) remained suppressed for 20 microseconds. Otherwise, suppression times measured for military and air carrier transponders were within the specification limit of 25 to 45 microseconds.

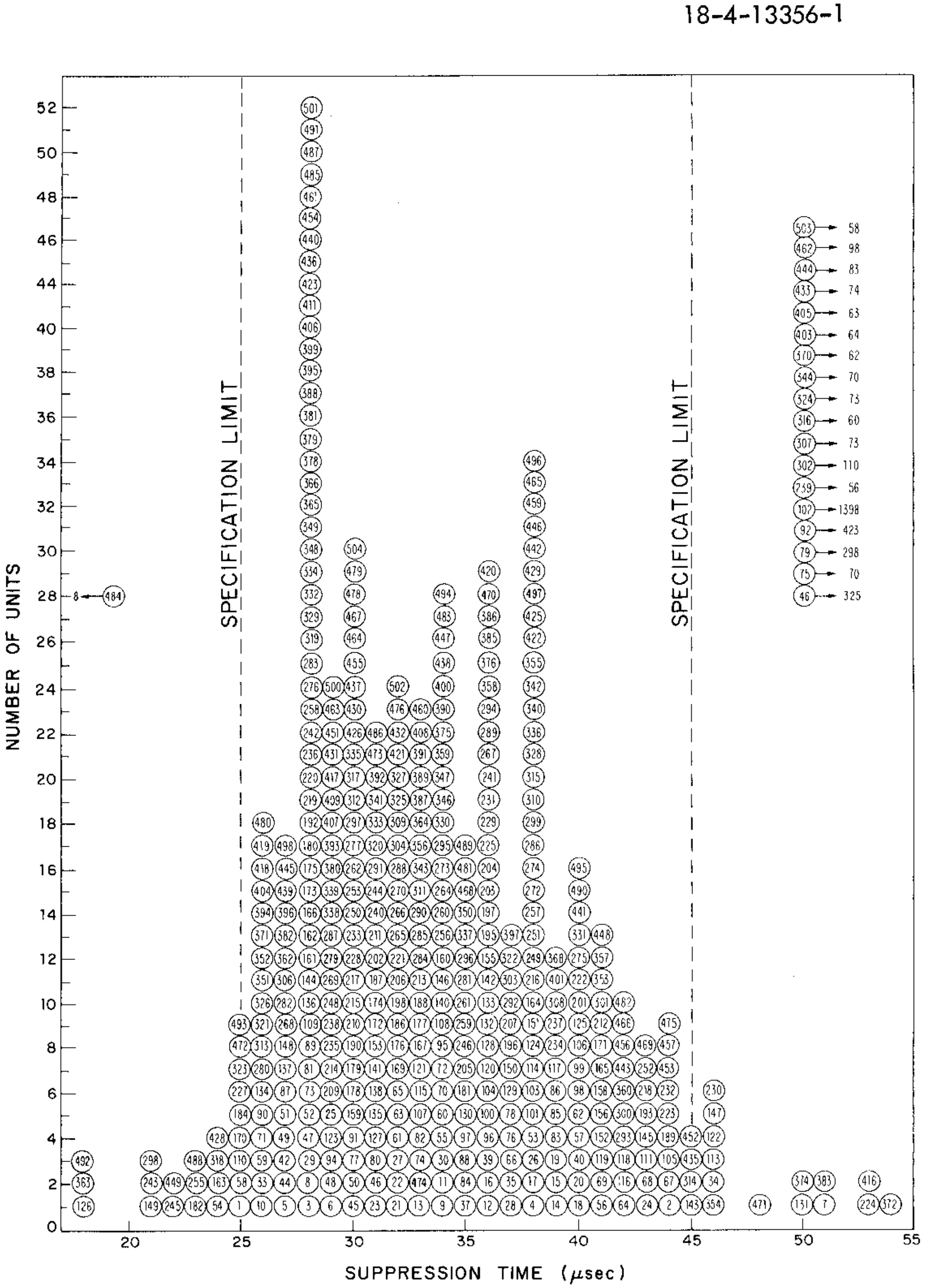

Fig. 14. Suppression time – general aviation transponders.

9. Framing Pulse Spacing

The spacing between framing pulses, measured from the start of the first framing pulse received to the start of the second pulse received when the transponder was using a 0000 code, is specified to be 20.3 ±0.1 microsecond.

Table VIII lists all units whose framing pulse spacing are out-of-specification. For general aviation transponders, 13 of 473 operable units were out of specification; for military transponders, 2 of 15 operable units were out of specification; and for air carrier, 1 of 27 operable units was out of specification.

10. Power Output and Sensitivity

Power output and sensitivity measurements are dependent for their accuracy on a knowledge of path attenuation between the instrumentation and the transponder antenna. In this test program it was not feasible to provide a direct connection between the instrumentation and the transponder antenna; the coupling was accomplished by the use of a horn radiating to the aircraft antenna.

A laboratory simulation was set up using a ground plane and typical transponder antennas to simulate the aircraft installations, and a series of measurements was made to determine the magnitude and consistency of coupling path losses between the test horn and the transponder antenna. A separation of 70 inches was selected as a standard distance from the transponder antenna to the front edge of the test horn. This separation was a compromise between

TABLE VIII

FRAMING PULSE SPACING

Readings Outside Specification Limits

	Test No	Spacing
General Aviation	164	20.5
	173	20.1
	180	20.5
	235	20.0
	264	20.1
	284	20.1
	320	20.1
	352	19.9
	376	20.1
	428	20.1
	471	20.1
	481	20.1
	494	20.1
Military	5	20.1
	14	20.1
Air Carrier	15	20.1

the elimination of near-field effects, which favored large separation, and the elimination of effects due to reflections from extraneous objects which favored a close spacing. The vertical position of the test horn was found to be relatively uncritical, and a position of the top edge of the test horn five inches above the center of the transponder antenna was arbitrarily chosen as a standard position. Detailed coupling measurements were made in the laboratory (see further discussion in Appendix B) and the coupling path loss was found to be a function of the height of the two antennas. A calibration curve was derived which was used in reducing the power output and sensitivity test data. This curve was later compared to the results of some coupling measurements which were made in the field. The field measurements indicated an rms deviation from the curve of 1.3 dB.

The results of the power output measurement are shown in Figures 15 and 16. The specified ranges are between 18.5 and 27 dBw for aircraft operating below 15,000 feet, and between 21 and 27 dBw for aircraft operating above 15,000 feet.

The results of the transponder sensitivity measurements are shown in Figures 17 and 18. The specification limits are -69 dBm and -77 dBm.

