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Minimum Operational Performance Standards for Airborne ATC Transponder Systems

DRAFT Version 0.3

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Prepared by: SC-209

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FOREWORD

These Minimum Operational Performance Standards (MOPS) were prepared by RTCA Special Committee 209 (SC-209) and approved by the RTCA Program Management Committee (PMC) on MM DD, YYYY, and supersedes RTCA/DO-144, "*Minimum Operational Characteristics for Airborne ATC Transponder Systems,*" dated March 12, 1970.

RTCA, Incorporated is a not-for-profit corporation formed to advance the art and science of aviation and aviation electronic systems for the benefit of the public. The organization functions as a Federal Advisory Committee and develops consensus-based recommendations on contemporary aviation issues. RTCA's objectives include, but are not limited to:

- Coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;

- Analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;

- Developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of Minimum Operational Performance Standards (MOPS) for electronic systems and equipment that support aviation; and

- Assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization (ICAO) and the International Telecommunication Union (ITU) and other appropriate international organizations can be based.

The recommendations of RTCA are often used as the basis for government and private sector decisions as well as the foundation for many Federal Aviation Administration Technical Standard Orders (TSO).

Since RTCA is not an official agency of the United States Government, its recommendations may not be regarded as statements of official government policy unless so enunciated by the United States Government organization or agency having statutory jurisdiction over any matters to which the recommendations relate.

CHANGE HISTORY

Date / Version	Description
1/19/06, v0.1	Initial version of DO-144 taken from RTCA in hardcopy only and scanned into an electronic file, and OCRed to produce the first editable electronic copy. Since the original DO-144 was written in Part I, Part II, Part III nomenclature, this was changed to chapters and subsections.
8/3/06, v0.2	Used to create the initial Comparison Matrix of the Outline of DO-144 versus the proposed DO-144A.
10/11/06, v0.3	This is the first version of the draft of DO-144A that has been rearranged into the standard RTCA MOPS format. The structure of the requirements section §2.2 was modeled after that in DO-181 and the corresponding information from DO-144 was copied into the appropriate section. The test procedure section §2.4 was populated with the existing test procedures from DO-144 section §2.3, while keeping the identical outline as was set up for §2.2. Since there were no sections in the original DO-144 dealing specifically with environmental testing, then in this draft, section §2.3 was populated with standard boilerplate text from the RTCA MOPS drafting standard. Section 3.0 of a standard RTCA MOPS document deals with Installed Equipment and in this draft that section has been populated with what was in the original DO-144 for Flight Tests in §2.3.

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1 PURPOSE AND SCOPE

1.1 Introduction

Many devices carried aboard aircraft to fulfill navigation, communications and ATC requirements are important not only to the aircraft itself and its occupants, but can have an effect on other aircraft sharing the airspace. The latter is particularly true when the airborne devices are used to transmit, receive or share intelligence in communications or navigation media in common usage. Agreement must exist on the Minimum Operational Performance Standards (MOPS) necessary not only to assure satisfactory performance for each aircraft but also to prevent derogation of the service being provided to other users or recipients of communications or navigation services.

Promulgation of basic characteristics of these systems upon which the MOPS for the airborne element must be based, has in the past often lagged implementation of systems by unacceptable periods of time; yet their timely issuance is necessary to that participants in the systems will know how properly to equip themselves.

If a satisfactory air navigation, communication and traffic control service is to be provided, a clear statement of MOPS for airborne systems must be agreed upon and must be adhered to by all participants in the system. For example, where separation between aircraft is achieved based on assumptions of certain characteristics of the individual aircraft devices, minimum requirements for these devices are needed, in order to assure adequate separation of one aircraft form another.

For achievements of satisfactory air navigation, communication and traffic control services, clear statements of MOPS of airborne systems are needed in two major areas:

a. For all users of aviation navigation and communications services, MOPS of the airborne system elements are needed to insure against derogation of service to other users of these services.

b. For those who are required by regulation to participate in the ATC system or who voluntarily choose to do so, additional MOPS for navigation, communication and air traffic control airborne system elements are needed to achieve at least that minimum performance on which control and separation is based.

1.1.1 International Standards

International standards exist for several electronic systems (e.g., VOR, ILS, and DME ICAO Standards). It is essential that navigation and communications systems that are international in character be covered by international standards. It follows that national and international standards, insofar as practical, should be the same so that aircraft are not forced to carry more than one type of equipment for a function or to meet more than one set of standards as they traverse international boundaries.

MOPS for airborne elements of navigation, communication and ATC systems should also be uniform, country to country. It is not desirable for foreign administrators to impose requirements on U.S. aircraft which are different from, or more stringent than, those imposed by the United States. The converse is equally true. Therefore, minimum requirements should be coordinated insofar as possible among the countries of the world to assure a single uniform level of requirement. Upon completion of informal coordination, it is appropriate to amend existing ICAO Standards to define the systems more fully and to describe the minimum acceptable characteristics of airborne elements.

1.1.2 Preparation of Minimum Operational Performance Standards for Airborne Systems

The Federal Aviation Administration is the responsible agency for certain aviation standards. However, FAA's regulatory effort is vastly improved by intelligent utilization of government/industry working arrangements, by which a variety and wealth of talent may be brought to bear on the development of a particular minimum requirement.

Therefore, to implement the concepts that have been outlined, RTCA established Special Committee 209 to update the Minimum Operational Performance Standards for Airborne System Elements, together with a method of demonstration of compliance. However, as pointed out in these concepts, concise statements of system characteristics are a prerequisite to meaningful minimum operational characteristics for airborne systems. Accordingly, SC-209 was directed to consider such system characteristics that exist and to include them in its reports. If none exist, best assumptions were to be formulated by SC-209 and included in the reports.

1.2 System Overview

1.3 Operational Application(s)

1.4 Intended Function

Compliance with the following MOPS is required to achieve at least that minimum performance on which control and separation of aircraft is based and to insure against derogation of service to other users of aviation navigation and communication services. These MOPS are applicable to all users of airborne ATC transponder systems who are required by regulation to participate in the ATC system or who voluntarily choose to do so.

1.5 Operational Goals

a. A concise statement of the minimum operational performance standards of the airborne system element needed to insure against derogation of service to other users of aviation navigation and communication services. These MOPS are applicable to all users of such airborne system element.

b. A concise statement of the minimum operational performance standards of the airborne system element needed to achieve at least that minimum performance on which control and separation of aircraft is based. These MOPS are applicable to all participants in controlled operations keyed to the use of such system element.

1.6 Assumptions

1.7 Test Procedures

1.8 Definition of Terms

2 Equipment Performance Requirements and Test Procedures

2.1 General Requirements

Minimum Operational Performance Standards of navigation, communication and ATC systems should be established and widely published. Where services provided in these areas depend upon certain characteristics of the airborne elements, minimum requirements must be established to assure that all airborne equipments are compatible with and operate properly within the service being provided. Such minimum requirements should be restricted to the actual minimum operational or performance characteristics and should not contain equipment specifications. These should be the prerogatives of the purchaser or seller of the equipment.

Further, the minimum requirements need not contain environmental standards, although such standards may be found useful and be utilized by manufacturers and purchasers to indicate that a given device can meet its operational characteristics in the intended application. The need is simply for the user to assure that his equipment will meet the needed operational characteristics in the environmental conditions in which he operates. As a means of determining the environmental characteristics of airborne equipment, there should be a convenient grouping of categories of environment encountered in typical aircraft. This type of standard is optional or guidance material, and may be used by equipment manufacturers or users to identify given equipment environmental capability. An equipment manufacturer has the option of:

Using the FAA "Environmental Test Procedures for Airborne Electronic Equipment," set forth in FAA Technical Standard Orders (TSO's); or

Using industry-developed environmental standards (such as RTCA, SAE); or

Stating the range of environmental conditions over which his equipment is capable of operating. As a minimum, temperature and altitude limitations should be stated. In order to achieve some degree of uniformity in the manner in which manufacturers state the range of environmental conditions over which their equipment is capable of operating, it is recommended that the environmental categories defined in the report of RTCA Special Committee 112 be employed for this purpose (See RTCA/DO-138).

2.1.1 Airworthiness

In the design and manufacture of the equipment, the manufacturer shall provide for installation so as not to impair the airworthiness of the aircraft.

2.1.2 Intended Function

The equipment **shall** perform its intended function(s), as defined by the manufacturer, and its proper use **shall not** create a hazard to other users of the National Airspace System.

The Minimum Operational Performance Standards for Airborne ATC Transponder Systems used in U.S.A. national and international service, which are stated below in Section 2.2, are based on the use of a system which consists of airborne transponders, ground interrogator-receiver, processing equipment, and an antenna system. The antenna may or may not be associated with, or slaved to, a primary surveillance radar. In operation, an interrogation pulse-group transmitted from the interrogator-transmitter unit, via an antenna assembly, triggers each airborne transponder located in the direction of the main beam, causing a multiple pulse reply group to be transmitted from each transponder. These replies are received by the ground receiver and, after processing, are displayed to the controller. Measurement of the round-trip transit time determines the range (rho) to the replying aircraft while the mean direction of the main beam of the interrogator antenna, during the reply, determines the azimuth (theta). The arrangement of the multiple-pulse reply provides individualized pressure altitude and identity information pertaining to the responding aircraft.

2.1.3 Federal Communications Commission Rules

All equipment **shall** comply with the applicable rules of the Federal Communication Commission.

2.1.4 Fire Protection

All materials used **shall** be self-extinguishing except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not contribute significantly to the propagation of a fire.

Note: *One means of showing compliance is contained in Federal Aviation Regulations (FAR), Part 25, Appendix F.*

2.1.5 Operation of Controls

The equipment **shall** be designed so that controls intended for use during flight cannot be operated in any position, combination or sequence that would result in a condition detrimental to the reliability of the equipment or operation of the aircraft.

2.1.6 Accessibility of Controls

Controls that do not require adjustment during flight **shall not** be readily accessible to flight personnel.

2.1.7 Effects of Test

The equipment **shall** be designed so that the application of specified test procedures **shall not** be detrimental to equipment performance following the application of the tests, except as specifically allowed.

The 4096 codes specified in §2.2.4 **shall** be manually selectable for reply to interrogations on Mode 3/A.

2.1.8 Display of Navigation Facility Identification

Note: *The following paragraph, or one similar in intent, should be added in MOPS for navigation equipment that may derive navigation guidance from co-located or closely spaced facilities.*

The frequency, or paired channel or other identification of the active facility or facilities being used for navigational guidance **shall** be displayed at all times, or optionally temporarily stored during recall of other navigation facility information. Equipment having the capability of optionally storing active facility identification **shall** include the following requirements:

a. The capability of recalling the active facility at any time for the purpose of identification

b. Display of facility identification from other than the active facility or facilities **shall not** interrupt or affect navigation guidance in any way.

c. An unambiguous indication **shall** be visible to the pilot when facility identification form other than the active facility or facilities is being displayed.

2.1.9 Design Assurance

This paragraph will discuss the appropriate design assurance level(s) that would be expected as a result of the function definitions and failure categorization(s) contained in Section 1 of the document. This should be based upon the criteria of AC 23.1309 and 25.1309-1b. This paragraph should address both misleading information and the loss of the function. MOPS should point to the latest revision of the RTCA Document No. DO-178() document as a method of establishing the appropriate software levels. A specific software level should not be established in the MOPS since the definitions of the levels could change in RTCA Document DO-178() after the MOPS is issued. The MOPS under development should also point to any hardware or system design assurance standards that are in effect at the time or writing (i.e., SAE ARP-4754).

