



The European Organisation for Civil Aviation Equipment
L'Organisation Européenne pour l'Équipement de l'Aviation Civile

MINIMUM OPERATIONAL PERFORMANCE SPECIFICATION FOR LIGHT AVIATION SECONDARY SURVEILLANCE RADAR TRANSPONDERS

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ED-115

August 2002

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FOREWORD

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3. This document largely relates to ED-73A "MOPS for Secondary Surveillance Radar Mode S Transponders". This is expressed by many cross-references to ED-73A. ED-73A is therefore an essential reference document to this document.
4. This document refers to alticoder requirements as outlined in ED-26 (Minimum Performance Specification for Airborne Altitude Measurement and coding systems). ED-26 is therefore an essential reference document to this document.
5. The Minimum Operational Performance Specification is recommendations only. EUROCAE is not an official body of the European Governments. Therefore its recommendations are valid as statements of official policy only when adopted by a particular government or conference of governments.
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CHAPTER 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

This Minimum Operational Performance Specification (MOPS) is designed to ensure that Light Aviation Secondary Surveillance Radar (SSR) Transponder equipments (LAST) in compliance with the MOPS, will be compatible with ICAO Annex 10, Volume IV, as to Amendment 77.

NOTE 1: *This MOPS also includes requirements and tests for a dedicated LAST power source (e.g. battery), a dedicated alticoder and antenna subsystem which may also be part of the LAST.*

NOTE 2: *A National Civil Aviation Authority may approve the use of a low RF power LAST for operation in its own country ensuring that reliable performance of collision avoidance and ground systems can be demonstrated. This LAST would not be ICAO compliant. With the exception of the lower transmitter power and adapted receiver sensitivity (see paragraph 1.4.2.4 and paragraph 3.2), it shall otherwise be in general accordance with this MOPS. In order to prevent the use of the equipment for flights in the airspace of other states, it should be clearly labelled as nationally approved only.*

This Minimum Operational Performance Specification does not include detailed descriptions of Mode S coding formats, protocols and interfaces; these can be found in ICAO Annex 10, Volume IV.

Chapter 1 provides information necessary to understand the need for the equipment requirements and tests defined in the remaining chapters. It describes typical equipment applications and operational objectives and is the basis for the performance criteria stated in Chapter 2 to Chapter 4. Definitions essential to proper understanding of this document are also provided in Chapter 1.

Chapter 2 contains general design specifications.

Chapter 3 contains the minimum performance specification for the equipment, defining performance under standard operating conditions.

Chapter 4 specifies the environmental test conditions 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 operations.

Chapter 5 details recommended test procedures for demonstrating compliance with Chapters 3 and 4.

Chapter 6 specifies the performance requirements of the installed equipment. It also includes ground and flight tests of the installed equipment that may be required when performance cannot be adequately determined through testing under standard test conditions.

1.2 APPLICABILITY

This MOPS is intended for transponders to be used on aircraft operating below 15,000 feet with a maximum cruising speed of 175 kts and MTOW not greater than 5700kg.

Examples of such vehicles are listed below in accordance to ICAO Doc 8643:

- a. Hang-gliders and other equipment for airports, with or without engine (unless mentioned below)
- b. Microlight aircraft (ULAC, UHEL, GYRO)
- c. Gliders and powered gliders (GLID) (Note: For the purpose of this document this also includes touring motor gliders)
- d. Air-balloons (BALL) with an envelope, which does not unduly affect the spherical radiation pattern of a single antenna
- e. Small airships (SHIP) with an envelope, which does not unduly affect the spherical radiation pattern of a single antenna
- f. Homebuilt, vintage and historic aircraft
- g. Other small aircraft (L, S, A, H, G, T, 1, P)
- h. Unmanned air vehicles (UAV)

NOTE: *The transponder capability and the mounting requirements of the transponder are dependent on the particular installation requirements, operational and airspace regulations of the region in which the aircraft are to be operated.*

Compliance with this minimum performance specification by manufacturers, installers and users is recommended as a means of ensuring that the equipment will satisfactorily perform its intended function(s) under all conditions encountered in normal aircraft operations.

Any regulatory application of this document in whole or in part is the sole responsibility of appropriate government agencies (Note should be taken of para 3.27 as well).

As the measured values of equipment performance characteristics may be a function of the method of measurement, standard test conditions and methods of test are recommended in this document. Alternative means of compliance may be agreed with the appropriate certification authorities.