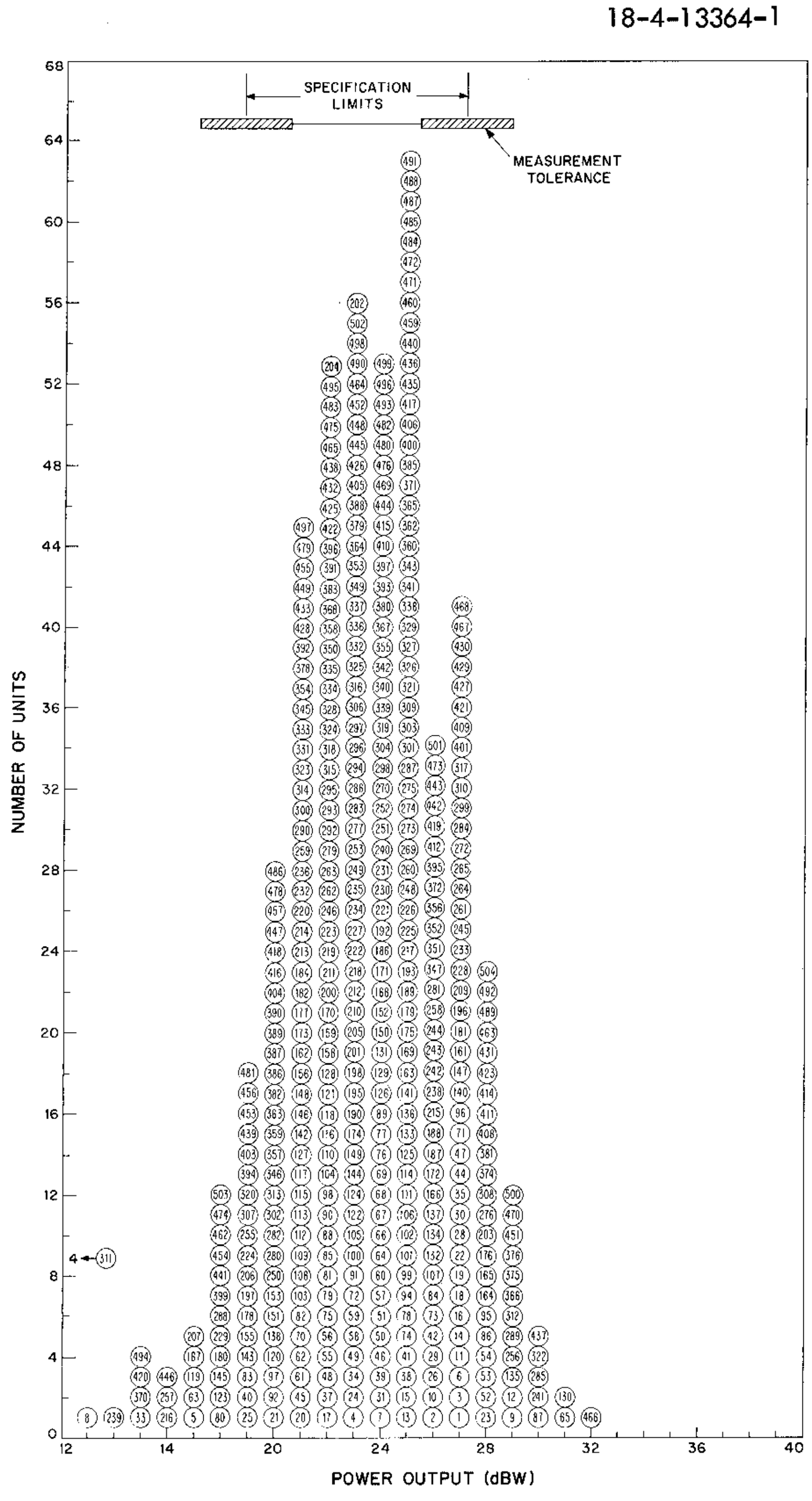

Fig. 15. Power output - general aviation transponders.

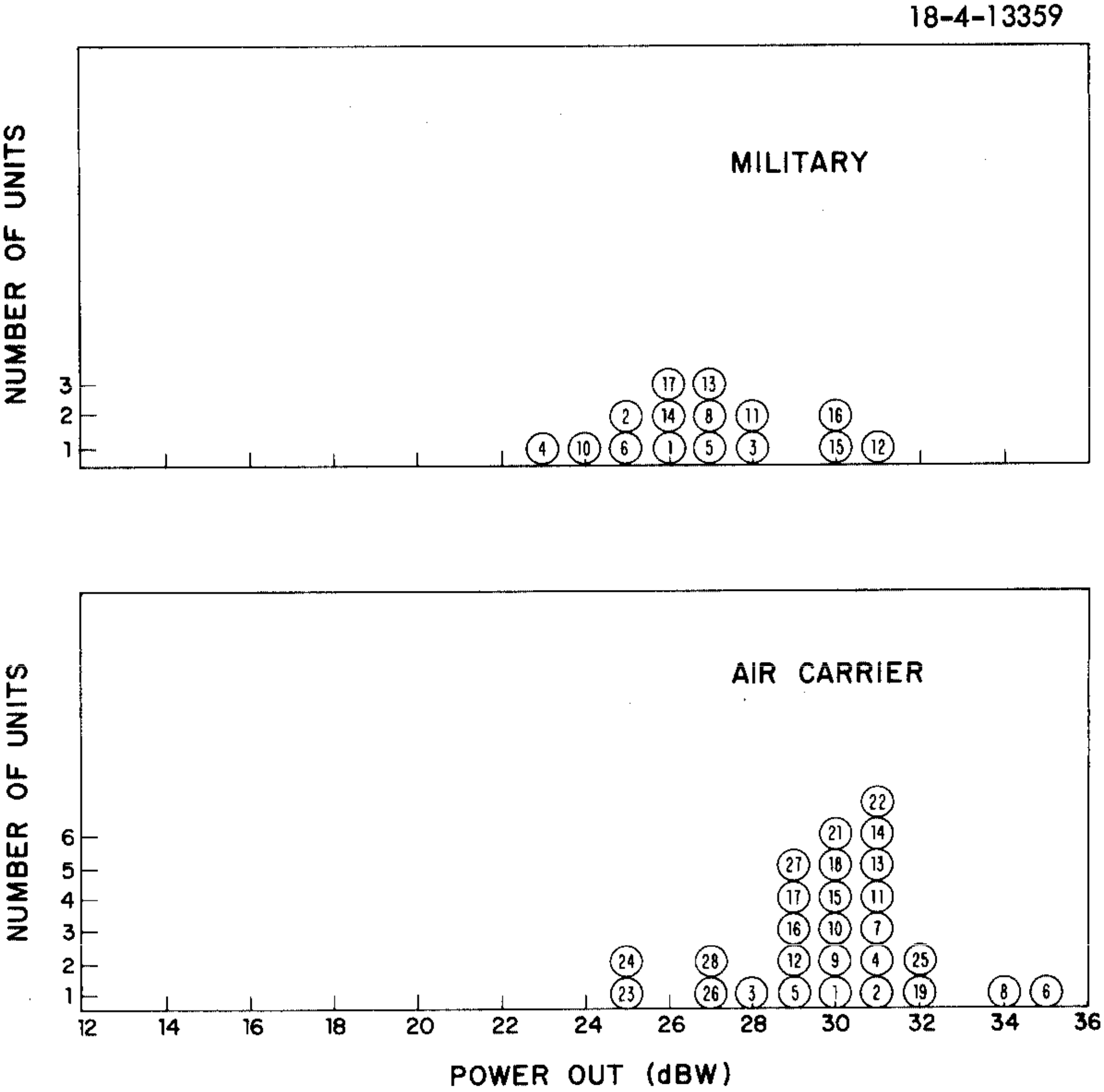

Fig. 16. Power output – military and air carrier transponders.