2.2 Equipment Performance – Standard Conditions

2.2.1 Definition of Standard Conditions

2.2.2 Receiver Characteristics

2.2.2.1 Transponder Receiver Bandwidth

The skirt bandwidth should be such that the sensitivity of the transponder is at least 60 db down at frequencies outside the band 1030 ±25 MHz. The response to signals with pulse groups and with pulse spacings of 2 microseconds and 8 microseconds in the band 30 to 1500 MHZ, excluding the band 960 to 1215 MHz, **shall** be at least 60 db below maximum sensitivity.

2.2.3 Transmitter Characteristics

The center frequency of the reply transmission **shall** be 1090 MHz. The frequency tolerance shall be ±3 MHz.

2.2.3.1 Transponder Power Output

a. For equipment intended for installation in aircraft which operate at altitudes above 15,000 feet, the peak pulse power available at the antenna end of the transmission line of the transponder **shall** be at least 21 db and not more than 27 db above 1 watt.

b. For equipment intended for installation in aircraft which operate at altitudes not exceeding 15,000 feet, the peak pulse power-available at the antenna end of the transmission line of the transponder **shall** be at least 18.5 db and not more than 27 db above 1 watt.

Note: *For the power output requirement of the above Paragraphs "a" and "b," a nominal 3 db transmission line loss and an antenna performance equivalent to that of a simple quarter-wave antenna are assumed. In the event these assumed conditions do not apply, the peak pulse power of the installed transponder system must be comparable to that of the assumed system.*

2.2.3.2 Emission of Spurious RF Energy

With the transponder is operating, but not being interrogated, the level of spurious CW RF energy, as measured at the output terminal of the transponder, over the range 960 to 1215 MHz **shall not** exceed -70 dbw.

Recommendation: With the transponder operating, but not being interrogated, the level of spurious CW RF energy as measured at the output terminal of the transponder, at all frequencies allocated to the aeronautical service outside of the range 960 to 1215 MHz should not exceed -70 dbw.

2.2.4 Reply Pulse Characteristics (Signals in Space)

2.2.4.1 Framing Pulses

The reply function **shall** employ a signal comprising two framing pulses spaced 20.3 microseconds, as the most elementary code.

2.2.4.2 Information Pulses

Information pulses **shall** be spaced in increments of 1.45 microseconds from the first framing pulse. The designation and position of these information pulses **shall** be as follows:

<u>Table 2.2.4.2:</u> Information Pulses

Pulse	Position (microseconds)
F_1	0.00
C_1	1.45
A_1	2.90
C_2	4.35
A_2	5.80
C_4	7.25
A_4	8.70
X	10.15
B_1	11.60
D_1	13.05
B_2	14.50
D_2	15.95
B_4	17.40
D_4	18.85
F_2	20.3

2.2.4.3 Special Position Identification (SPI) Pulses

In addition to the information pulses provided, a Special Position Identification Pulse, which may be transmitted with the information pulses, **shall** occur at a pulse interval of 4.35 microseconds following the last framing pulse.

2.2.4.4 Reply Pulse Shape

All reply pulses **shall** have a pulse duration of 0.45 ±0.10 microsecond, a pulse rise time between 0.05 and 0.1 microsecond, and a pulse decay time between 0.05 and 0.2 microsecond. The pulse amplitude variation of one pulse with respect to any other pulse in a reply group **shall not** exceed 1 db.

<u>Note:</u> *The intent of the lower limit of rise and decay times (0.05 microsecond) is to reduce sideband radiation. Equipment will meet this requirement if the sideband radiation is no greater than that which theoretically would be produced by a trapezoidal wave having 0.05 microsecond rise and decay times and a 0.35 microsecond pulse duration.*

2.2.4.5 Reply Pulse Interval Tolerances

The pulse interval tolerance for each pulse (including the last framing pulse) with respect to the first framing pulse of the reply group **shall** be ±0.10 microsecond. The pulse interval tolerance of the Special Position Identification Pulse with respect to the last framing pulse of the reply group **shall** be ±0.10 microsecond. The pulse interval tolerance of any pulse in the reply group with respect to any other pulse (except the first framing pulse) **shall** not exceed ±0.15 microsecond.

2.2.4.6 Reply Delay and Jitter

The time delay between the arrival at the transponder of the leading edge of P_3, and the transmission of the leading edge of the first pulse of the reply **shall** be 3 ±0.5 microseconds. The total jitter of the reply pulse code group with respect to P_3 **shall not** exceed ±0.1 microsecond for receiver input levels between 3 and 50 db above minimum triggering level. Delay variations between modes on which the transponder is capable of replying **shall not** exceed 0.2 microseconds.

2.2.4.7 Transmission Time of Special Position Identification (SPI) Pulse

When manually initiated, the SPI pulse **shall** be transmitted for a period of between 15 and 30 seconds and must be capable of being reinitiated at any time.

2.2.5 Side Lobe Characteristics

2.2.5.1 Reply

When selected to reply to a particular interrogation mode (See Appendix A), the transponder **shall** reply (not less than 90 percent efficiency) under each of the following conditions:

a. The received amplitude of P_3 is in excess of a level 1 db below the received amplitude of P_1 but no greater than 3 db above the received amplitude of P_1.

b. Either the received amplitude of P_1 is in excess of a level of 9 db above the received amplitude of P_2, or no pulse is received at the position 2 ±0.7 microseconds. following P_1.

c. The received amplitude of a proper interrogation is more than 10 db above the received amplitude of random pulses where the latter are not recognized by the transponder as P_1, P_2, or P_3.

2.2.5.2 No Reply

The transponder **shall not** reply to more than 10 percent of the interrogations under each of the following conditions:

a. To interrogations when the interval between pulses P_1 and P_3 differs from that defined in Appendix A for the mode selected in the transponder by more than ±1 microsecond.

b. Upon receipt of any single pulse which has no amplitude variations approximating a normal interrogation condition.

2.2.5.3 Suppression

Upon receipt of an interrogation complying with the interrogation modes defined in Appendix A selected manually or automatically, the transponder **shall** be suppressed (not less than 99 percent efficiency) when the received amplitude of P_2 is equal to or in excess of the received amplitude of P_1 and spaced 2 ±0.15 microseconds.

Note: *It is not the intent of this paragraph to require the detection of P_3 as a prerequisite for initiation of suppression action.*

a. The transponder suppression **shall** be for a period of 35 ±10 microseconds.

b. The suppression **shall** be capable of being reinitiated for the full duration within two microseconds after the end of any suppression period.

2.2.6 Pulse Decoder Characteristics

2.2.6.1 Receiver Sensitivity and Dynamic Range

a. The minimum triggering level (MTL) of the transponder **shall** be such that replies are generated to 90 percent of the interrogation signals when:

(1) The two pulses P_1 and P_3 constituting an interrogation are of equal amplitude and P_2 is not detected; and

(2) The amplitude of these signals received at the antenna end of the transmission line of the transponder is nominally 71 db below 1 milliwatt with limits between 69 and 77 db below 1 milliwatt.

Note: *For this MTL requirement, a nominal 3 db transmission line loss and an antenna performance equivalent to that of a simple quarter wave antenna are assumed. In the event these assumed conditions do not apply, the MTL of the installed transponder system must be comparable to that of the assumed system.*

b. The variation of the minimum triggering level between modes **shall not** exceed 1 db for nominal pulse spacings and pulse widths.

c. The reply characteristics **shall** apply over a received signal amplitude range between minimum triggering level and 50 db above minimum triggering level.

d. The suppression characteristics **shall** apply over a received, .signal amplitude range between 3 db above minimum triggering level and 50 db above minimum triggering level.

2.2.6.2 Pulse Duration Discrimination

a. Signals of received amplitude between minimum triggering level and 6 db above this level, and of a duration less than 0.3 microsecond at the antenna, **shall not** cause the transponder to initiate more than 10% reply or suppression action.

b. With the exception of single pulses with amplitude variations approximating an interrogation, any single pulse of a duration more than 1.5 microseconds **shall not** cause the transponder to initiate reply or suppression action over the signal amplitude range of minimum triggering level to 50 db above minimum triggering level.

2.2.7 Desensitization and Recovery Characteristics

2.2.7.1 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.

2.2.7.2 Echo Suppression and Recovery

The transponder **shall** contain an echo suppression facility designed to permit normal operation in the presence of echoes of signals in space. The provision of this facility **shall** be compatible with the requirements for suppression of side lobes given in §2.2.5.3.

2.2.7.2.1 Desensitization

Upon receipt of any pulse more than 0.7 microseconds in duration, the receiver **shall** be desensitized by an amount that is within at least 9 db of the amplitude of the desensitizing pulse, but **shall** at no time exceed the amplitude of the desensitizing pulse, with the exception of possible overshoot during the first microsecond following the desensitizing pulse. Single pulses of duration less than 0.7 microseconds are not required to cause the specified desensitization, and **shall not** cause desensitization of duration greater than that permitted herein or by §2.2.7.2.2.

2.2.7.2.2 Recovery

Following desensitization, the receiver **shall** recover sensitivity (within 3 db of minimum triggering level) within 15 microseconds after reception of a desensitizing pulse having a signal strength up to 50 db above minimum triggering level. Recovery **shall** be nominally linear at an average rate not exceeding 3.5 db per microsecond.

<u>Note:</u> *Transponders that respond to military modes will recover within 15 microseconds, but may employ methods other than nominally linear recovery.*

2.2.7.3 Reply Rate

a. For equipment intended for installation in aircraft which operate at altitudes above 15,000 feet, the transponder **shall** be capable of at least 1,200 replies per second for a 15-pulse coded reply.

b. For equipment intended for installation in aircraft which operate at altitudes not exceeding 15,000 feet, the transponder **shall** be capable of at least 1,000 replies per second for a 15-pulse coded reply.

c. A sensitivity reduction type reply rate limit control **shall** be incorporated in the transponder. The range of this control **shall** permit adjustment, as a minimum, to any value between 500 and 2,000 replies per second, or to the maximum reply rate capability, if less than 2,000 replies per second, without regard to the number of pulses in each reply. Sensitivity reduction in excess of 3 db **shall not** take effect until 90 percent of the selected value is exceeded. Sensitivity reduction **shall** be at least 30 db for rates in excess of 150 percent of the selected value.

<u>Recommendation:</u> The reply rate limit control should be set at 1,200 replies per second, or the maximum value below 1,200 replies per second of which the transponder is capable. (See Paragraph b, above).

2.2.8 Response in the Presence of Interference

Installation in the aircraft **shall** be made in such a manner that, with all possible interfering equipments installed in the same aircraft operating in their normal manner on operational channels of maximum interference, but with the absence of bona fide interrogations, the random triggering rate (squitter) of the transponder **shall not** exceed 30 replies and/or suppressions per second as integrated over an interval equivalent to at least 300 random triggers, or 30 seconds, whichever is less.