1.3 DESCRIPTION OF THE SSR SYSTEM

SSR is a cooperative surveillance and communications system for Air Traffic Control (ATC) and Airborne Collision Avoidance System (ACAS). It employs ground- or air-based interrogators and airborne transponders.

1.3.1 Mode A/C SSR

Mode A/C SSR uses the aircraft transponder to respond to interrogations from the interrogators to provide:

- a. a 4 096-code identity code (Mode A), or,
- b. pressure altitude information, in 100 feet increments (Mode C).

The Mode A code is entered by aircrew via a control unit in the cockpit; Mode C pressure altitude information is derived from an encoding barometric altimeter or air data computer system.

The plan position of the aircraft, with respect to the ground interrogator, is determined from range and azimuth measurements made on the transponder replies.

1.3.2 Mode S SSR

Mode S SSR can accommodate ground-air-ground data link communications integrally with the surveillance interrogations and replies.

Mode S interrogators provide surveillance of Mode A/C-equipped aircraft as well as Mode S-equipped aircraft; Mode S transponders include Mode A/C functions and will reply to Mode A/C interrogators. In addition, the data link potential of Mode S permits use of the transponder for a number of Air Traffic Management (ATM) and Airborne Separation Assurance (ASA) functions (e.g. ACAS, TIS, FIS, etc.).

1.4 AIRCRAFT EQUIPMENT

1.4.1 General

The transponder is the principal component of the airborne equipment of Mode A/C and Mode S SSR. It performs all the necessary surveillance functions by providing the appropriate reply to Mode A/C and/or Mode S interrogations.

When used for data link transmissions, the Mode S transponder accepts the message as it arrives as part of an interrogation and passes it on to its destination. A message to be transmitted to the ground is accepted by the Mode S transponder at the interface and is incorporated in a reply made to an interrogation.

All Mode S transmissions, uplink as well as downlink, are protected by a 24-bit parity code. The transponder performs decoding and encoding as required, so that the surveillance function as well as the message content is protected.

The complexity of the transponder required for Light Aviation (SSR surveillance only), has been kept at the minimum needed for this function.

Some Mode S transponders may be equipped with uplink and downlink message interfaces providing interaction with input/output (I/O) devices. Some transponders may include such devices as an integral part of their design.

1.4.2 Classes, Capability and Applicability of Equipment

1.4.2.1 Transponder Functionality

ICAO documentation defines five 'levels' of transponder to indicate the Mode S protocols that the transponder is designed to support.

- a. Level 1
Surveillance only (No 112 bit Mode S format capabilities).
- b. Level 2
Surveillance and Comm A/B.
- c. Level 3
Surveillance, Comm A/B, and Uplink ELM.

- d. Level 4
Surveillance, Comm A/B, Uplink ELM and Downlink ELM.
- e. Level 5
Full level 4 plus enhanced protocols for parallel processing of Comm-B, Uplink ELM and Downlink ELM transactions.
- f. Extended squitter
Extended squitter transponders shall have a minimum capability of Level 2, and also those prescribed for extended squitter operation (see ED-73A para 3.21.2.6).
- g. SI Capability
Protocols for SI code operation (see ED-73A para 3.18.4.34).

A Mode S capable LAST shall as a minimum have the functionality of a Mode S transponder as specified in paragraphs 3.20, and 3.21 of this document (including SI code capability). There is no requirement to provide data interfaces to onboard devices, however for Level 2 and above Mode S transponders it may be of some advantage if such interfaces are provided, for example to allow the connection of a handheld computer to obtain data link services in future (e.g. weather data or Traffic Information Service TIS).

NOTE 1: *ADS-B and some ATC services (e.g. Flight Information Service and Traffic Information Service) can **not** be implemented when a Level 1 transponder is foreseen.*

NOTE 2: *A Level 1 transponder may not be acceptable to certain national authorities for use within their airspace.*

A Mode A/C only capable LAST shall have the capabilities as specified by paragraph 3.27.

1.4.2.2 Transponder Labelling

Each transponder shall be clearly labelled indicating its actual functional level and its variant according to 2.11.

For Mode A/C only capable LASTs the label consists of 'Lc0' followed by the installation variant as defined in 2.11.

For Mode S capable LASTs the label shall consist of 'LcX' where X is the level of the Mode S transponder, followed by "e" if Extended Squitter is supported and by "s" to indicate that SI codes are supported. All previous label constituents are then followed by the installation variant as defined in 2.11

NOTE 1: *For example a Mode A/C Transponder would be labelled 'Lc0 V2', a Mode S Level 2 transponder with extended squitter would be labelled 'Lc2 es V2'*

NOTE 2: *It is recognised that a LAST will normally have a small form factor so that the label may not fit in a visible place when the transponder is installed. It is therefore alternatively also permissible to display the transponder level on the display after power up.*

The label must be clearly visible when the transponder is mounted on the aircraft. In the case of a change of transponder level or capability the label must be changed appropriately.