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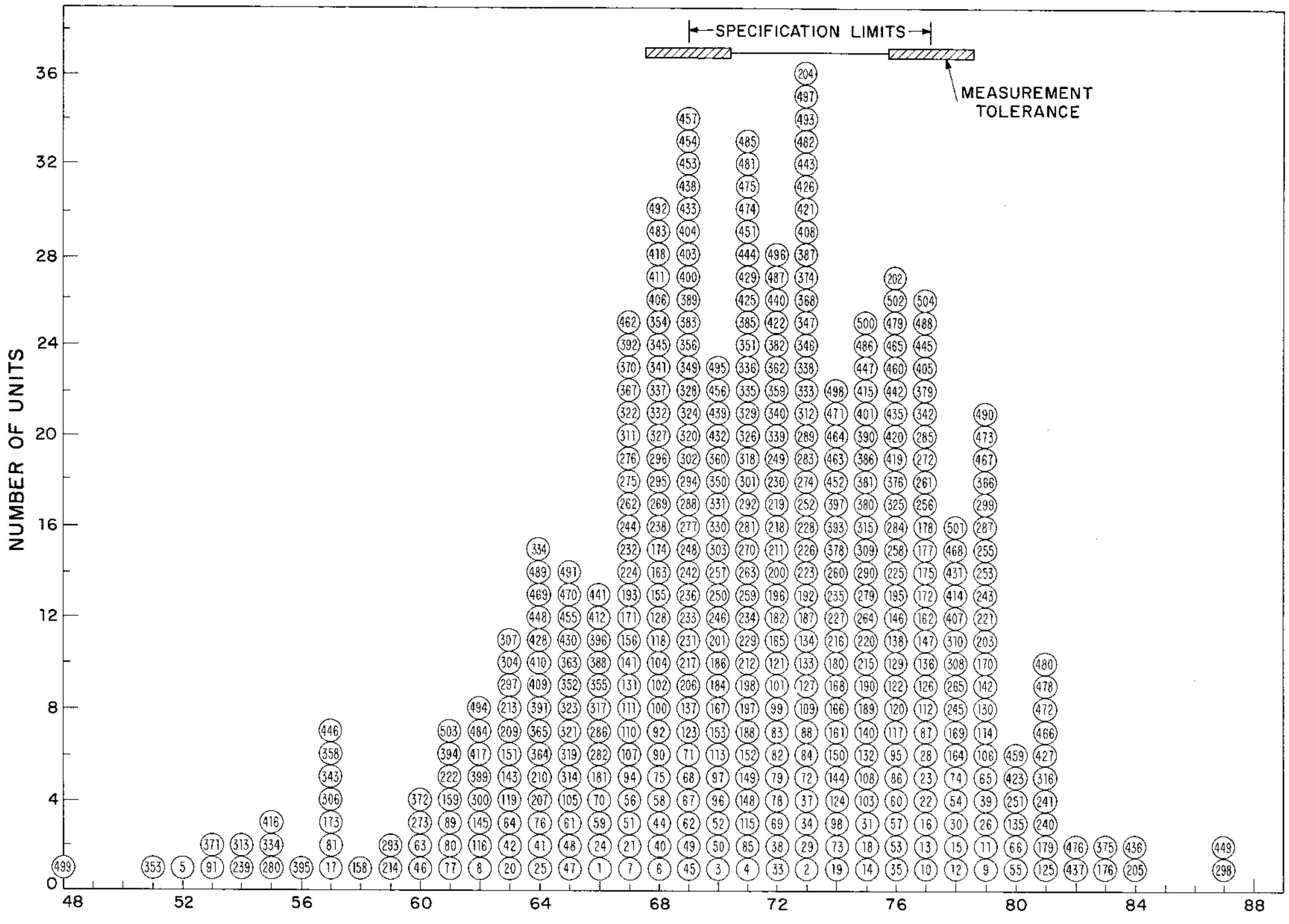

Fig. 17. Sensitivity - general aviation transponders.

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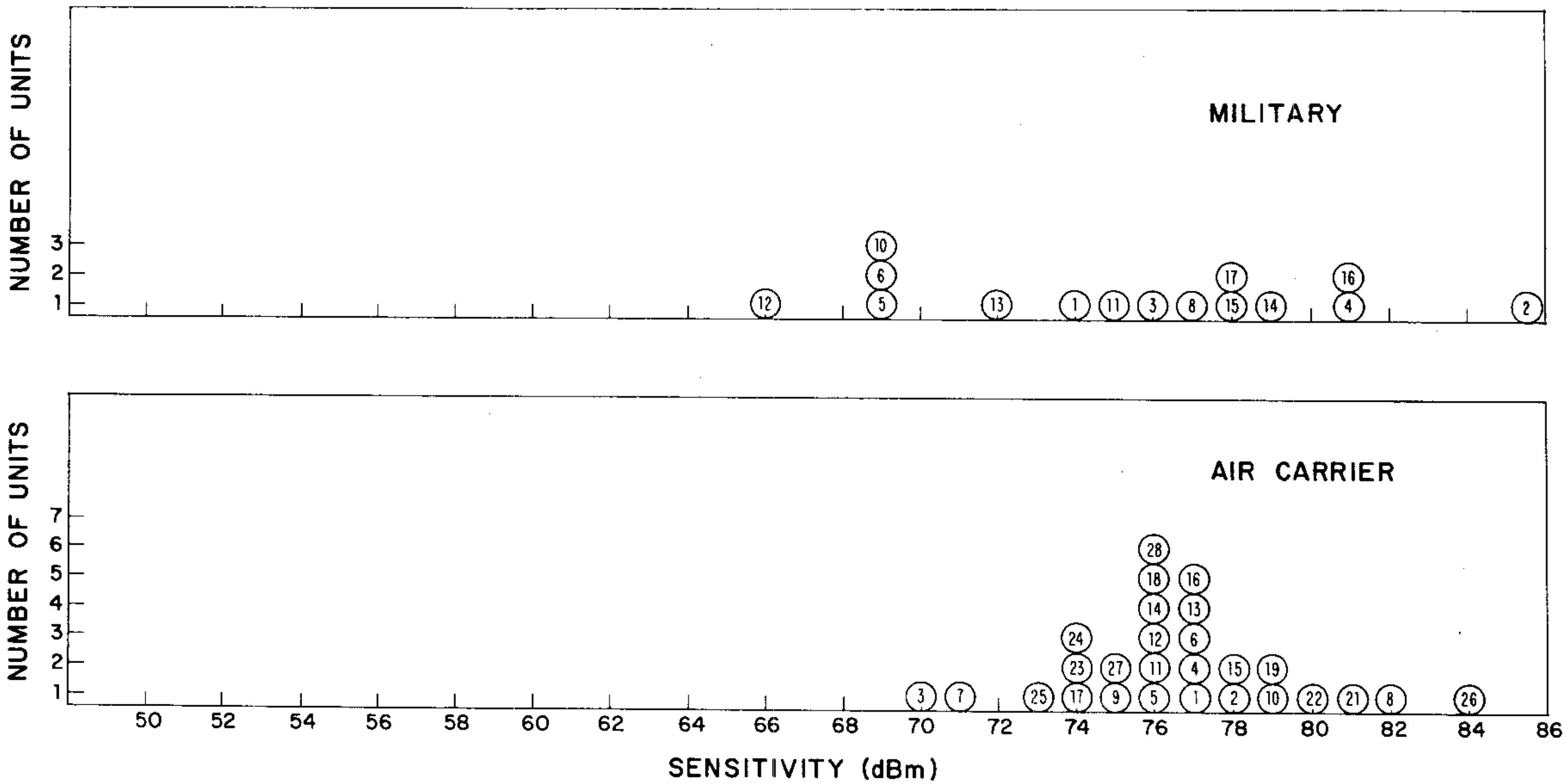

Fig. 18. Sensitivity - military and air carrier transponders.

III. SUMMARY OF RESULTS

Thirty-one of 504 general aviation transponders, two of 17 military transponders, and one of 28 air carrier transponders tested were inoperative.

Squitter did not appear to be a significant problem with the transponders tested. Only nine of 504 general aviation transponders tested exhibited squitter in excess of the specification limit of 30 false replies per second.

Approximately 10 percent of the general aviaiton transponders tested were radiating at frequencies outside the specification limits. Air carrier units and all except one of the military units tested were within specification limits.

Approximately 6 percent of the general aviation transponders tested failed to meet the full specification on the delay measurement. All except 10 units were within specification for the signal range from 10 to 50 dB above minimum triggering level. Of these 10, six displayed excessive delay at all signal levels; the other four were slightly over the upper specification limit at the 10 dB signal level. Military and air carrier units tested were within the specification limits.

One hundred eleven transponders did not reply to a Mode C interrogation. This may be due to manufacturing or installation procedures which permanently locked out this mode when no alticoder is used.