2.2.9 Undesired Replies

SAME TEXT AS in §2.2.8. NEEDS TO BE EDITED HERE. Installation in the aircraft **shall** be made in such a manner that, with all possible interfering equipments installed in the same aircraft operating in their normal manner on operational channels of maximum interference, but with the absence of bona fide interrogations, the random triggering rate (squitter) of the transponder **shall not** exceed 30 replies and/or suppressions per second as integrated over an interval equivalent to at least 300 random triggers, or 30 seconds, whichever is less.

2.2.10 Transponder Self Test and Monitor

2.2.10.1 Manual Self-Test

(1) When a manual self-test device is provided, it **shall** be limited to intermittent use by a spring loaded return-to-off switch, or equivalent.

(2) The test interrogation rate **shall not** exceed 450 per second.

(3) The lowest RF level at the input to the antenna required to accomplish the test **shall** be used. The maximum RF level at the input to the antenna **shall not** exceed 40 db below 1 milliwatt.

2.2.10.2 Automatic Self-Test

(1) When an automatic self-test device is provided, it **shall** be limited to use only in the absence of a valid ground interrogation. (A minimum period of 15 seconds will be sufficient to establish the absence of ground interrogations).

(2) The maximum test time for the automatic self-test **shall not** exceed 0.1 second in any given l5-second interval.

(3) The test interrogation rate **shall not** exceed 450 per second.

(4) The lowest RF level at the input to the antenna required to accomplish the test **shall** be used. The maximum RF level at the input to the antenna **shall not** exceed 40 db below 1 milliwatt.

2.2.11 Response in Mutual Suppression Pulses

If the equipment is designed to accept and respond to suppression pulses from other electronic equipment in the aircraft (to disable it while the other equipment is transmitting), the equipment must regain normal sensitivity within 3 db, not later than 15 microseconds after the end of the applied suppression pulse.

2.2.12 Diversity

2.2.13 Data Handling and Interfaces

2.2.13.1 Code Nomenclature

The code designations **shall** consist of four digits, each of which lies between 0 and 7 inclusive, and is determined by the sum of the pulse subscripts given in Table 2.2.4.2, employed as follows:

Digit	**Pulse Group**
First (most significant)	A
Second	B
Third	C
Fourth	D

Examples:

Code 3600 would consist of information pulses A_1, A_2, B_2 and B_4

Code 2057 would consist of A_2, C_1, C_4, D_1, D_2 and D_4

Code 0301 would consist of B_1, B_2 and D_1

2.2.13.2 Identification

The 4096 codes specified in §2.2.4 **shall** be manually selectable for reply to interrogations on Mode 3/A.

2.2.13.3 Pressure Altitude Transmissions

(1) Independently of the other modes and codes manually selected, the transponder **shall** automatically reply to Mode C interrogations.

(2) The reply to Mode C interrogations **shall** consist of the two framing pulses together with the information pulses specified in §2.2.4.

(3) At as early a date as practicable, transponders **shall** be provided with means to remove the information pulses, but to retain the framing pulses when the provision of §2.2.13.3.(6) is not complied with, in reply to Mode C interrogation.

Note: *The information pulses should be capable of being removed either in response to a failure detection system or manually at the request of the controlling agency.*

(4) The information pulses **shall** be automatically selected by an analog-to-digital converter connected to a pressure-altitude data source in the aircraft referenced to the standard pressure setting of 29.92 inches of mercury.

(5) Pressure altitude **shall** be reported in 100-foot increments by selection of pulses as shown in Figure 1.

(6) The digitizer code selected **shall** correspond to within ±125 feet, on a 95 percent probability basis with the pressure altitude information (referenced to the standard pressure setting of 29.92 inches of mercury) used on board the aircraft to adhere to the assigned flight profile.

2.2.14 ATCRBS Transponder

2.2.15 Antennas

The transponder antenna system when installed on an aircraft **shall** have a radiation pattern which is essentially omni-directional in the horizontal plane and should have a vertical beam-width sufficient to provide system operation during normal maneuvers of the aircraft.

2.2.15.1 Frequency

The center frequency of the reply transmission **shall** be 1090 MHz. The frequency tolerance **shall** be ±3 MHz.

2.2.15.2 Impedance and VSWR

2.2.15.3 Polarization

Polarization of the reply transmissions **shall** be predominantly vertical.

2.2.15.4 Radiation Pattern

2.2.16 Power

2.2.16.1 Cold Start

2.2.16.2 Interruption

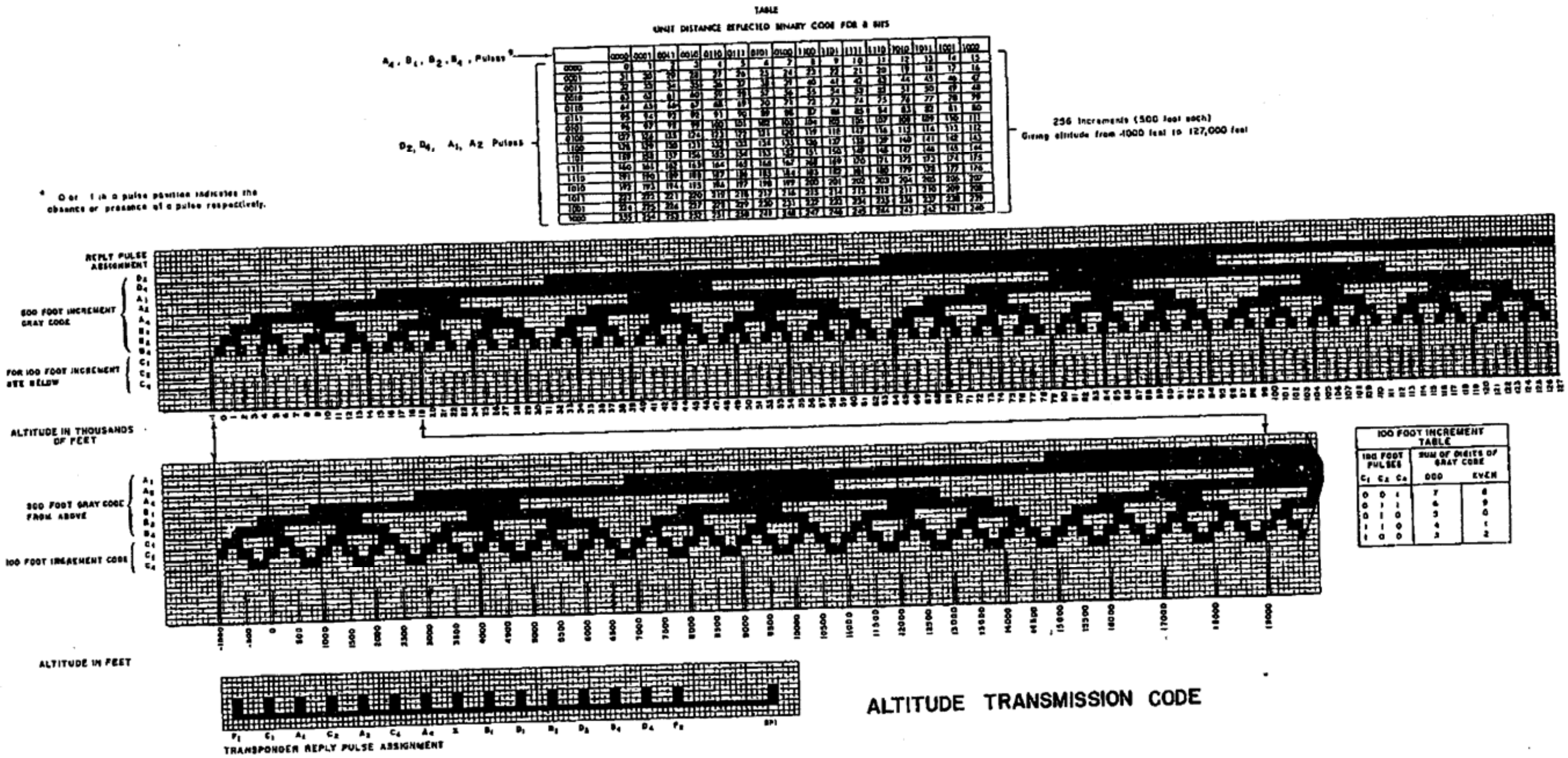
TABLE
UNIT DISTANCE REFLECTED BINARY CODE FOR 8 BITS
256 Increments (500 feet each)
Giving altitude from -1000 feet to 127,000 feet
REPLY PULSE ASSIGNMENT
500 FOOT INCREMENT GRAY CODE
FOR 100 FOOT INCREMENT SEE BELOW
ALTITUDE IN THOUSANDS OF FEET
500 FOOT GRAY CODE FROM ABOVE
100 FOOT INCREMENT CODE
ALTITUDE IN FEET
100 FOOT INCREMENT TABLE
ALTITUDE TRANSMISSION CODE
TRANSPONDER REPLY PULSE ASSIGNMENT

Figure 1

2.3 Equipment Performance – Environmental Conditions

The environmental tests and performance requirements described in this subsection are intended to provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual aeronautical operation.

Unless otherwise specified, the test procedures applicable to a determination of equipment performance under environmental test conditions are contained in RTCA Document No. DO-160D, *Environmental Conditions and Test Procedures for Airborne Equipment*. General information on the use of RTCA/DO-160D is contained in Sections 1 through 3 of that document. Also, a method of identifying which environmental tests were conducted and other amplifying information on the conduct of the tests is contained in Appendix A of RTCA/DO-160D.

Some of the performance requirements in Subsection 2.2 are not required to be tested to all of the conditions contained in RTCA/DO-160D. Judgement and experience have indicated that these particular parameters are not susceptible to certain environmental conditions and that the level of performance specified in Subsection 2.2 will not be measurably degraded by exposure to these conditions.

In addition to the exceptions above, certain environmental tests contained in this subsection are not required for minimum performance equipment unless the manufacturer wishes to qualify the equipment for additional environmental conditions. If the manufacturer wishes to qualify the equipment to these additional conditions, then these tests shall be performed.

2.3.1 Temperature and Altitude Tests (RTCA/DO-160C, Section 4.0)

RTCA/DO-160D contains several temperature and altitude test procedures that are specified according to equipment category. These categories are included in §4.3 of RTCA/DO-160D. The following subparagraphs contain the applicable test conditions specified in Section 4.0 of RTCA/DO-160D.

2.3.1.1 Low Operating Temperature Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §4.5.1, and the following requirements of this standard **shall** be met;

2.3.1.2 High Short-Time Operating Temperature Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §4.5.2, and the following requirements of this standard **shall** be met:

2.3.1.3 High Operating Temperature

The equipment **shall** be subject to the test conditions as specified in RTCA/DO-160D, §4.5.3, and the following requirements of this standard **shall** be met:

2.3.1.4 In-Flight Loss of Cooling

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §4.5.4, and the following requirements of this standard **shall** be met:

2.3.1.5 Altitude Tests

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §4.6.1, and the following requirements of this standard **shall** be met:

2.3.1.6 Decompression Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §4.6.2, and the following requirements of this standard **shall** be met:

2.3.1.7 Overpressure Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §4.6.3, and the following requirements of this standard **shall** be met:

2.3.2 Temperature Variation Test (RTCA/DO-160D, Section 6.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §5.0, and the following requirements of this standard **shall** be met:

2.3.3 Humidity Test (RTCA/DO-160D, Section 6.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §6.0, and the following requirements of this standard **shall** be met:

2.3.4 Shock Tests (RTCA/DO-160D, Section 7.0)

2.3.4.1 Operational Shocks

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §7.2, and the following requirements of this standard **shall** be met:

2.3.4.2 Crash Safety Shocks

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §7.3, and **shall** meet the requirements specified therein.