1.4.2.3 Mutual Suppression

Mutual Suppression is not as a minimum required for LAST equipments as it is not expected that they are used in a multi equipment environment. However, it may still be useful to include mutual suppression for installations where it is required.

1.4.2.4 Equipment Class

The LAST should as a minimum be compatible with CLASS 2

The specified performance for CLASS 2 is as follows:

CLASS 2 equipment may be used in aircraft that operate at altitudes not exceeding 15 000 ft, and have a maximum cruising true airspeed not exceeding 175 kt (324 km/h), and shall meet the following requirements:

- a. RF peak output power > 18.5 dBW (see paragraph 3.3)
- b. Reply transmission frequency tolerance ± 3 MHz for Mode A/C, and ± 1 MHz for Mode S (see paragraph 3.3)
- c. Mode A and C reply rate capability > 1000 replies/second (see paragraph 3.4)

1.4.2.5 Antenna Diversity

Antenna diversity is not required for the LAST as a minimum.

1.4.2.6 Altitude Quantisation

LASTs are expected to contain either an integral or external altitude encoder according to ICAO Annex 10, Volume IV (paragraph 3.1.1.7.12.2.4).

1.4.2.7 ACAS

Local onboard ACAS related features are not required for LASTs.

NOTE: *Since an onboard ACAS would have a significant power consumption on its own right, it is not foreseen that it would be operated with a LAST.*

1.4.3 Composition of Equipment

- a. The word "equipment" as used in this document includes all components and units necessary for the system to properly perform its intended function(s). For example, the "equipment" may include a transponder, control panel, antenna(s), interconnecting cables and mounting provisions.
- b. In the case of this example, all of the foregoing components and units comprise the "equipment". It should not be inferred from this example that each SSR transponder equipment design will necessarily include all of the foregoing components or units. This will depend on the specific design chosen by the manufacturer.

1.5 DEFINITIONS, ABBREVIATIONS AND MEASUREMENT CONVENTIONS

1.5.1 Mandating and Recommendation Phrases

a. "Shall"

The use of the word SHALL indicates a mandated criterion; i.e. compliance with the particular procedure.

b. "Should"

The use of the word SHOULD (and phrases such as "IT IS RECOMMENDED THAT ...", etc.) indicate that though the procedure or criterion is regarded as the preferred option, alternative procedures, specifications or criteria may be applied, provided that the manufacturer, installer or tester can provide information or data to adequately support and justify the alternative.

1.5.2 Definitions

Algorithm - A set of well-defined rules for the solution of a problem in a finite number of steps.

Aircraft ID - The callsign by which the crew of an aircraft is called. It is provided in the flight plan or it is the registration mark of the aircraft

Burst - A series of interrogations.

Cancellation - This is a protocol used by the ADLP to cancel downlink messages that are queued in the transponder awaiting extraction by the Mode S ground system.

Closeout - This is a protocol that confirms to a transponder that Comm-B, Comm-C (ELM) or Comm-D (ELM) transactions have been successfully completed and must be cleared from the transponder.

Data Chip - A Space carrier wave interval in the Mode S uplink transmission signal related to the duration of one data bit.

Desensitisation - Temporary reduction of transponder sensitivity after receipt of a signal. Used to reduce echo (multipath) effects.

Diversity - A method of selecting the reply transmission path based on the relative amplitude of the received interrogation signal from two or more channels with independent antennas.

Downlink - A signal propagated from the transponder.

Dynamic Range - The ratio between the overload level and the minimum triggering level in a transponder.

Extended Squitter - The transmission of a specified reply format at a minimum rate without the need to be interrogated. The extended squitter contains more information than standard (acquisition) squitters.

Field - A group of bits in a message treated as a single unit of information.

Framing Pulse - One of the two pulses F_1 and F_2 spaced a nominal 20.3 μ s apart which bracket a reply to Mode A and Mode C interrogations.

Format - The specific order in which fields of information appear in a Mode S digital message transmission.

ICAO 24 bit address - The unique address by which each aircraft's Transponder can be selected.

Lockout - This is a protocol which provides a means of preventing a Mode S transponder from replying to 'All-Call' interrogations. See Annex 10 para 3.1.2.6.9 for full information.