Thirty-two units (approximately 6.5 percent of the general aviation population) were found to have excessive dead times. Twenty-nine of the thirty-two were the same model transponder. The dead time distribution was found to have a significant peak around 35 microseconds. Three military units were found to have dead times beyond the specification limit of 125 microseconds. All air carrier units tested met the specification.

In the measurement of the P2/P1 ratio required for suppression, 14 of 83 units in a test sample were found to be significantly beyond the specification limits. These 14 units represented ten different models manufactured by six different companies.

The AN/APX-25 transponder found in nine of the 17 military aircraft tested did not have side-lobe suppression capability.

Approximately nine percent of the general aviation transponders tested exhibited suppression times which were beyond specification limits. Of the five military transponders tested with operable suppression circuitry, one had a shorter than specified suppression time, as did one of the 26 air carrier units with working suppression circuitry.

Out-of-tolerance framing pulse spacing was found in thirteen of 504 general aviation units, two of 17 military units, and one of 28 air carrier units.

The power output distribution showed a smaller spread than did the sensitivity distribution for general aviation transponders. After making an allowance for possible measurement error, approximately seven percent of general aviation transponders tested had power outputs outside of specification limits, while approximately 24 percent had sensitivities which were beyond the allowable range. Military and air carrier units generally showed higher than specified power output levels.

ACKNOWLEDGEMENTS

Acknowledgement is hereby made of a valuable contribution to the program by L. V. Giusti who managed the airport test site and aircraft availability arrangements in addition to the administrative workload.

It is impractical to list all the individuals connected with the airports visited who provided cooperation in arranging for transponder tests. Special thanks go to individual and corporate aircraft owners who made their equipment available for test, as well as military and air carrier operations and maintenance personnel who were most cooperative.

The important contributions of the test team members and the individuals who assisted in the data reduction is recognized and appreciated.

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APPENDIX A

COUPLING CALIBRATION CURVE

A laboratory simulation of a typical aircraft antenna installation was constructed of a three-foot square aluminum plate with mounting holes in the center for the transponder antenna under test. The plate was mounted horizontally with the antenna on the under side, and supported by the corners, by four wooden uprights. A series of coupling tests were made with the following parameter variations: coupling loss as a function of relative antenna heights; coupling loss as a function of separation; and coupling loss as a function of absolute height with relative height maintained constant.

The tests showed that the coupling varied about one-half dB as the distance between the center lines of the horn and the antenna ranged over about 3/4 of a wavelength (8 in). A setting with the horn top 5 inches above the center of the transponder antenna was chosen after viewing aircraft installations. This height provided a realistic coupling value for cases in which the aircraft structure interfered with the radiation in a horizontal direction without detracting from performance for the more ideal installations.

Tests of coupling as a function of separation showed the variation to change from near-field behavior to far-field behavior in the vicinity of 50 inches of separation. A standard separation of 70 inches was chosen as being adequate to avoid near-field interaction effects and as being sufficiently great to allow placement of the horn antenna without interference with aircraft structure.

With the horn maintained five inches above the center of the transponder antenna, and the separation maintained at 70 inches, tests of coupling were made as a function of absolute height above the ground. The tests were repeated using three different transponder antennas, a Narco blade antenna, a King quarter-wave antenna (herein called a "monopole"), and an IFD quarter wave antenna (herein called a "stub"). The coupling measurement results were virtually identical for all three antennas. Antenna pattern measurements for all three antennas were also nearly identical. Therefore, there was no adjustment made for the various antenna types.

The results yielded a coupling calibration curve as shown in Figure 19. The triangular points represent the measurements made in the laboratory prior to the test program and the circular points represent field measurements. The field measurements were made by substituting an interconnecting cable, whose loss was known, in place of the test horn and aircraft antenna and noting the change in path attenuation. The rms deviation of field measured points from the assumed curve is 1.3 dB.

The coupling calibration curve was used in the calculations of power output and sensitivity.

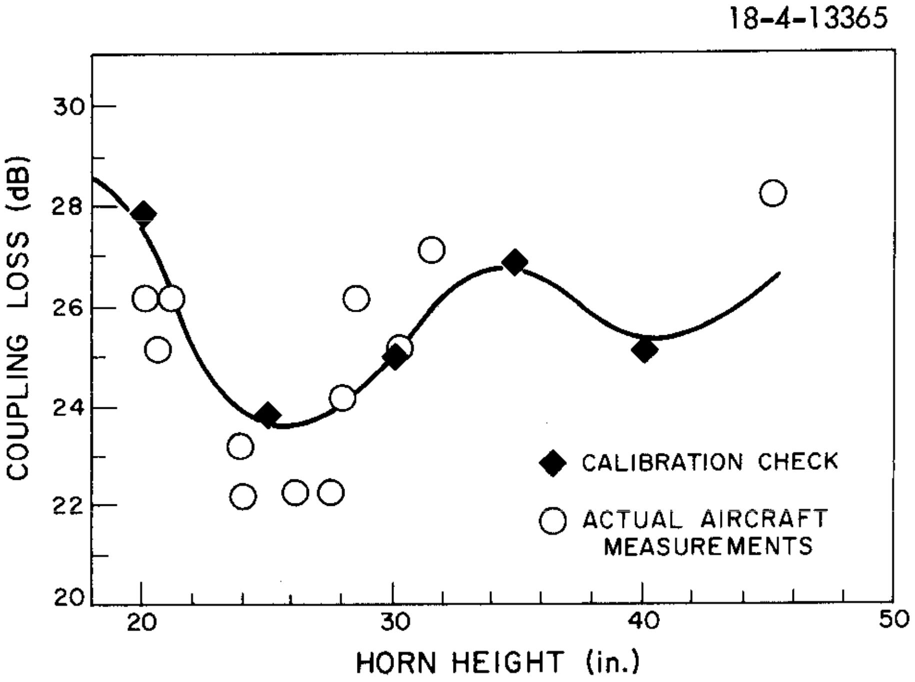

Fig. 19. Coupling calibration curve.

APPENDIX B

RF LEAKAGE INVESTIGATION

Background

Following the reduction of the test data accumulated during the first phase of the field measurements, it became apparent that the P2/P1 ratio measurements on certain models of transponders were yielding results which were at variance with the applicable portions of the National Standard. An analysis of the data collected showed an apparent strong correlation between unsatisfactory P2/P1 suppression performance at the higher signal levels in the case of the Bendix TPR-610 transponders, and some degradation of performance at low signal levels in the case of the King KXP-750. As a result of the apparent correlation between model and unsatisfactory P2/P1 ratio performance, an investigation was initiated to determine the reason such results were obtained. The initial phase of the investigation was centered around Bendix TPR 610 type transponders as the phenomenon was most pronounced with these units.

Two distinct sources of leakage were discovered during the course of the investigation: the first, due to the transmissivity of the modulator employed for the generation of the P2 pulse, produced a CW leakage signal at a level approximately 44 dB below the amplitude of the P2 pulse; a second leakage path, which was independent of the signal level of the P1 or P2 pulse, resulted from radiation from RF components and connectors and produced a leakage as high as -75 dBm.

The leakage problem associated with the development of the P2 pulse was identified and remedied so that all tests conducted above number 416 can be considered free of this problem. An examination of the data indicates that the CW leakage level from RF components was reduced or eliminated when the test setup was overhauled following the completion of test number 96.

The Investigation

Two Bendix units were removed from their aircraft to allow extensive bench testing using the same equipment as employed in the field tests. Also tested were three Bendix TPR-741 transponders supplied by the manufacturer for this purpose.

The bench tests of the Bendix TPR-741 units using the equipment as configured for the field tests (hereafter referred to as the "initial test setup") and the same procedure (with the exception that the signal source was coupled directly through an attenuator to the input rather than through antennas) yielded results similar to those obtained in the field; namely, the units would not respond to a suppression pulse pair at the high signal levels.