The application of the Crash Safety Shock tests may result in damage to the equipment under test. Therefore this test may be conducted after the other tests have been completed. In this case, §2.1.7, "Effects of Test" does not apply.

2.3.5 Vibration Tests (RTCA/DO-160D, Section 8.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §8.0, and the following requirements of this standard **shall** be met:

2.3.6 Explosion Test (RTCA/DO-160D, Section 9.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §9.0. During these tests, the equipment **shall not** cause detonation of the explosive mixture within the test chamber.

2.3.7 Waterproofness Test

2.3.7.1 Drip Proof Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §10.3.1, and the following requirements of this standard **shall** be met:

2.3.7.2 Spray Proof Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §10.3.2, and the following requirements of this standard **shall** be met:

This test **shall** be conducted with the spray directed perpendicular to the equipment.

2.3.7.3 Continuous Stream Proof Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §10.3.3, and the following requirements of this standard **shall** be met:

This test **shall** be conducted with the spray directed perpendicular to the equipment.

2.3.8 Fluids Susceptibility Tests (RTCA/DO-160D, Section 11.0)

The following subparagraphs contain the applicable test conditions specified in §11.0 of RTCA/DO-160D.

2.3.8.1 Spray Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §11.4.1, and the following requirements of this standard **shall** be met:

a. At the end of the 24-hour operational period, the equipment **shall** function.

b. Following the two-hour operational period at ambient temperature, after the 160 hour exposure period at elevated temperature, the following requirements of this standard **shall** be met:

2.3.8.2 Immersion Test

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §11.4.2, and the following requirements of this standard **shall** be met:

a. At the end of the 24-hour operational period, the equipment **shall** function.

b. Following the two-hour operational period at ambient temperature, after the 160 hour exposure period at elevated temperature, the following requirements of this standard **shall** be met:

2.3.9 Sand and Dust Test (RTCA/DO-160D, Section 12.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §12.0, and the following requirements of this standard **shall** be met:

2.3.10 Fungus Resistance Test (RTCA/DO-160D, Section 13.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §13.0, and the following requirements of this standard **shall** be met:

2.3.11 Salt Spray Test (RTCA/DO-160D, Section 14.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §14.0, and the following requirements of this standard **shall** be met:

2.3.12 Magnetic Effect Test (RTCA/DO-160D, Section 15.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §15.0, and the equipment **shall** meet the requirements of the appropriate instrument or equipment class specified therein.

2.3.13 Power Input Tests (RTCA/DO-160D, Section 16.0)

2.3.13.1 Normal Operating Conditions

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §16.5.1 and §16.5.2, as appropriate, and the following requirements of this standard **shall** be met:

2.3.13.2 Abnormal Operating Conditions

The application of the Low Voltage Conditions (DC) (Category B Equipment) test may result in damage to the equipment under test. Therefore, this test may be conducted after the other tests have been completed. §2.1.7 "Effect of Test" does not apply,

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §16.5.3 and §16.5.4, as appropriate, and the following requirements of this standard **shall** be met:

2.3.14 Voltage Spike Conducted Test (RTCA/DO-160D, Section 17.0)

The following subparagraphs contain the applicable test conditions specified in §17.0 of RTCA/DO-160D.

2.3.14.1 Category A Requirements (If Applicable)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §17.4, and the following requirements of this standard **shall** be met:

2.3.14.2 Category B Requirements (If Applicable)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §17.4, and the following requirements of this standard **shall** be met:

2.3.15 Audio Frequency Conducted Susceptibility Test (RTCA/DO-160D, Section 18.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §18.0, and the following requirements of this standard **shall** be met:

2.3.16 Induced Signal Susceptibility Test (RTCA/DO-160D, Section 19.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §19.0, and the following requirements of this standard **shall** be met:

2.3.17 Radio Frequency Susceptibility Test (RTCA/DO-160D, Section 20.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §20.0, and the following requirements of this standard **shall** be met:

2.3.18 Emission of Radio Frequency Energy Test (RTCA/DO-160D, Section 21.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §21.0, and the following requirements of this standard **shall** be met:

2.3.19 Lightning Induced Transient Susceptibility Test (RTCA/DO-160D, Section 22.0)

The equipment **shall** be subjected to the test conditions as specified in RTCA/DO-160D, §22.0, and the following requirements of this standard **shall** be met:

2.4 Equipment Test Procedures

Compliance with the Minimum Operational Performance Standards contained in Section §2.2 may be demonstrated by a combination of bench tests of the individual system components (or certification thereof by either the manufacturer or the installer) and flight tests of the entire installed system. A suggested procedure which will minimize the need for extensive evaluation in the field is as follows in the paragraphs below.

2.4.1 Definitions of Terms and Conditions of Test (§2.2.1)

The following are definitions of terms and the conditions under which the tests described in this subsection should be conducted.

a. Power Input Voltage – Unless otherwise specified, all tests shall be conducted with the power input voltage adjusted to design voltage, plus or minus 2%. The input voltage **shall** be measured at the input terminals of the equipment under test.

b. Power Input Frequency

   1) In the case of equipment designed for operation form an AC source of essentially constant frequency (e.g., 400 Hz), the input frequency **shall** be adjusted to design frequency, plus or minus 2%.

   2) In the case of equipment designed for operation form an AC source of variable frequency (e.g., 300 to 1,000 Hz), unless otherwise specified, tests **shall** be conducted with the input frequency adjusted to within 5% of a selected frequency and within the range for which the equipment is designed.

c. Adjustment of Equipment – The circuits of the equipment under test **shall** be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests.

d. Test Equipment – All equipment used in the performance of the tests should be identified by make, model and serial number where appropriate, and its latest calibration date. When appropriate, all test equipment calibration standards should be traceable to national and/or international standards.

e. Test Instrument Precautions – Adequate precautions shall be taken during the test to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes and other test instruments across the input and output impedances of the equipment under test.

f. Ambient Conditions – Unless otherwise specified, all tests **shall** be made within the following ambient conditions:

1) Temperature: +15 to +35 degrees C (+59 to +95 degrees F).

2) Relative Humidity: Not greater than 85%.

3) Ambient Pressure: 84 to 1-7 kPa (equivalent to +5,000 to –1,500 ft) (+1,525 to –460m).

g. Connected Loads – Unless otherwise specified, all tests **shall** be performed with the equipment connected to loads having the impedance values for which it is designed.

2.4.2 Verification of Receiver Characteristics (§2.2.2)

2.4.2.1 Verification of Transponder Receiver Bandwidth (§2.2.2.1)

Purpose/Introduction:

The skirt bandwidth should be such that the sensitivity of the transponder is at least 60 db down at frequencies outside the band 1030 ±25 MHz. The response to signals with pulse groups and with pulse spacings of 2 microseconds and 8 microseconds in the band 30 to 1500 MHZ, excluding the band 960 to 1215 MHz, **shall** be at least 60 db below maximum sensitivity.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.17: Interrogate the transponder at 500 interrogations per second with a Mode 3/A interrogation signal. Determine the interrogation signal level (MTL) which results in a transponder reply rate of 450. Set the interrogation frequency to 1055 and 1005 MHz and verify that the transponder sensitivity is at least 60 db below the MTL level measured above in both cases.

2.4.3 Verification of Transmitter Characteristics (§2.2.3)

The center frequency of the reply transmission **shall** be 1090 MHz. The frequency tolerance **shall** be ±3 MHz.

2.4.3.1 Verification of Transponder Power Output (§2.2.3.1)

Purpose/Introduction:

a. For equipment intended for installation in aircraft which operate at altitudes above 15,000 feet, the peak pulse power available at the antenna end of the transmission line of the transponder **shall** be at least 21 db and not more than 27 db above 1 watt.

b. For equipment intended for installation in aircraft which operate at altitudes not exceeding 15,000 feet, the peak pulse power-available at the antenna end of the transmission line of the transponder **shall** be at least 18.5 db and not more than 27 db above 1 watt.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.14: Transponder power output may be determined with a dummy load and power meter which are suitable for use at 1090 MHz.

(1) For equipment intended for installation in aircraft which operate at altitudes above 15,000 feet, the peak pulse power at the load should be at least +21 dbw and not more than +27 dbw.

(2) For equipment intended for installation in aircraft which operate at altitudes not exceeding 15,000 feet, the peak pulse power at the load should be at least +18.5dbw and not more than + 27 dbw.

2.4.3.2 Verification of Emission of Spurious RF Energy (§2.2.3.2)

Purpose/Introduction:

With the transponder is operating, but not being interrogated, the level of spurious CW RF energy, as measured at the output terminal of the transponder, over the range 960 to 1215 MHz **shall not** exceed -70 dbw.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.19: With the transponder operating but not being interrogated and with suitable test equipment connected to the transponder output terminal, scan the band of frequencies from 960 to 1215 MHz. Determine that spurious CW signals do not exceed -70 dbw.

Note: *In connection with the recommendation contained in §2.2.3.2, see appropriate FCC Rules and Regulations for tables of frequencies allocated to the aeronautical service.*

2.4.4 Verification of Reply Pulse Characteristics (Signals in Space) (§2.2.4)

The reply transmission characteristics can be determined with a demodulating probe and a wide band oscilloscope comparing the reply pulse group waveform against an accurate timing waveform such as from a crystal oscillator.

2.4.4.1 Verification of Framing Pulses (§2.2.4.1)

Purpose/Introduction:

The reply function **shall** employ a signal comprising two framing pulses spaced 20.3 microseconds, as the most elementary code.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.3: With the transponder interrogated on Mode 3/A and replying on Code 0000, the time interval between the 0.5 amplitude points on the leading edges of the two framing pulses should be within 20.3 ±0.10 microseconds.

2.4.4.2 Verification of Information Pulses (§2.2.4.2)

Purpose/Introduction:

Information pulses **shall** be spaced in increments of 1.45 microseconds from the first framing pulse. The designation and position of these information pulses **shall** be as shown in Table 2.2.4.2.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.3: With the transponder replying on Code 7777, the time interval between the 0.5 amplitude points on the leading edge of each pulse, including the last framing pulse, with respect to the first framing pulse should be equal to that listed in §2.2.4.2 with a tolerance of ±10 microsecond. Also, the time interval between any pulse in the reply group with respect to any other pulse (except the first framing pulse) should not exceed ±0.15 microsecond.

2.4.4.3 Verification of Special Position Identification (SPI) Pulses (§2.2.4.3)

Purpose/Introduction:

In addition to the information pulses provided, a Special Position Identification Pulse, which may be transmitted with the information pulses, **shall** occur at a pulse interval of 4.35 microseconds following the last framing pulse.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.3: With the transponder replying with the SPI pulse, the time interval between the 0.5 amplitude points on the leading edge of the second framing pulse and the SPI pulse should be 4.35 ±0.10 microseconds.

2.4.4.4 Verification of Reply Pulse Shape (§2.2.4.4)

Purpose/Introduction:

All reply pulses **shall** have a pulse duration of 0.45 ±0.10 microsecond, a pulse rise time between 0.05 and 0.1 microsecond, and a pulse decay time between 0.05 and 0.2 microsecond. The pulse amplitude variation of one pulse with respect to any other pulse in a reply group **shall not** exceed 1 db.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.3: The duration of each reply pulse, as measured between the 0.5 amplitude points on the leading and trailing edge, should be between 0.35 and 0.55 microsecond.