Message - An arbitrary amount of information whose beginning and end are defined or implied.

Minimum Triggering Level (MTL) - The minimum input power level that results in a 90% reply ratio, if the interrogation signal has all nominal spacings and widths and if the replies are the correct replies assigned to the interrogation format.

Mode A/C - For the purpose of this document, Mode A/C is taken as referring to non-Mode S transactions. Where specific Mode A or Mode C transactions are involved, these are identified individually.

NOTE: *The US term for non-Mode S SSR is ATCRBS (Air Traffic Control Radar Beacon System). It is not used in this document.*

Mode S - Selective addressing Mode of the SSR system

Monopulse - A radar system using a receiving antenna having two or more partially overlapping lobes in the radiation pattern. Sum and difference channels in the receiver compare the amplitudes or phases of the received signal to interpolate azimuth measurement within the radar beam.

Multipath - The propagation phenomenon that results in signals reaching the receiving antenna by two or more paths, generally with a time or phase difference.

ONE(s) - The affirmative value(s) of a binary bit.

Protocol - A set of conventions between communicating processes on the formats and contents of messages to be exchanged.

Side Lobe Suppression (SLS) - A technique to prevent responses from transponders not in the main beam of the interrogating antenna.

Special Position Identification (SPI) - A special pulse used in Mode A/C replies located 4.35 μ s following the second framing pulse. When used with Mode S, SPI appears as a code in the flight status (FS) field.

Squitter - The transmission of a specified reply format at a minimum rate without the need to be interrogated.

Transaction - The process of accepting and processing an interrogation and generating a corresponding reply.

Uplink - Signal propagated toward a transponder.

ZERO(s) - The negative value(s) of a binary bit.

NOTE: *Definitions of Mode S coding formats, protocols and interfaces are contained in ICAO Annex 10.*

1.5.3 Abbreviations

1	Single Engine (Second Character of Aircraft Type Description)
A	Amphibian (First Character of Aircraft Type Description)
ACAS	Airborne Collision Avoidance System
AIS	Aircraft Identification Subfield
ASA	Airborne Separation Assurance
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATM	Air Traffic Management
BALL	Balloon
BITE	Built-in Test Equipment
CA	Capability
CC	Crosslink Capability
Comm-A	Short Uplink Communication Message
Comm-B	Short Downlink Communication Message
Comm-C	Long Uplink Communication Message
Comm-D	Long Downlink Communication Message
Comm-U	ACAS Air-Air 'Uplink' Communication Message
Comm-V	ACAS Air-Air 'Downlink' Communication Message
DC	Direct Current
DELM	Downlink Extended Length Messages
DF	Downlink Format
DPSK	Differential Phase Shift Keying
ELM	Extended Length Message
ESD	Electrostatic Discharge
EUT	Equipment Under Test
FIS	Flight Information Service
FS	Flight Status
G	Gyrocopter (First Character of Aircraft Type Description)
GICB	Ground Initiated Comm-B
GIRO	Micro-/Ultra-light Gyrocopter
GLID	Glider
H	Helicopter (First Character of Aircraft Type Description)
ICAO	International Civil Aviation Organization
ID	Identification (4096 code)
KE	Control ELM
L	Landplane (First Character of Aircraft Type Description)
LAST	Light Aviation SSR Transponder
Lc0	LAST capability of Mode A/C only

LcX	LAST capability of Mode S (including Mode A/C)
LSCW	Low Supply Capacity Warning
MA	Message Field In Comm-A
MB	Message Field In Comm-B
MC	Message Field in Comm-C
MD	Message Field in Comm-D
ME	Message Extended Squitter
MES	Multisite ELM Subfield
MOPS	Minimum Operational Performance Specification
MSB	Most Significant Bit
MTL	Minimum Triggering Level
MTOW	Maximum Take-Off Weight
MU	Message Field in Comm-U
MV	Message Field in Comm-V
N	Number of transitions at « 1 » in DPSK modulation
NC	Number of C segments
P	Piston Engine (Third Character of Aircraft Type Description)
PAM	Pulse Amplitude Modulation
PI	Priority/Interrogator Identity
PR	Probability of Reply
PRF	Pulse Repetition Frequency
RA	Resolution Advisory
RAI	Resolution Advisory Indicator
RAT	Resolution Advisory Terminated Indicator
RI	Reply Information
S	Seaplane (First Character of Aircraft Type Description)
SD	Special Designation
SHIP	Airship
SI	Surveillance Identifier
SL	Sensitivity Level
SLA	Sealed Lead Acid (Battery)
SLS	Side Lobe Suppression
T	Tilt-Wing Aircraft (First Character of Aircraft Type Description)
TAS	True Air Speed
TIS	Traffic Information Service
UELM	Uplink Extended Length Message
UAV	Unmanned Air Vehicle
UF	Uplink Format
UHEL	Micro-/Ultra-light Helicopter
ULAC	Micro-/Ultra-light Aircraft