The units were then retested using a Hewlett-Packard modulator (HP 8403A-H01) designed specifically for ATCRBS test signal pulse generation. Using this modulator, the units were all found to operate within specification throughout the input signal range from 3 to 50 dB above the minimum triggering level (MTL).

A series of tests was then initiated to determine the difference in test conditions between the two equipment configurations. Following the elimination of several possible factors the magnitude of potential RF leakage signals was measured. It was found that a significant leakage path did exist through the P2 modulator due to an improperly functioning modulator driver.

The net effect was to allow a CW signal to pass through the P2 modulator with an attenuation of 44 dB. In other words, for a given setting of P2, a CW leakage signal was present which was 44 dB below the P2 amplitude. A second potential leakage path was also located which was independent of the level of P1 or P2, but which was highly dependent on RF components, and the tightness of RF connectors. This path could produce signals as high as -75 dBm under certain conditions, but it was impossible to determine whether or not such signals did actually exist during the first phase of field testing. The conclusions were that the P2 dependent leakage signal did exist, and that the steady leakage signal may have existed at levels lower than -75 dBm.

The findings of this investigation were then used to structure controlled tests of the Bendix and King transponders to verify that the leakage signals were producing the effects observed during the field tests.

Tests on Transponders

Detailed measurements made in the laboratory on Bendix transponders showed that CW leakage signals of the order of -70 to -80 dBm could interfere with suppression action at all signal levels. A leakage signal passing through the P2 modulator with an transmissivity of 44 dB would reach this level when the input signal level was in the range -26 to -36 dBm. Since the design sensitivity (MTL) for these units is -74 dBm, the leakage would be expected to interfere with suppression action when the test signal levels were 38 to 48 dB above the MTL. This finding correlates well with field test experience where suppression was often noted to cease between 35 and 40 dB above MTL for Bendix TPR-610's.

Following the verification with the Bendix units that CW leakage signals could seriously interfere with suppression action, the initial test setup was corrected to eliminate the leakage sources by replacement of the P2 modulation driver and installation of a metal shield under the system RF oscillator. Tests numbered above 416 were performed with the improved setup.

The additional components necessary to allow inclusion of a controllable leakage path were also assembled, and used in a short series of tests designed to determine the possible effects of leakage signals on the parameters being measured.

As anticipated, leakage signals had no effect on reply frequency, delay, dead time, suppression time or power output. Leakage did not induce squitter in any unit retested.

Correlation of original results with results obtained in retesting at various levels of induced leakage showed that a steady CW leakage signal of -84 dBm or below may well have been present in the test setup during measurements on units through test number 96. Such a signal could decrease the P2 sensitivity of the King KXP-750 to a point that no suppression would occur for a signal level 3 dB above minimum, thus explaining the results previously reported.

Tests showed that leakage signals of -70 dBm or less had no measured effect on Genave Beta 4096, or an IFD Starlight transponder tested. Other units retested with variable leakage levels included a Narco AT5-A, a Narco UAT-1, a Bendix TPR-610, a King KT-75 and a King KXP-750. These units showed a gradual reduction in receiver sensitivity with increasing leakage levels

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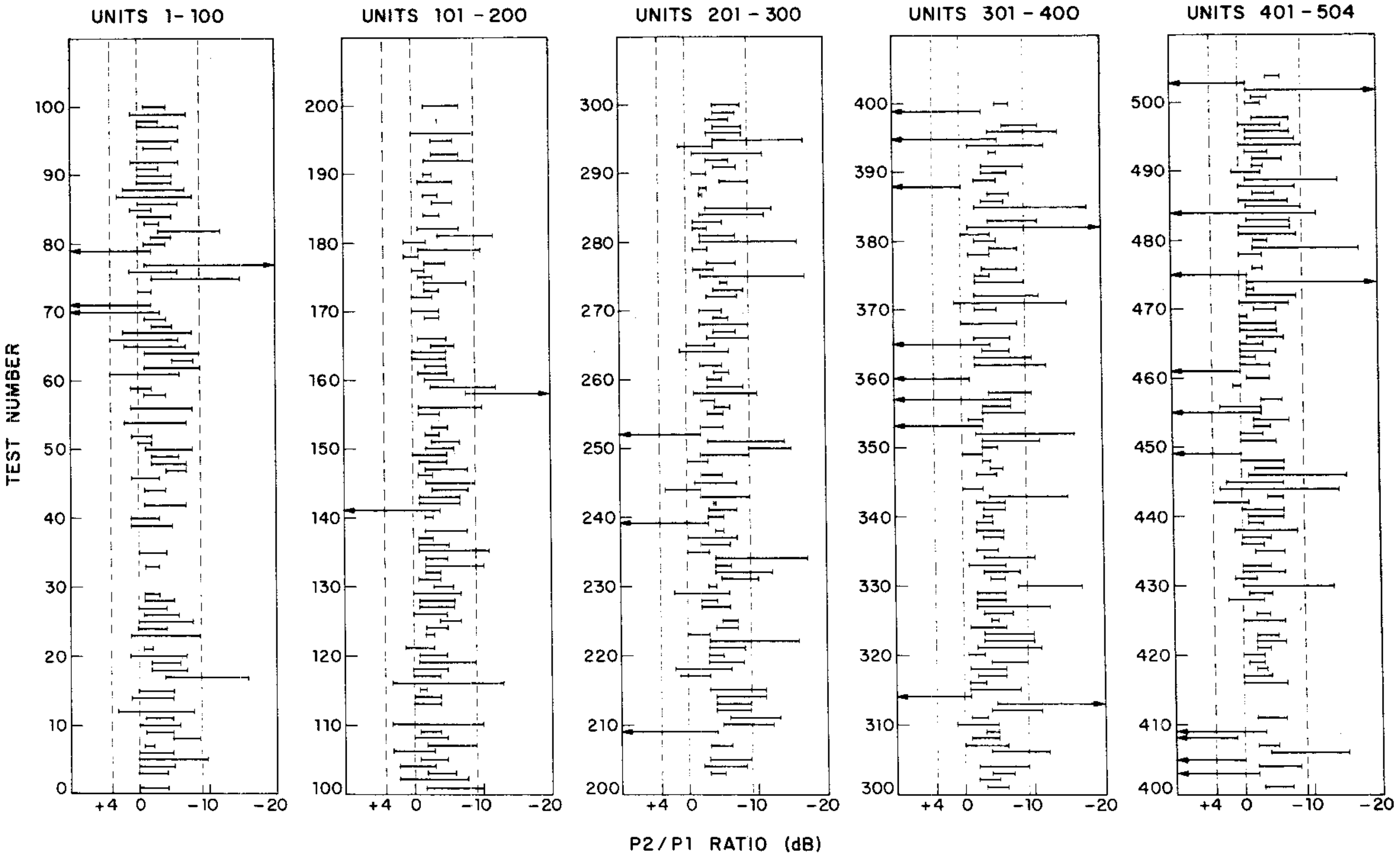

Fig. 20. P2/P1 ratio for suppression - general aviation transponders.
(Adjusted complete sample.)

for levels above approximately -79 dBm. At the leakage levels of -84 dBm or less that may have been present in the test setup effects on receiver sensitivity were not apparent.

APPENDIX C

DATA TABLE 1.

Abbreviations

Manufacturers

Short Form	Name & Address
Bendix	The Bendix Corporation Ft. Lauderdale, Florida
Genave	General Aviation Electronics, Inc. Indianapolis, Indiana
IFD	In-Flight Devices Corporation Columbus, Ohio
King	King Radio Corporation Olathe, Kansas
Narco	Narco Scientific Industries Ft. Washington, Pennslyvania
Regency	Regency Electronics, Inc. Indianapolis, Indiana
Wilcox	Wilcox Electric Company, Inc. Kansas City, Missouri
RCA	RCA Corporation Van Nuys, California
ARC	Aircraft Radio Corporation Boonton, New Jersey
Collins	Collins Radio Company Cedar Rapids, Iowa.