The rise time of each reply pulse, as measured between the 0.1 amplitude and 0.9 amplitude points on the leading edge should be between 0.05 and 0.10 microsecond.

The decay time of each reply pulse, as measured between the 0.9 amplitude and 0.1 amplitude points on the trailing edge should be between 0.05 and 0.20 microsecond.

The amplitude variation of anyone pulse as measured with respect to any other pulse in a reply group should not exceed 1 db.

Note: *The fundamental requirements of sideband radiation can be met either as described above or by determining that the actual sideband radiation is no greater than that which theoretically would be produced by a trapezoidal wave having 0.05 microsecond rise and decay times and a 0.35 microsecond pulse duration.*

2.4.4.5 Verification of Reply Pulse Interval Tolerances (§2.2.4.5)

Purpose/Introduction:

The pulse interval tolerance for each pulse (including the last framing pulse) with respect to the first framing pulse of the reply group **shall** be ±0.10 microsecond. The pulse interval tolerance of the Special Position Identification Pulse with respect to the last framing pulse of the reply group **shall** be ±0.10 microsecond. The pulse interval tolerance of any pulse in the reply group with respect to any other pulse (except the first framing pulse) **shall not** exceed ±0.15 microsecond.

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.4.6 Verification of Reply Delay and Jitter (§2.2.4.6)

Purpose/Introduction:

The time delay between the arrival at the transponder of the leading edge of P_3, and the transmission of the leading edge of the first pulse of the reply **shall** be 3 ±0.5 microseconds. The total jitter of the reply pulse code group with respect to P_3 **shall not** exceed ±0.1 microsecond for receiver input levels between 3 and 50 db above minimum triggering level. Delay variations between modes on which the transponder is capable of replying **shall not** exceed 0.2 microseconds.

Measurement Procedures:

(a) Interrogate the transponder with a Mode 3/A signal. Measure the time interval between the 50% voltage point of the leading edge of P_3 and the 50% voltage point of the leading edge of the first framing pulse at the antenna terminal. Vary the interrogation RF level from 3 to 50 db above MTL. The delay should be within the limits of 3 ±0.5 microsecond.

(b) Repeat step (a) for Mode C. Verify that the delay variation between Mode A and C does not exceed 0.2 microsecond.

(c) Measure the jitter from the leading edge of P_3 to the leading edge of the first framing pulse for signal levels between 3 and 50 db above MTL. Perform this test for both Modes A and C. The jitter should not exceed ±0.1 microsecond.

2.4.4.7 Verification of Transmission Time of Special Position Identification (SPI) Pulse (§2.2.4.7)

Purpose/Introduction:

When manually initiated, the SPI pulse **shall** be transmitted for a period of between 15 and 30 seconds and must be capable of being reinitiated at any time.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.16: Interrogate the transponder with a Mode 3/A interrogation signal. With the transponder operating, manually initiate the SPI pulse and verify that the transmission time of the SPI pulse is between 15 and 30 seconds, and that it can be re-initiated immediately.

2.4.5 Verification of Side Lobe Characteristics (§2.2.5)

2.4.5.1 Verification of Reply (§2.2.5.1)

Purpose/Introduction:

When selected to reply to a particular interrogation mode (See Appendix A), the transponder **shall** reply (not less than 90 percent efficiency) under each of the following conditions:

a. The received amplitude of P_3 is in excess of a level 1 db below the received amplitude of P_1 but no greater than 3 db above the received amplitude of P_1.

b. Either the received amplitude of P_1 is in excess of a level of 9 db above the received amplitude of P_2, or no pulse is received at the position 2 ±0.7 microseconds. following P_1.

c. The received amplitude of a proper interrogation is more than 10 db above the received amplitude of random pulses where the latter are not recognized by the transponder as P_1, P_2, or P_3.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.4: Interrogate the transponder with interrogation pulse signals described in Appendix A for Mode 3/A and C, at a repetition rate of 500 interrogations per second and with a signal level 3 db above the receiver minimum triggering level (See §2.4.6.1). In the absence of P_2 pulses, slowly adjust the interval between P_1 and P_3 from 7.8 microseconds to 8.2 microseconds, and from 20.8 microseconds to 21.2 microseconds, respectively, and note the reply rate in each case.

(1) Using the nominal pulse interval between P_1 and P_3 for Mode 3/A, vary the amplitude of P_3 between 1 db below and 3 db above the amplitude of P_1. Note the lowest reply rate obtained. Repeat for Mode C.

(2) Increase the signal level of P_1 and P_3 20 db, (for Mode 3/A only) with P_3 equal in amplitude to P_1 and with P_2 set to an amplitude 9 db below that of P_1 and P_3. Vary the interval of P_2 from 1.3 to 2.7 microseconds with respect to P_1 and note the lowest reply rate obtained.

(3) Repeat step (2) with the level of P_1, P_2, and P_3 set to be equal. Set the spacing of P_2 at 1.3 and 2.7 microseconds respectively with respect to P_1 and note the reply rate obtained.

(4) Repeat step (2) above but with P2 at the nominal interval following P1. Combine the interrogation signal with a non-synchronous single pulse generator operating at 5000 prf and at an RF level 10 db below that of P1 and P3.

The reply rates obtained in each case above should be at least 450 replies per second.

2.4.5.2 Verification of No Reply (§2.2.5.2)

Purpose/Introduction:

The transponder **shall** not reply to more than 10 percent of the interrogations under each of the following conditions:

a. To interrogations when the interval between pulses P_1 and P_3 differs from that defined in Appendix A for the mode selected in the transponder by more than ±1 microsecond.

b. Upon receipt of any single pulse which has no amplitude variations approximating a normal interrogation condition.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.5: Interrogate the transponder with interrogation pulse signals described in Appendix A for Modes 3/A and C, at a repetition rate of 500 interrogations per second and with a signal level 3 db above the receiver minimum triggering level. (See §2.3.2.1.8). In the absence of P_2 pulses, adjust the interval between P_1 and P_3 to 7.0, 9.0, 20.0 and 22.0 microseconds, respectively. Note the reply rate in each case. The reply rate should be no more than 50 replies per second.

2.4.5.3 Verification of Suppression (§2.2.5.3)

Purpose/Introduction:

Upon receipt of an interrogation complying with the interrogation modes defined in Appendix A selected manually or automatically, the transponder **shall** be suppressed (not less than 99 percent efficiency) when the received amplitude of P_2 is equal to or in excess of the received amplitude of P_1 and spaced 2 ±0.15 microseconds.

Note: *It is not the intent of this paragraph to require the detection of P_3 as a prerequisite for initiation of suppression action.*

a. The transponder suppression **shall** be for a period of 35 ±10 microseconds.

b. The suppression **shall** be capable of being reinitiated for the full duration within two microseconds after the end of any suppression period.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.7: Interrogate the transponder with Mode 3/A interrogation pulse signals described in Appendix A at a repetition rate of 500 interrogations per second and at a signal level of 3 db above receiver minimum triggering level. Adjust P_2 equal in amplitude to P_1 with spacings from 1.85 to 2.15 microseconds and note the reply rate. Repeat with P_2 adjusted to 10 db greater than P_1 and note the reply rate. Both rates should be no greater than 5 replies per second.

(1) Disable P_3 and readjust P_2 equal in amplitude to P_1 and at nominal spacing. Using a second signal source (set to at least 3 db above the receiver minimum triggering level) with the interrogation rate synchronized with the first but delayed more than 50 microseconds, interrogate the transponder on Mode 3/A. Gradually shorten the delay until no replies are received from the second interrogation source. Note the interval between P_2 of the first signal source and P_1 of the second signal source. This interval should be between 25 and 45 microseconds.

(2) Increase the delay time of the second interrogation source by 2 microseconds from that at which no replies were received in step (1) above. There should be at least 450 replies per second from the second interrogation source. Insert a P_2 into the second interrogation source equal in amplitude to P_1. The reply rate from the second interrogation source should not exceed 5 replies per second.

2.4.6 Verification of Pulse Decoder Characteristics (§2.2.6)

2.4.6.1 Verification of Receiver Sensitivity and Dynamic Range (§2.2.6.1)

<u>Purpose/Introduction:</u>

a. The minimum triggering level (MTL) of the transponder shall be such that replies are generated to 90 percent of the interrogation signals when:

(1) The two pulses P_1 and P_3 constituting an interrogation are of equal amplitude and P_2 is not detected; and

(2) The amplitude of these signals received at the antenna end of the transmission line of the transponder is nominally 71 db below 1 milliwatt with limits between 69 and 77 db below 1 milliwatt.

<u>Note:</u> *For this MTL requirement, a nominal 3 db transmission line loss and an antenna performance equivalent to that of a simple quarter wave antenna are assumed. In the event these assumed conditions do not apply, the MTL of the installed transponder system must be comparable to that of the assumed system.*

b. The variation of the minimum triggering level between modes **shall not** exceed 1 db for nominal pulse spacings and pulse widths.

c. The reply characteristics **shall** apply over a received signal amplitude range between minimum triggering level and 50 db above minimum triggering level.

d. The suppression characteristics **shall** apply over a received, .signal amplitude range between 3 db above minimum triggering level and 50 db above minimum triggering level.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.8:

(1) Interrogate the transponder with Mode 3/A interrogation pulse signals described in Appendix A at a repetition rate of 500 interrogations per second. Adjust P1 and P3 equal in amplitude (no P2 pulses) and apply a signal level known to be below minimum triggering level. Increase the signal generator output level until the transponder reply rate is 450 replies per second. This is the transponder minimum triggering level (MTL). The installed system MTL (including transmission line loss) should be between 69 and 77 db below 1 milliwatt.

EXAMPLE:		
	Transponder MTL	-74 dbm
	Transmission Line Loss	3 db
	System MTL	-71 dbm

(2) Repeat step (1) above using interrogation pulse signals described in Appendix A for Mode C. The variation in MTL between steps (1) and (2) should not exceed 1 db.

(3) Repeat Paragraph §2.4.5.1, "Reply," and steps (1) through (4) but with selected interrogation levels of 3, 10, 25, and 50 db above the receiver minimum triggering level.

(4) Repeat Paragraph §2.4.5.2, "No Reply," but with selected interrogation levels of 3, 10, 25, and 50 db above the receiver minimum triggering level.

2.4.6.2 Verification of Pulse Duration Discrimination (§2.2.6.2)

Purpose/Introduction:

a. Signals of received amplitude between minimum triggering level and 6 db above this level, and of a duration less than 0.3 microsecond at the antenna, **shall** not cause the transponder to initiate more than 10% reply or suppression action.

b. With the exception of single pulses with amplitude variations approximating an interrogation, any single pulse of a duration more than 1.5 microseconds **shall not** cause the transponder to initiate reply or suppression action over the signal amplitude range of minimum triggering level to 50 db above minimum triggering level.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.9:

(1) Interrogate the transponder with Mode 3/A interrogations at a repetition rate of 500 interrogations per second. Adjust P_1 and P_3 (no P_2 pulse) to a width of 0.3 microseconds and set the RF level to 6 db above minimum triggering level. The reply efficiency should not exceed 10%.