VFR	Visual Flight Rule
VS	Vertical Status
VSWR	Voltage Standing Wave Ratio
w.r.t	with respect to

1.5.4 Measurement Conventions

The following measurement conventions apply to the signal and pulse characteristics defined in paragraph 1.6.

PULSE AMPLITUDE - Defined as the peak voltage amplitude of the pulse envelope.

PULSE DURATION - Measured between the half voltage points of the leading and trailing edges.

PULSE RISE TIME - Measured as the time interval between 10% and 90% of peak amplitude on the leading edge of the pulse.

PULSE DECAY TIME - Measured as the time interval between 90% and 10% of peak amplitude on the trailing edge of the pulse.

PULSE-TO-PULSE INTERVALS - Measured between the half voltage points of the leading edges of consecutive pulses.

PHASE REVERSAL LOCATION - Measured at the 90° point of the phase transition.

PHASE REVERSAL DURATION - Measured between the 10° and 170° points of the transition.

PHASE REVERSAL INTERVALS - Measured between 90° points of the transitions.

1.6 INTERROGATION SIGNALS

The following paragraphs describe the signal in space expected to appear at the transponder antenna. The signals in space comprise two types of interrogations distinguished by different modulation techniques: pulse amplitude modulation (PAM) and differential phase shift keying (DPSK).

1.6.1 Received PAM Signals

- a. The following interrogations are exclusively PAM signals.
 - Mode A,
 - Mode C,
 - Mode A/Mode S All-Call,
 - Mode C/Mode S All-Call,
 - Mode A-Only All-Call,
 - Mode C-Only All-Call.
- b. All of these interrogations use two or more of the four pulses described in paragraph 1.6.3. The pulses are designated P1, P2, P3 and P4.

1.6.2 Interrogation Carrier Frequency

Mode A/C interrogators:	1 030 MHz $\pm$ 0.1 MHz
Mode S interrogators:	1 030 MHz $\pm$ 0.01 MHz

The carrier frequencies of the control transmission and of each of the interrogation pulse transmissions shall not differ from each other by more than 0.2 MHz.

1.6.3 PAM Pulse Characteristics

a. Pulse Shapes

The pulse shapes for PAM interrogations are summarised in Table 1-1.

Pulse Designator	Pulse Duration	Duration Tolerance	Rise Time Min/Max	Decay Time Min/Max
P1,P2,P3,P5	0.8 μ s	$\pm$ 0.1 μ s	0.05/0.1 μ s	0.05/0.2 μ s
P4 (short)	0.8 μ s	$\pm$ 0.1 μ s	0.05/0.1 μ s	0.05/0.2 μ s
P4 (long)	1.6 μ s	$\pm$ 0.1 μ s	0.05/0.1 μ s	0.05/0.2 μ s

TABLE 1-1: PAM INTERROGATION PULSE SHAPES

b. Pulse Patterns (see Figure 1-1)

The pulse patterns of the PAM interrogations are defined in Table 1-2.

INTERROGATION TYPE	INTERVAL (μ s)			P4 TYPE
	P1-P2	P1-P3	P3-P4	
Mode A	2 $\pm$ 0.15	8 $\pm$ 0.2	-	None
Mode C	2 $\pm$ 0.15	21 $\pm$ 0.2	-	None
Mode A/Mode S All-Call	2 $\pm$ 0.15	8 $\pm$ 0.2	2 $\pm$ 0.05	Long
Mode C/Mode S All-Call	2 $\pm$ 0.15	21 $\pm$ 0.2	2 $\pm$ 0.05	Long
Mode A-Only All-Call	2 $\pm$ 0.15	8 $\pm$ 0.2	2 $\pm$ 0.05	Short
Mode C-Only All-Call	2 $\pm$ 0.15	21 $\pm$ 0.2	2 $\pm$ 0.05	Short

TABLE 1-2: PAM INTERROGATION PULSE PATTERNS

c. Relative Pulse Amplitudes

P3 amplitude is $P1 \pm 1$ dB

P4 amplitude is $P3 \pm 1$ dB