DATA TABLE 1. Abbreviations (cont)

Antennas

Short Form	Description
Blade	One of several similar vertically polarized L-band stub antennas mounted within a fin-like radome. Dimensions: Approx. 4" high x 3" wide x 1/2" thick. Suppliers: Bendix, Narco, Wilcox, et al.
Monopole	One of several similar vertically polarized L-band antennas consisting primarily of a metal rod of approximately 1/8" diameter and approximately 3" long top-loaded with a metal ball of approximately 1/4" diameter. Suppliers: Genave, King, Wilcox, et al.
Stub	A vertically polarized L-band antenna consisting primarily of a single metal element approximately 3" long x 1/4" wide x 1/8" thick. Supplier: IFD
Flush	One of several similar antennas designed for mounting flush with the aircraft skin. The military AT 234/APX is an example.

DATA TABLE 1.

General Aviation Transponders

#	Mfg	Model	Antenna
1.	Narco	AT5-A	Blade
2.	King	KXP-750	Pole
3.	Narco	AT5-A	Blade
4.	King	KT-75	Pole
5.	Narco	UAT-1	Blade
6.	Narco	AT6-A	Blade
7.	Genave	Beta 4096	Pole
8.	Narco	UAT-1	Blade
9.	King	KT-75	Pole
10.	Wilcox	814B	Blade
11.	King	KT-75	Pole
12.	King	KXP-750	Pole
13.	Bendix	TPR-610	Pole
14.	King	KT-75	Blade
15.	King	KT-75	Blade
16.	King	KXP-750	Pole
17.	Regency	505-I	Pole
18.	King	KT-75	Pole
19.	King	KT-75	Pole
20.	Genave	Beta 4096	Blade
21.	Narco	AT6-A	Blade
22.	King	KXP-750	Pole
23.	Regency	505-I	Pole
24.	Genave	Beta 4096	Pole
25.	IFD	Starlight	Stub
26.	King	KT-75	Pole
27.	IFD	Century31	Blade
28.	King	KT-75	Pole
29.	Narco	AT6-A	Blade
30.	King	KXP-750	Pole
31.	Bendix	TPR-610	Pole
32.	Narco	AT6-A	Blade
33.	Narco	UAT-1	Blade
34.	Bendix	TPR-610	Pole
35.	King	KT-75	Pole
36.	IFD	Starlight	Stub
37.	Bendix	TPR-610	Pole
38.	King	KT-75	Pole
39.	King	KT-75	Pole
40.	Genave	Beta 4096	Pole
41.	Narco	AT6-A	Blade
42.	Narco	AT6-A	Blade
43.	Narco	AT6-A	Blade
44.	Narco	AT6-A	Blade
45.	Wilcox	814B	Pole
46.	IFD	Starlight	Stub
47.	Narco	AT6-A	Blade
48.	Narco	UAT-1	Blade
49.	Narco	UAT-1	Blade
50.	Narco	UAT-1	Blade
51.	Narco	AT6-A	Blade
52.	Narco	AT6-A	Blade
53.	King	KXP-750	Pole
54.	Wilcox	814B	Blade
55.	Bendix	TPR-610	Pole
56.	Genave	Beta 4096	Pole
57.	King	KXP-750	Stub
58.	Narco	UAT-1	Blade
59.	IFD	Starlight	Stub
60.	King	KXP-750	Pole
61.	Wilcox	1014	Pole
62.	Genave	Beta 4096	Pole
63.	Narco	UAT-1	Blade
64.	Genave	Beta 4096	Pole
65.	Wilcox	814B	Pole
66.	King	KT-75	Pole
67.	Genave	Beta 4096	Pole
68.	RCA	AVQ-65	Blade
69.	RCA	AVQ-65	Blade
70.	Narco	AT-50	Stub
71.	Narco	UAT-1	Blade
72.	Bendix	TPR-610	Pole
73.	Narco	AT6-A	Blade
74.	Bendix	TPR-600	Pole
75.	Bendix	TPR-600	Pole
76.	Narco	AT-50	Pole
77.	Narco	UAT-1	Blade
78.	King	KXP-750	Pole
79.	IFD	Starlight	Stub
80.	Narco	UAT-1	Blade
81.	Narco	AT6-A	Blade
82.	ARC	400	Blade
83.	IFD	Century 31	Blade
84.	Narco	AT-50	Pole
85.	Genave	Beta 4096	Pole
86.	King	KT-75	Pole
87.	Wilcox	814B	Blade
88.	Genave	Beta 4096	Pole
89.	Narco	AT6-A	Blade
90.	Narco	AT6-A	Blade
91.	Narco	AT6-A	Blade
92.	IFD	Starlight	Stub

DATA TABLE 1. (cont)

#	Mfg	Model	Antenna
93.	Wilcox	814B	Blade
94.	Narco	AT6-A	Blade
95.	King	KT-75	Pole
96.	King	KXP-750	Pole
97.	Genave	Beta 4096	Pole
98.	Genave	Beta 4096	Pole
99.	King	KXP-750	Pole
100.	IFD	Starlight	Stub
101.	Regency	505-I	Pole
102.	IFD	Starlight	Stub
103.	King	KT-75	Pole
104.	Genave	Beta 4096	Pole
105.	Genave	Beta 4096	Pole
106.	King	KXP-750	Pole
107.	ARC	400	Blade
108.	Narco	AT-50	Pole
109.	Narco	AT-50	Pole
110.	IFD	Starlight	Stub
111.	Bendix	TPR-600	Pole
112.	Narco	UAT-1	Blade
113.	Narco	AT-50	Pole
114.	King	KT-75	Pole
115.	Narco	UAT-1	Blade
116.	Narco	AT6-A	Blade
117.	Genave	Beta 4096	Pole
118.	Genave	Beta 4096	Pole
119.	Genave	Beta 4096	Pole
120.	Narco	AT-50	Pole
121.	IFD	Starlight	Stub
122.	Bendix	TPR-610	Stub
123.	Narco	AT6-A	Blade
124.	Narco	UAT-50	Pole
125.	Wilcox	1014	Blade
126.	Wilcox	814B	Blade
127.	Narco	AT-50	Pole
128.	Narco	AT-50	Pole
129.	King	KXP-750	Pole
130.	Wilcox	1014	Pole
131.	IFD	Starlight	Stub
132.	Narco	AT-50	Pole
133.	Genave	Beta 4096	Pole
134.	Narco	AT-50	Blade
135.	Wilcox	1014	Pole
136.	Narco	AT-5A	Blade
137.	Narco	AT6-A	Blade
138.	Wilcox	814B	Pole
139.	Narco	AT-50	Pole
140.	Wilcox	814B	Pole
141.	Narco	AT6-A	Blade
142.	Narco	AT-50	Pole
143.	IFD	Starlight	Stub
144.	Narco	UAT-1	Blade
145.	Genave	Beta 4096	Pole
146.	Narco	AT-50	Pole
147.	Wilcox	814B	Blade
148.	Narco	AT6-A	Blade
149.	Wilcox	814B	Blade
150.	King	KT-75	Pole
151.	King	KT-75	Pole
152.	Genave	Beta 4096	Pole
153.	Narco	AT6-A	Pole
154.	Narco	UAT-1	Pole
155.	Narco	AT-50	Pole
156.	Genave	Beta 4096	Pole
157.	Narco	UAT-1	Blade
158.	Genave	Beta 4096	Pole
159.	Narco	UAT-1	Blade
160.	Wilcox	1014	Pole
161.	Narco	AT6-A	Blade
162.	Narco	At6-A	Blade
163.	Wilcox	814B	Blade
164.	King	KXP-750	Pole
165.	Bendix	TRA-61	Blade
166.	Wilcox	814B	Blade
167.	Bendix	TPR-610	Pole
168.	Wilcox	814B	Pole
169.	Narco	AT6-A	Blade
170.	Narco	UAT-1	Blade
171.	Regency	505-I	Pole
172.	Wilcox	814B	Blade
173.	Narco	UAT-1	Blade
174.	Narco	At6-A	Blade
175.	Narco	AT6-A	Blade
176.	Wilcox	814B	Pole
177.	Narco	AT-50	Pole
178.	Narco	UAT-1	Pole
179.	Regency	505-I	Stub
180.	Narco	AT6-A	Blade
181.	King	KT-75	Pole
182.	Wilcox	814B	Blade