(2) Interrogate the transponder with Mode 3/A interrogations at a repetition rate of 500 interrogations per second. Adjust the RF level of P_1, P_2 and P_3 to 6 db above minimum triggering level. Reduce the width of P_2 to 0.3 microseconds. The reply efficiency should not be less than 90%.

(3) Interrogate the transponder with a single input pulse at 1030 MHz. Vary the pulse width of the interrogation signal from 1.5 to 22 microseconds at input signal levels of 3, 10, 25, and 50 db above MTL. At each input signal, verify that the transponder does not reply to, and/or is not suppressed by, the interrogation signal.

2.4.7 Verification of Desensitization and Recovery Characteristics (§2.2.7)

2.4.7.1 Verification of Dead Time (§2.2.7.1)

Purpose/Introduction:

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.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.6: In the absence of P_2 pulses, interrogate the transponder on Mode 3/A at a repetition rate of 500 interrogations per second and at a signal level at least 3 db above the receiver minimum triggering level. Using a second signal source (set to a comparable output level) with the interrogation rate synchronized with the first but delayed more than 150 microseconds, interrogate the transponder on Mode C. Gradually shorten the delay until the replies to the Mode C interrogations disappear. Note the interval between the SPI pulse of the Mode 3/A reply and the first framing pulse of the Mode C reply. The interval should be between 0 and 125 microseconds.

2.4.7.2 Verification of Echo Suppression and Recovery (§2.2.7.2)

Purpose/Introduction:

The transponder **shall** contain an echo suppression facility designed to permit normal operation in the presence of echoes of signals in space. The provision of this facility **shall** be compatible with the requirements for suppression of side lobes given in §2.2.5.3.

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.7.2.1 Verification of Desensitization (§2.2.7.2.1)

Purpose/Introduction:

Upon receipt of any pulse more than 0.7 microseconds in duration, the receiver **shall** be desensitized by an amount that is within at least 9 db of the amplitude of the desensitizing pulse, but **shall** at no time exceed the amplitude of the desensitizing pulse, with the exception of possible overshoot during the first microsecond following the desensitizing pulse. Single pulses of duration less than 0.7 microseconds are not required to cause the specified desensitization, and **shall not** cause desensitization of duration greater than that permitted herein or by §2.2.7.2.2.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.10.1: Interrogate the transponder with Mode 3/A interrogation pulse signals described in Appendix A at a repetition rate of 500 interrogations per second. Precede P1 by 2.8 microseconds with a single 0.8 microsecond wide pulse at a signal level of 50 db above the receiver minimum triggering level. Adjust P1 and P3 equal in amplitude and increase the output to a level causing a reply rate of 450 replies per second. This level should be between 34 and 43 db above the receiver minimum triggering level.

2.4.7.2.2 Verification of Recovery (§2.2.7.2.2)

Purpose/Introduction:

Following desensitization, the receiver **shall** recover sensitivity (within 3 db of minimum triggering level) within 15 microseconds after reception of a desensitizing pulse having a signal strength up to 50 db above minimum triggering level. Recovery **shall** be nominally linear at an average rate not exceeding 3.5 db per microsecond.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.10.2: Note the signal levels required to just maintain 450 replies per second as the interval between the 0.8 microsecond pulse and P1 is gradually increased. Also note that the average rate does not exceed 3.5 db per microsecond as the signal level and interval is changed to just maintain the 450 pulses per second reply rate. At an interval of 15 microseconds, note that the sensitivity returns to at least -47 dbm.

Note: *An interval corresponding to a normal Mode 3/A interrogation and a side lobe interrogation is excluded.*

2.4.7.3 Verification of Reply Rate (§2.2.7.3)

Purpose/Introduction:

a. For equipment intended for installation in aircraft which operate at altitudes above 15,000 feet, the transponder **shall** be capable of at least 1,200 replies per second for a 15-pulse coded reply.

b. For equipment intended for installation in aircraft which operate at altitudes not exceeding 15,000 feet, the transponder **shall** be capable of at least 1,000 replies per second for a 15-pulse coded reply.

c. A sensitivity reduction type reply rate limit control **shall** be incorporated in the transponder. The range of this control **shall** permit adjustment, as a minimum, to any value between 500 and 2,000 replies per second, or to the maximum reply rate capability, if less than 2,000 replies per second, without regard to the number of pulses in each reply. Sensitivity reduction in excess of 3 db **shall not** take effect until 90 percent of the selected value is exceeded. Sensitivity reduction **shall** be at least 30 db for rates in excess of 150 percent of the selected value.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.12: Interrogate the transponder with a Mode 3/A signal at an RF level of 3 db above minimum trigger level. Adjust the interrogation rate at 1080 interrogations per second or 90% of the transponder's maximum reply rate whichever is less. The reply efficiency should not be less than 90%.

Increase the interrogation rate to 1800 interrogations per second or 150% of the transponder's maximum reply rate whichever is greater. The RF level to maintain 1080 replies should be no greater than 33 db above MTL.

2.4.8 Verification of Response in the Presence of Interference (§2.2.8)

Purpose/Introduction:

Installation in the aircraft **shall** be made in such a manner that, with all possible interfering equipments installed in the same aircraft operating in their normal manner on operational channels of maximum interference, but with the absence of bona fide interrogations, the random triggering rate (squitter) of the transponder **shall not** exceed 30 replies and/or suppressions per second as integrated over an interval equivalent to at least 300 random triggers, or 30 seconds, whichever is less.

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.9 Verification of Undesired Replies (§2.2.9)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.10 Verification of Transponder Self-Test and Monitor (§2.2.10)

2.4.10.1 Verification of Manual Self-Test (§2.2.10.1)

Purpose/Introduction:

(1) When a manual self-test device is provided, it **shall** be limited to intermittent use by a spring loaded return-to-off switch, or equivalent.

(2) The test interrogation rate **shall** not exceed 450 per second.

(3) The lowest RF level at the input to the antenna required to accomplish the test **shall** be used. The maximum RF level at the input to the antenna **shall not** exceed 40 db below 1 milliwatt.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.18.1:

(a) If the self-test or monitor device is of a type which radiates a signal, or interferes with transponder reply function during the test period, the actuating system must be designed to limit test operation to only that time when manipulated. A spring return rotary switch or push button is considered to be such a device.

(b) The test interrogation rate may be measured on the bench using a suitable detector and counter. The interrogation rate averaged over a five-second interval should not exceed 450 interrogations per second.

(c) The test signal level may be measured at the antenna end of the transmission line in the actual aircraft, or on the bench using a length of transmission line equal to that in the airplane. One way to measure the level is to adjust a second test transponder to just trigger at the prescribed radiation limit. Connect this test transponder to the transmission line and determine if it is triggered when the self-testing device of the first transponder is operated.

Note: *Due to the close proximity of the units and because of the high signal level, the transmitter of the first transponder should be disabled. A calibrated attenuator should be placed in the transmission line between the transponders to prevent receiver damage.*

2.4.10.2 Verification of Automatic Self-Test (§2.2.10.2)

Purpose/Introduction:

(1) When an automatic self-test device is provided, it **shall** be limited to use only in the absence of a valid ground interrogation. (A minimum period of 15 seconds will be sufficient to establish the absence of ground interrogations).

(2) The maximum test time for the automatic self-test shall not exceed 0.1 second in any given l5-second interval.

(3) The test interrogation rate shall not exceed 450 per second.

(4) The lowest RF level at the input to the antenna required to accomplish the test **shall** be used. The maximum RF level at the input to the antenna **shall not** exceed 40 db below 1 milliwatt.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.18.2:

(a) Interrogate the transponder at a nominal interrogation rate of 100 interrogations per second. Stop the interrogations and, using a timing device (such as an oscilloscope) and a suitable RF detector at the transponder output, verify that no test transmissions occur for a period of 15 seconds after the interrogations cease.

(b) With no external interrogations, observe the output of the RF detector and verify that the automatic self-test transmissions do not occur for more than 0.1 second in any given 15 second interval.

(c) The test interrogation rate may be measured on the bench using a suitable detector and counter. The interrogation rate averaged over a five second interval should not exceed 450 interrogations per second.

(d) The test signal level may be measured at the antenna end of the transmission line in the actual aircraft, or on the bench using a length of transmission line equal to that in the airplane. One way to measure the level is to adjust a second test transponder to just trigger at the prescribed radiation limit. Connect this test transponder to the transmission line and determine if it is triggered when the self-testing device of the first transponder is operated.

Note: *Due to the close proximity of the units and because of the high signal level, the transmitter of the first transponder should be disabled. A calibrated attenuator should be placed in the transmission line between the transponders to prevent receiver damage.*

2.4.11 Verification of Response in Mutual Suppression Pulses (§2.2.11)

Purpose/Introduction:

If the equipment is designed to accept and respond to suppression pulses from other electronic equipment in the aircraft (to disable it while the other equipment is transmitting), the equipment must regain normal sensitivity within 3 db, not later than 15 microseconds after the end of the applied suppression pulse.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.11: If the transponder is provided with an external suppression jack, perform the following test:

Interrogate the transponder with a Mode 3/A signal at an RF level of 50 db above minimum triggering level at an interrogation rate of 500 pulses per second. Inject a suppression pulse into the external suppression jack. The pulse should have a width of 35 ±10 microseconds, a rise-time of no less than 20 volts/microsecond, a fall time of no less than 10 volts/microsecond, and an amplitude of 18 volts. The leading edge of the suppression pulse, at the 0.5 amplitude point, should precede the leading edge of P1 by 2 ±1.0 microseconds. The reply rate should not exceed five interrogations per second.

Delay the interrogation to 15 microseconds and note that the reply rate returns to 450 replies per second.

2.4.12 Verification of Diversity (§2.2.12)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.13 Verification of Data Handling and Interfaces (§2.2.13)

2.4.13.1 Verification of Code Nomenclature (§2.2.13.1)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.13.2 Verification of Identification (§2.2.13.2)

Purpose/Introduction:

The 4096 codes specified in §2.2.4 **shall** be manually selectable for reply to interrogations on Mode 3/A.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.15.1: Mode 3/A reply coding can be checked by changing the Mode 3/A code number while monitoring the transmitted output with a demodulator probe and oscilloscope. Only the framing pulses, F_1 and F_2, will appear when all code numbers are set to zero. The twelve information pulses and the SPI pulse appear in the positions and pattern described in §2.2.4.

2.4.13.3 Verification of Pressure Altitude Transmissions (§2.2.13.3)

Purpose/Introduction:

(1) Independently of the other modes and codes manually selected, the transponder **shall** automatically reply to Mode C interrogations.

(2) The reply to Mode C interrogations **shall** consist of the two framing pulses together with the information pulses specified in §2.2.4.

(3) At as early a date as practicable, transponders **shall** be provided with means to remove the information pulses, but to retain the framing pulses when the provision of §2.2.13.3.(6) is not complied with, in reply to Mode C interrogation.

Note: *The information pulses should be capable of being removed either in response to a failure detection system or manually at the request of the controlling agency.*

(4) The information pulses **shall** be automatically selected by an analog-to-digital converter connected to a pressure-altitude data source in the aircraft referenced to the standard pressure setting of 29.92 inches of mercury.

(5) Pressure altitude **shall** be reported in 100-foot increments by selection of pulses as shown in Figure 1.

(6) The digitizer code selected **shall** correspond to within ±125 feet, on a 95 percent probability basis with the pressure altitude information (referenced to the standard pressure setting of 29.92 inches of mercury) used on board the aircraft to adhere to the assigned flight profile.

Measurement Procedures:

Originally from DO-144 §2.3.2.1.15.2:

(a) Transponder response to Mode C interrogations may be monitored with a demodulator probe and an oscilloscope. A Mode C reply without the digitizer connected to the transponder should consist of the two framing pulses F1 and F2.

(b) The altitude reporting switch in the "off" position should prevent the transmission of digitizer information pulses but not the transmission of the framing pulses.

(c) If a digitizer is connected to the transponder, the information pulses will appear in accordance with the pattern represented in Figure 1.

2.4.14 Verification of ATCRBS Transponder (§2.2.14)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.15 Antennas (§2.2.15)

2.4.15.1 Verification of Frequency (§2.2.15.1)

Purpose/Introduction:

The center frequency of the reply transmission **shall** be 1090 MHz. The frequency tolerance **shall** be ±3 MHz.

Measurement Procedures:

Originally from DO-144: Interrogate the transponder and verify that the reply frequency is 1090 ±3 MHz.

2.4.15.2 Verification of Impedance and VSWR (§2.2.15.2)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.15.3 Verification of Polarization (§2.2.15.3)

Purpose/Introduction:

Polarization of the reply transmissions **shall** be predominantly vertical.

Measurement Procedures:

Originally from DO-144: An inspection of the antenna system should affirm that radiation will be predominately vertically polarized.

An antenna system which produces vertically polarized radiation will be considered to have complied with this paragraph if it is mounted on the aircraft so that its polarization axis lies within an angle of 15° from the true vertical in level flight attitude.

2.4.15.4 Verification of Radiation Pattern (§2.2.15.4)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.16 Verification of Power (§2.2.16)

2.4.16.1 Verification of Cold Start (§2.2.16.1)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

2.4.16.2 Verification of Interruption (§2.2.16.2)

Purpose/Introduction:

Measurement Procedures:

Step 1: ***Brief descriptive title for this test step***

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3 INSTALLED EQUIPMENT PERFORMANCE

This section states the minimum acceptable level of performance for the equipment when installed in the aircraft. For the most part, installed performance requirements are the same as those contained in Section 2, which were verified through bench and environmental test. However, certain requirements may be affected by the physical installation (e.g., antenna patterns, receiver sensitivity, etc.) and can only be verified after installation. The installed performance limits stated below take in consideration these situations.

3.1 Equipment Installation

The airborne ATC transponder system should have been installed in the aircraft by the use of acceptable workmanship and engineering practices in an airworthy manner, and in accordance with the equipment manufacturer's recommendations as set forth in his equipment installation manual or other appropriate publication. To assure that the airborne ATC transponder system has been properly and safely installed in the aircraft, make a thorough visual inspection thereof and conduct a gross over-all operational/functional check of the system on the ground prior to flight.

3.1.1 Equipment Accessibility

Equipment controls and display(s) installed for in-flight operation **shall** be readily accessible from the normal seated position. The appropriate operator/crew members(s) **shall** have an unobstructed view of the display(s) when in the normal sitting position.

3.1.2 Inadvertent Turn Off

Appropriate controls **shall** be provided with adequate protection against inadvertent turn off.

3.1.3 Displays

All installed system displays **shall** be readily visible and readable from the crew member's normal position in all ambient lighting conditions for which system use is required.

Note: *Visors, glareshields or filters may be an acceptable means of obtaining daylight visibility.*

3.1.4 Aircraft Power Source

The voltage and voltage tolerance characteristics of the equipment **shall** be compatible with the aircraft power source of appropriate category as specified in RTCA/DO-160D.

3.1.5 Transmission Line(s)

The transmission line(s) connecting antenna(s) and transponder(s) **shall** have impedance, power handling and loss characteristics in accordance with the equipment manufacturer's specifications.

3.1.6 Antenna Location

a. Single Antenna

The antenna **shall** be installed on the bottom of the aircraft as close to the longitudinal axis of the aircraft as possible.

b. Diversity Transponder Installation

The top and bottom antennas **shall** be mounted as near as possible to the center line of the fuselage. Antennas **shall** be located so as to minimize obstruction to their fields in the horizontal plane.

Recommendation: *The horizontal distance between the top and bottom antennas should not be greater than 7.6 meters.*

Note: *This recommendation is intended to support the operation of any diversity transponder (including cables) with any diversity antenna installation and still satisfy the requirement of §3.1.6 c.*

c. Reply Delay of Diversity Transponders.

The total two-way transmission difference in mean reply delay between the two antenna channels (including the differential delay caused by transponder-to-antenna cables and the horizontal distance along the aircraft centerline between the two antennas) **shall** not exceed 0.130 microseconds for interrogations of equal amplitude. This requirement **shall** hold for interrogation signal strengths between MTL +3 dB and -21 dBm. The jitter requirements on each individual channel **shall** remain as specified for non-diversity transponders (see §**Error! Reference source not found.**).

Note: *This requirement limits the total apparent jitter caused by antenna switching and by cable and antenna location delay differences.*

3.1.7 Mutual Suppression

If other equipment is installed in the aircraft operating at or near 1030 and 1090 MHz, such as DME, the need for mutual suppression **shall** be determined. When mutual suppression is used, the requirements of §**Error! Reference source not found. shall** be met.

3.2 Conditions of Test

The conditions of test stated in the following subparagraphs are applicable to the equipment tests specified in Subsection §3.3. Ground tests may be used for all tests specified.

3.2.1 Power Input

Tests may be conducted using either the aircraft's electrical power distribution system or an appropriate external power supply.

3.2.2 Interference Effects

With the equipment energized from the aircraft's electrical power generating system, individually operate each of the other electrically operated aircraft equipment and systems to determine that no significant conducted or radiated interference exists. Evaluate all reasonable combinations of control settings and operating modes. Operate communication and navigation equipment on at least the low, high and one mid-band frequencies. If appropriate, repeat tests using emergency power source(s).

3.2.3 Environment

During the tests, the equipment **shall not** be subjected to environmental conditions that exceed those in RTCA/DO-160D as specified by the equipment manufacturer.

3.2.4 Adjustment of Equipment

Circuits of the equipment under test **shall** be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests.

3.2.5 Warm-up Period

Unless otherwise specified, all tests **shall** be conducted after a warm-up period of not more than 15 minutes.

3.2.6 Radiation Pattern

The antenna **shall** have a radiation pattern which is essentially omnidirectional in the horizontal plane and have sufficient vertical beamwidth to assure proper equipment operation during normal aircraft maneuvers.

3.3 Test Procedures for Installed Equipment Performance

The test procedures set forth below are considered satisfactory in determining required installed equipment performance. Testing requirements are stated, in a manner that will make maximum use of bench test data while limiting flight tests to those requirements which cannot be tested conveniently by other means. Although suggested test procedures are cited, it is recognized that other methods may be preferred by the installing activity. These alternate procedures may be used if the installing activity can show that they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures.

Installed equipment performance tests confirm surveillance functions. Data link functions will be dealt with in a future document.

Current U.S. operating regulations require tests similar to those described herein be performed bi-annually to ensure against deterioration of performance. Since equipment installation requires initial performance of these tests, they are included herein.

3.3.1 Conformity Inspection

Visually inspect the installed equipment to determine the use of acceptable workmanship and engineering practices. Verify that all mechanical and electrical connections have been made properly and that the equipment has been installed and located in accordance with the manufacturer's recommendations.

3.3.2 Bench Tests

The equipment **shall** have been tested and certified by the equipment manufacturer to demonstrate compliance with the minimum requirements stated in Section §**Error! Reference source not found.**.0.

The transponder tests required below may be conducted using portable test equipment.

3.3.3 Reply Frequency

Interrogate the installed transponder and verify that the reply frequency of the system is 1090 ±3 MHz for aircraft operating below 15,000 feet, or 1090, ±1 MHz for aircraft operating above 15,000 feet.

3.3.4 Framing Pulse Spacing

Verify that the time interval between the leading edges of the two framing pulses is 20.3 ±0.10 microseconds.

3.3.5 Reply Codes

a. Verify that all Mode 3/A reply pulses listed below in Table 3.3.5 are present.

<u>Table 3.3.5:</u> Mode 3/A Reply Pulses

Pulse	Position (microseconds)	4096 code for this pulse only
F1	0.00	
C1	1.45	0010
A1	2.90	1000
C2	4.35	0020
A2	5.80	2000
C4	7.25	0040
A4	8.70	4000
B1	11.60	0100
D1	13.05	0001
B2	14.50	0200
D2	15.95	0002
B4	17.40	0400
D4	18.85	0004
F2	20.30	
SPI	24.65	

b. Interrogate the transponder a sufficient number of times to verify that the correct 4096 code is transmitted. Use more than one 4096 code.

3.3.6 Pressure Altitude Transmissions

a. Verify that the transponder response to Mode C interrogations consists only of framing pulses F1 and F2. If complete altitude reporting capability is provided, the altitude digitizer may not be connected to the transponder at the time of the test.

b. Verify that the transponder response to Mode C interrogations consists of only framing pulses F1 and F2 with the altitude switch in the “OFF” position.

3.3.7 Altitude Reporting Test

a. A sufficient number of test points **shall** be checked to ensure that the altitude reporting equipment and transponder perform their intended function through their entire range while ascending or descending. Tests of each altitude code segment of the encoder (2300, 2500, 3800, 4300, 4800, 6800, 14,800 and 30,800 if available) are sufficient to ensure proper operation of each altitude code segment of the encoder.

b. Verify that the correspondence value of the altimeter system is 125 feet or less.

3.3.8 Reply Pulse Width

Verify that the duration of the F1 and F2 pulses between the 0.5 amplitude points on the leading and trailing edge is 0.45, ±0.10 microsecond with the transponder replying on Mode 3/A, code 0001, and code 7477.

3.3.9 Receiver Sensitivity

a. Verify that for ATCRBS interrogations the receiver sensitivity of the system at the antenna end of the transmission line is -73, ±4 dBm.

b. Verify that for Mode S P_6 type interrogations the sensitivity of the equipment at the antenna end of the transmission line is -74 dBm, ±3 dB.

c. The minimum triggering level (MTL) of the transponder shall be such that replies are generated to 90 percent of the interrogation signals when:

(1) The two pulses P_1 and P_3 constituting an interrogation are of equal amplitude and P_2 is not detected; and

(2) The amplitude of these signals received at the antenna end of the transmission line of the transponder is nominally 71 db below 1 milliwatt with limits between 69 and 77 db below 1 milliwatt.

Note: *For this MTL requirement, a nominal 3 db transmission line loss and an antenna performance equivalent to that of a simple quarter wave antenna are assumed. In the event these assumed conditions do not apply, the MTL of the installed transponder system must be comparable to that of the assumed system.*

d. The variation of the minimum triggering level between modes **shall** not exceed 1 db for nominal pulse spacings and pulse widths.

e. The reply characteristics **shall** apply over a received signal amplitude range between minimum triggering level and 50 db above minimum triggering level.

f. The suppression characteristics **shall** apply over a received, .signal amplitude range between 3 db above minimum triggering level and 50 db above minimum triggering level.