DATA TABLE 1, (cont)

#	Mfg	Model	Antenna
183.	Genave	Beta 500	Pole
184.	Narco	AT6-A	Blade
185.	IFD	Starlight	Stub
186.	ARC	400	Blade
187.	Narco	AT6-A	Blade
188.	Bendix	TPR-610	Pole
189.	Collins	621	Blade
190.	Narco	AT5-A	Blade
191.	Genave	Beta 4096	Pole
192.	Wilcox	814B	Blade
193.	Genave	Beta 4096	Pole
194.	Narco	AT6-A	Blade
195.	Narco	AT-50	Pole
196.	King	KXP-750	Pole
197.	Bendix	TPR-610	Pole
198.	Bendix	TPR-600	Pole
199.	Narco	AT-50	Blade
200.	Wilcox	814B	Blade
201.	Bendix	TR-610	Pole
202.	Bendix	TR-610	Blade
203.	King	KT-75	Pole
204.	Narco	AT-50	Pole
205.	Bendix	TPR-600	Blade
206.	Bendix	TPR-610	Pole
207.	Narco	AT-50	Pole
208.	Narco	UAT-1	Blade
209.	Narco	AT6-A	Blade
210.	Narco	AT5-A	Blade
211.	Narco	AT6-A	Blade
212.	Genave	Beta 4096	Pole
213.	Narco	AT-50	Pole
214.	Narco	AT6-A	Blade
215.	Narco	AT5-A	Blade
216.	Bendix	TPR-610	Pole
217.	Wilcox	814B	Pole
218.	Genave	Beta 4096	Pole
219.	Narco	UAT-1	Blade
220.	Narco	AT5-A	Blade
221.	Narco	AT-50	Pole
222.	Genave	Beta 4096	Pole
223.	IFD	Starlight	Stub
224.	Narco	AT-50	Pole
225.	King	KT-75	Pole
226.	Genave	Beta 4096	Pole
227.	Wilcox	814B	Blade
228.	Narco	AT5-A	Blade
229.	Narco	AT-50	Pole
230.	IFD	Starlight	Stub
231.	Genave	Beta 4096	Pole
232.	Genave	Beta 4096	Pole
233.	Narco	AT5-A	Blade
234.	Genave	Beta 4096	Pole
235.	Narco	AT6-A	Blade
236.	Narco	AT6-A	Blade
237.	King	KXP-750	Pole
238.	Narco	AT6-A	Blade
239.	Narco	AT6-A	Blade
240.	Narco	AT6-A	Blade
241.	King	KXP-750	Blade
242.	Narco	AT6-A	Blade
243.	Wilcox	814B	Blade
244.	Narco	AT6-A	Blade
245.	Wilcox	814B	Blade
246.	Wilcox	814B	Blade
247.	Genave	Beta 4096	Pole
248.	Narco	AT6-A	Blade
249.	Genave	Beta 4096	Pole
250.	Narco	UAT-1	Blade
251.	Genave	Beta 4096	Pole
252.	Regency	505-I	Stub
253.	Narco	AT6-A	Blade
254.	Genave	Beta 4096	Pole
255.	IFD	Starlight	Stub
256.	Wilcox	814B	Pole
257.	Genave	Beta 500	Pole
258.	Wilcox	814B	Blade
259.	Narco	AT-50	Pole
260.	Wilcox	814B	Pole
261.	Wilcox	814B	Blade
262.	Narco	AT6-A	Blade
263.	King	KT-75	Pole
264.	King	KXP-750	Pole
265.	Wilcox	1014	Blade
266.	Wilcox	1014	Pole
267.	King	KT-75	Stub
268.	Wilcox	814B	Blade
269.	Wilcox	1014	Blade
270.	Wilcox	1014	Blade
271.	Regency	505-I	Blade
272.	RCA	AVQ-65	Blade

DATA TABLE 1. (cont)

#	Mfg	Model	Antenna
273.	King	KT-75	Pole
274.	King	KT-75	Pole
275.	Regency	505-I	Pole
276.	Wilcox	1014	Blade
277.	Narco	UAT-1	Blade
278.	Narco	AT6-A	Blade
279.	Narco	AT6-A	Blade
280.	Narco	UAT-1	Blade
281.	King	KT-75	Pole
282.	Narco	AT6-A	Blade
283.	Narco	AT6-A	Blade
284.	Regency	505-I	Blade
285.	Regency	505-I	Blade
286.	Bendix	TPR-610	Pole
287.	Narco	AT6-A	Blade
288.	Narco	UAT-1	Blade
289.	King	KXP-750	Blade
290.	IFD	Starlight	Stub
291.	King	KXP-750	Blade
292.	King	KT-75	Pole
293.	King	KXP-750	Blade
294.	King	KXP-750	Pole
295.	ARC	400	Blade
296.	King	KT-75	Pole
297.	Narco	AT6-A	Blade
298.	Wilcox	814B	Blade
299.	King	KT-75	Pole
300.	Genave	Beta 4096	Pole
301.	Narco	AT-50	Pole
302.	IFD	Starlight	Stub
303.	King	KT-75	Pole
304.	Narco	AT5-A	Blade
305.	Narco	AT6-A	Blade
306.	Narco	AT6-A	Blade
307.	IFD	Starlight	Stub
308.	King	KT-75	Pole
309.	Wilcox	1014	Blade
310.	King	KXP-750	Pole
311.	Narco	AT6-A	Blade
312.	Narco	AT-50	Blade
313.	King	KXP-750	Blade
314.	IFD	Starlight	Stub
315.	IFD	Century 31	Blade
316.	IFD	*Skyline	Blade
317.	Narco	AT5-A	Blade
318.	Wilcox	814B	Blade
319.	Narco	UAT-1	Pole
320.	Narco	UAT-1	Blade
321.	Narco	AT5-A	Blade
322.	King	KXP-750	Blade
323.	Narco	UAT-1	Pole
324.	IFD	Starlight	Stub
325.	ARC	400	Blade
326.	Narco	UAT-1	Blade
327.	Regency	505-I	Pole
328.	Narco	AT-50	Pole
329.	Narco	AT5-A	Blade
330.	Narco	UAT-1	Blade
331.	King	KT-75	Pole
332.	Narco	UAT-1	Blade
333.	Narco	AT6-A	Blade
334.	Narco	AT6-A	Blade
335.	Narco	AT6-A	Blade
336.	Bendix	TPR-610	Pole
337.	Narco	AT-50	Pole
338.	Narco	AT5-A	Blade
339.	Narco	AT6-A	Blade
340.	Narco	AT-50	Pole
341.	Narco	AT6-A	Blade
342.	Narco	AT-50	Pole
343.	ARC	400	Blade
344.	IFD	Starlight	Stub
345.	Wilcox	814B	Pole
346.	Narco	AT-50	Pole
347.	King	KT-75	Pole
348.	Narco	UAT-1	Blade
349.	Narco	AT6-A	Blade
350.	Narco	AT-50	Pole
351.	Narco	AT5-A	Blade
352.	Wilcox	814B	Blade
353.	Regency	505-I	Stub
354.	IFD	Starlight	Stub
355.	Narco	AT-50	Pole
356.	ARC	400	Blade
357.	Regency	505-I	Pole
358.	King	KT-75	Pole
359.	Bendix	TPR-610	Blade
360.	Regency	505-I	Pole
361.	Regency	505-I	Pole
362.	Wilcox	814B	Blade

* Skyline 300

DATA TABLE I. (cont)

#	Mfg	Model	Antenna
363.	IFD	Starlight	Stub
364.	ARC	400	Blade
365.	Narco	UAT-1	Blade
366.	Wilcox	814B	Blade
367.	ARC	500	Blade
368.	King	KXP-750	Pole
369.	King	KT-75	Pole
370.	IFD	Starlight	Stub
371.	Wilcox	814B	Blade
372.	IFD	*Skyline	Blade
373.	Wilcox	814B	Blade
374.	Wilcox	814B	Blade
375.	Wilcox	814B	Pole
376.	ARC	500	Blade
377.	Narco	AT6-A	Blade
378.	Narco	AT6-A	Blade
379.	Narco	AT6-A	Blade
380.	Narco	AT6-A	Blade
381.	Narco	AT6-A	Blade
382.	Narco	UAT-1	Blade
383.	Genave	Beta 4096	Pole
384.	Regency	505-I	Pole
385.	King	KT-75	Blade
386.	King	KT-75	Pole
387.	Narco	AT-50	Pole
388.	Narco	AT6-A	Blade
389.	IFD	Starlight	Pole
390.	Narco	AT-50	Pole
391.	Narco	AT-50	Pole
392.	Bendix	TPR-610	Pole
393.	Narco	AT6-A	Blade
394.	IFD	Starlight	Stub
395.	Narco	AT6-A	Blade
396.	Narco	AT6-A	Blade
397.	King	KT-75	Blade
398.	Wilcox	814B	Pole
399.	Narco	AT6-A	Blade
400.	King	KT-75	Pole
401.	King	KT-75	Pole
402.	King	KXP-750	Pole
403.	IFD	*Skyline	Pole
404.	IFD	Starlight	Stub
405.	IFD	*Skyline	Pole
406.	Narco	AT5-A	Blade
407.	Narco	AT-50	Blade
408.	King	KT-75	Pole
409.	Narco	AT6-A	Blade
410.	King	KT-75	Pole
411.	Narco	AT5-A	Blade
412.	Narco	AT6-A	Blade
413.	IFD	Starlight	Stub
414.	Wilcox	814B	Pole
415.	Narco	UAT-1	Blade
416.	IFD	Starlight	Stub
417.	Narco	AT6-A	Blade
418.	Narco	AT6-A	Blade
419.	Narco	AT6-A	Blade
420.	Bendix	TPR-610	Pole
421.	Narco	AT5-A	Blade
422.	Narco	AT-50	Pole
423.	Narco	AT5-A	Blade
424.	Narco	AT5-A	Blade
425.	Narco	AT-50	Pole
426.	Narco	AT5-A	Blade
427.	King	KXP-750	Pole
428.	Narco	UAT-1	Blade
429.	Narco	AT5-A	Blade
430.	Narco	AT6-A	Blade
431.	Narco	AT5-A	Blade
432.	Narco	AT5-A	Blade
433.	IFD	*Skyline	Pole
434.	Narco	AT6-A	Blade
435.	King	KT-75	Stub
436.	Narco	AT6-A	Blade
437.	Wilcox	814B	Pole
438.	Narco	AT-50	Pole
439.	Narco	UAT-1	Blade
440.	Narco	AT5-A	Blade
441.	Genave	Beta 4096	Pole
442.	King	KXP-750	Blade
443.	Collins	621A	Blade
444.	IFD	*Skyline	Pole
445.	Wilcox	814B	Blade
446.	Narco	AT-50	Blade
447.	Bendix	TPR-600	Blade
448.	Narco	AT-50	Pole
449.	Narco	UAT-1	Blade
450.	Narco	UAT-1	Blade
451.	Narco	AT5-A	Blade
452.	IFD	Starlight	Stub

* Skyline 300

DATA TABLE 1. (cont)

#	Mfg	Model	Antenna
453.	IFD	Starlight	Stub
454.	Narco	UAT-1	Blade
455.	Narco	AT6-A	Blade
456.	IFD	Starlight	Stub
457.	Bendix	TPR-600	Blade
458.	Narco	UAT-1	Blade
459.	Bendix	TPR-600	Blade
460.	Narco	AT-50	Pole
461.	Narco	UAT-1	Blade
462.	IFD	Starlight	Stub
463.	Narco	AT5-A	Blade
464.	Narco	AT6-A	Blade
465.	IFD	Century31	Blade
466.	Bendix	TRA-61	Blade
467.	Wilcox	1014	Blade
468.	King	KT-75	Blade
469.	Wilcox	814B	Blade
470.	King	KT-75	Pole
471.	IFD	Starlight	Stub
472.	Wilcox	1014	Blade
473.	Bendix	TPR-600	Pole
474.	Bendix	TPR-610	Pole
475.	Bendix	TPR-610	Blade
476.	Wilcox	1014	Pole
477.	Wilcox	1014	Pole
478.	Narco	AT6-A	Blade
479.	Regency	505-I	Stub
480.	Narco	AT6-A	Blade
481.	Narco	AT-50	Pole
482.	King	KXP-750	Pole
483.	Narco	AT-50	Pole
484.	Narco	AT5-A	Blade
485.	Narco	AT5-A	Blade
486.	Narco	AT-50	Pole
487.	Narco	AT5-A	Blade
488.	Wilcox	814B	Blade
489.	Wilcox	814B	Blade
490.	Bendix	TPR-610	Pole
491.	Narco	AT6-A	Blade
492.	Narco	UAT-1	Blade
493.	Narco	AT6-A	Blade
494.	Genave	Beta 4096	Pole
495.	Genave	Beta 4096	Pole
496.	Genave	Beta 4096	Pole
497.	Genave	Beta 4096	Pole
498.	Narco	UAT-1	Blade
499.	Narco	UAT-1	Blade
500.	Narco	AT6-A	Blade
501.	Narco	AT6-A	Blade
502.	Narco	AT6-A	Blade
503.	IFD	Starlight	Stub
504.	Wilcox	814B	Pole

Military Transponders

1		AN/APX-25	Blade
2		AN/APX-25	Flush
3		AN/APX-25	Flush
4		AN/APX-25	Flush
5		AN/APX-44	Blade
6		AN/APX-44	Blade
7		AN/APX-72	Blade
8		AN/APX-72	Blade
9		AN/APX-44	Blade
10	Narco	AT6-A	Blade
11		AN/APX-25	Flush
12		AN/APX-64	Blade
13	Narco	AT6-A	Blade
14		AN/APX-25	Flush
15		AN/APX-25	Flush
16		AN/APX-25	Blade
17		AN/APX-25	Blade

Air Carrier Transponders

1	Collins	621A	Flush
2	Wilcox	914A	Flush
3	Wilcox	914A	Blade
4	Wilcox	914A	Blade
5	Wilcox	914A	Blade
6	Wilcox	914A	Blade
7	Wilcox	914A	Blade
8	Wilcox	914A	Blade
9	Wilcox	914A	Blade
10	Wilcox	914A	Blade
11	Wilcox	914A	Flush

DATA TABLE 1. (cont)

#	Mfg	Model	Antenna
12	Wilcox	914A	Flush
13	Wilcox	914A	Blade
14	Wilcox	914A	Blade
15	Wilcox	914A	Blade
16	Wilcox	914A	Blade
17	Collins	621A	Blade
18	Wilcox	914A	Blade
19	Wilcox	914A	Blade
20	Wilcox	914A	Flush
21	Collins	621A	Blade
22	Collins	621A	Blade
23	Collins	621A	Blade
24	Collins	621A	Blade
25	Collins	621A	Blade
26	Collins	621A	Blade
27	Collins	621A	Blade
28	Collins	621A	Blade