3.3.10 Transmitter Power Output

a. Verify that transponders operating at altitudes above 15,000 feet and/or at normal cruising speeds in excess of 175 knots have a peak pulse power at the antenna end of the transmission line of at least +21 dBW and not more than +27 dBW.

b. Verify that transponders intended for operation at altitudes not above 15,000 feet have a peak pulse power at the antenna end of the transmission line of at least +18.5 dBW and not more than +27 dBW.

3.3.11 Mode S Address

Verify that the 24-bit discrete address transmitted in the Mode S squitter is the Mode S address that has been assigned to this aircraft. (See Advisory Circular 20-131A for information regarding Mode S address assignment.)

3.3.12 Received Reply

Interrogate the equipment with its discrete address and verify received reply.

3.3.13 Airspeed Fixed Field

Interrogate the equipment to confirm the maximum airspeed report.

3.3.14 On-the-Ground Condition

Verify that the equipment correctly reports the "on-the-ground" condition. If it is feasible to simulate the airborne condition, verify that the equipment correctly reports an "airborne" condition.

Also verify that when the unit is in the "inhibit replies" condition (see §**Error! Reference source not found.**.b), the transponder continues to generated Mode S squitters and replies to discretely-addressed Mode S interrogations (UF=0, 4, 5, 16, 20, 21, 24), but does not reply to ATCRBS, ATCRBS/Mode S All-Call or Mode S-Only All-Call interrogations.

If the unit is not in the "inhibit replies" condition verify that the transponder continues to generate Mode S squitters and to reply to ATCRBS, ATCRBS/Mode S All-C all or Mode S-Only All-Call and discretely-addressed Mode S interrogations (UF=0, 4, 5, 16, 20, 21, 24).

3.3.15 Diversity Antenna Installations

Verify that the antennas on the aircraft are no more than 7.6 meter (25 feet) apart in the horizontal plane. The cables **shall** be essentially of equal electrical length.

3.4 Flight Test Procedures

The following test procedures provide one means of determining installed equipment performance. Although specific test procedures are cited, it is recognized that other methods may be preferred by the installing activity. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures. The equipment shall be tested to determine compliance with the minimum requirements stated in §2.2. In order to meet this requirement, test results supplied by the equipment manufacturer or other proof of conformity may be accepted in lieu of bench tests performed by the installing activity.

This guidance material offers examples of flight test procedures for demonstration of selected performance functions. Flight demonstration of installed performance may be required by the aircraft operator or by airworthiness inspection agencies.

A schedule must be arranged with the area air traffic control facility so that a controller is available to observe the transponder reply and communicate with the test aircraft to confirm performance of the transponder.

Select a test area such that line-of-sight signal propagation is assured. Test maneuvers may include standard rate turns through 360 degrees, climbs and descents so that ATC can confirm valid return through normal flight attitudes. Verification of Ident codes selected and reported altitude response to Mode C should be checked.

3.4.1 Ground Pre-Flight Tests

Originally from DO-144 §2.3.2.2.1:

The following transponder characteristic should be determined and the performance level noted:

(1) Random triggering of the transponder should not exceed 30 replies per second as integrated over an interval equivalent to at least 300 random triggers, or 30 seconds, whichever is less. This should be determined with all possible interfering equipments operating in their normal manner on operational channels of maximum interference, but with the absence of bona fide transponder interrogations. This test can be performed by using an RF detector sufficiently coupled to the antenna to count the rate of non-interrogated replies.

(2) Receiver/Transmitter system characteristics should be assured by determining the attenuation constant of the installed coaxial transmission line and the characteristics of the antenna. Measure the length of transmission line and refer to suitable handbooks regarding the type of coaxial cable or the transponder manufacturer's equipment manual to determine the amount, of attenuation in decibels. Inspect the antenna system and carefully observe that the antenna is installed in accordance with the manufacturer's recommendations, and that there are no protrusions from the aircraft which will affect the efficiency of the antenna. The following examples are given to empirically determine the system compliance:

EXAMPLE #1:

Effective radiated power =ERP

$ERP = P_T - L + G_A$

Where: P_T = Power in dbw at the antenna terminal of the

		transponder. (Refer to §2.3.2.1.14)
L	=	Transmission Line Loss
G_A	=	Antenna gain above isotropic

Assume the following:

a) The measured transmitter power at the transponder antenna terminal is 100 watts (+20 dbw). The measured receiver sensitivity is -71 dbm.

b) 10 feet of RG-8/U = 0.9 db.

c) Antenna gain is unity with respect to isotropic which results in 0 db.

Then:

Transmitted ERP = 20 – 0.9 + 0
= 19.1 dbw

Effective Receiver Sensitivity = -71 + 0.9 – 0
= -70.1 dbm

This example would allow the system to operate in aircraft for altitudes not exceeding 15,000 feet.

EXAMPLE #2:

Assume the following:

a) The measured transmitter power at the trans- ponder terminal is 29 dbw.

b) 33 feet of RG-8/U = 3 db

c) Antenna gain is unity with respect to isotropic which results in 0 db.

Then:

Transmitter ERP = 29 – 3 + 0
= 26 dbw

Effective Receiver Sensitivity = -74 + 3 – 0
= -71 dbm

This example would allow the system to operate in aircraft intended to operate at all altitudes.

(3) Automatic altitude reporting performance should be checked as follows with aircraft on the ground:

(a) Set the altimeter normally used to maintain flight altitude to 29.92 inches of mercury (1013.2 millibars).

(b) Select 10 or more evenly-spaced altitude test points between zero (sea level) and the maximum operating altitude of the aircraft. Test each of these test points for increasing altitude and for decreasing altitude.

(c) Apply pressure to the static system. If separate static systems serve altimeter and digitizer, apply identical pressures simultaneously to each. Approach each test point slowly, decreasing pressure for increasing altitude, and vice versa, until a transition to the test point value occurs in the digital output. Record the pilot's altimeter reading at the instant of transition in the digitizer.

(d) The installation is acceptable if the altimeter normally used to maintain flight altitude corresponds with the output of the digitizer within 125 feet at each test point and within ±62 feet at not less than 70 percent of the test points.

3.4.2 Operational Flight Tests

Originally from DO-144 §2.3.2.2.2:

(1) Perform the flight test using an ATC facility and procedures. The flight should be conducted from the airport to approximately 25 miles from the ground facility. Put the aircraft through those maneuvers normally associated with take-off, climb, holding procedures, descent and final approach. Determine in the course of these maneuvers that the transponder performs its intended function and is suitable for use in the ATC system.

(2) If the system includes altitude reporting and while performing (1) above, request ATC to monitor the altitude being reported by the transponder and compare with the altimeter being used to maintain flight altitude.

(3) Request ATC to verify proper performance while operating on several different codes. Do not use codes 7700 or 7600, unless requested by ATC.

Note: *It should be recognized that some aircraft attitudes with respect to the ground station will cause momentary loss of contact.*

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4 EQUIPMENT OPERATIONAL PERFORMANCE CHARACTERISTICS

4.1 Required Operational Performance Requirements

To ensure the operator that operations can be conducted safely and reliably in the expected operational environment, there are specific minimum acceptable performance requirements that shall be met. The following paragraphs identify these requirements.

4.1.1 Power Inputs

Prior to flight, verify that the equipment is receiving primary input power necessary for proper conditions.

4.1.2 Equipment Operating Modes

The equipment shall operate in each of its operating modes.

4.1.3 Continue with Other Operational Requirements as Necessary

4.2 Test Procedures for Operational Performance Requirements

Operation equipment tests may be conducted as part of normal pre-flight tests. For those tests that can only be run in flight, procedures should be developed to perform these tests as early during the flight as possible to verify that the equipment is performing its intended function(s).

4.2.1 Power Input

With the aircraft's electrical power generating system operating, energize the equipment and verify that electrical power is available to the equipment.

4.2.2 Equipment Operating Modes

Verify that the equipment performs its intended function(s) for each of the operating modes available to the operator.

4.2.3 Continue with Other Test Procedures

Continue with other test procedures to verify the requirements of paragraph 4.1.

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Membership

RTCA Special Committee 209
Minimum Operational Performance Standards
for
Airborne ATC Transponder Systems

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Appendix A
Basic Characteristics of the
ATC Radar Beacon System

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A Basic Characteristics of the ATC Radar Beacon System

This Appendix discusses

1. Pulse Shape and Spacing Definitions

   a. Pulse Amplitude

   The peak voltage amplitude of the pulse envelope.

   b. Pulse Duration

   The time interval between the 0.5 amplitude points on the leading and trailing edges of the pulse envelope.

   c. Pulse Interval

   The time interval between the 0.5 amplitude point on the leading edge of the first pulse and the 0.5 amplitude point on the leading edge of the second pulse.

   d. Pulse Rise Time

   The rise time as measured between the 0.1 amplitude and 0.9 amplitude on the leading edge of the pulse envelope.

   e. Pulse Decay Time

   The decay time as measured between the 0.9 amplitude and 0.1 amplitude on the trailing edge of the pulse envelope.

2. Interrogation and Control (Interrogation Side Lobe Suppression) Radio Frequencies Ground-to- Air)

   a. Center frequency of the interrogation and control transmissions **shall** be 1030 MHz. The frequency tolerance **shall** be ±0.2 MHz.

   b. Center frequency of the control transmission and each of the interrogation pulse transmissions **shall** not differ from each other by more than 0.2 MHz.

3. Interrogation Modes (Signals-in-Space)

   a. The interrogation **shall** consist of two transmitted pulses designated P_1 and P_3. A control pulse P_2 **shall** be transmitted following the first interrogation pulse P_1.

   b. The polarization of the interrogation and control transmission **shall** be predominantly vertical.

   c. The interrogation modes **shall** be as defined in subparagraph d, below.

d. The interval between P_1 and P_3 shall determine the mode of interrogation and shall be as follows:

Mode 3/A: 8 ±0.2 microseconds.

Mode C: 21 ±0.2 microseconds

e. The interval between P_1 and P_2 **shall** be 2 ±0.15 microseconds.

f. The duration of pulses P_1, P_2 and P_3 **shall** be 0.8 ±0.1 microsecond.

g. The rise time of pulses P_1, P_2, and P_3 **shall** be between 0.05 and 0.1 microsecond.

h. The decay time of pulses P_1, P_2 and P_3 **shall** be between 0.05 and 0.2 microsecond.

Note: *The intent of the lower limit of rise and decay times (0.05 microsecond) is to reduce sideband radiation. Equipment will meet this requirement if the sideband radiation is no greater than that which theoretically would be produced by a trapezoidal wave having the stated rise and decay times.*

4. Interrogation and Side Lobe Suppression Transmission Characteristics (Signals-in-Space)

a. The system relies on pulse amplitude comparison between pulses P_1 and P_2 in the transponder to prevent response to side lobe interrogation. The radiated amplitude of P_2 at the antenna of the transponder **shall** be (1) equal to or greater than the radiated amplitude of P_1 from the greatest side lobe transmission of the antenna radiating P_1 and, (2) at a level lower than 9 db below the radiated amplitude of P_1 within the desired arc of interrogation.

b. Within the desired arc of the directional interrogation (main lobe), the radiated amplitude of P_3 **shall** be within 1 db of the radiated amplitude of P_1.