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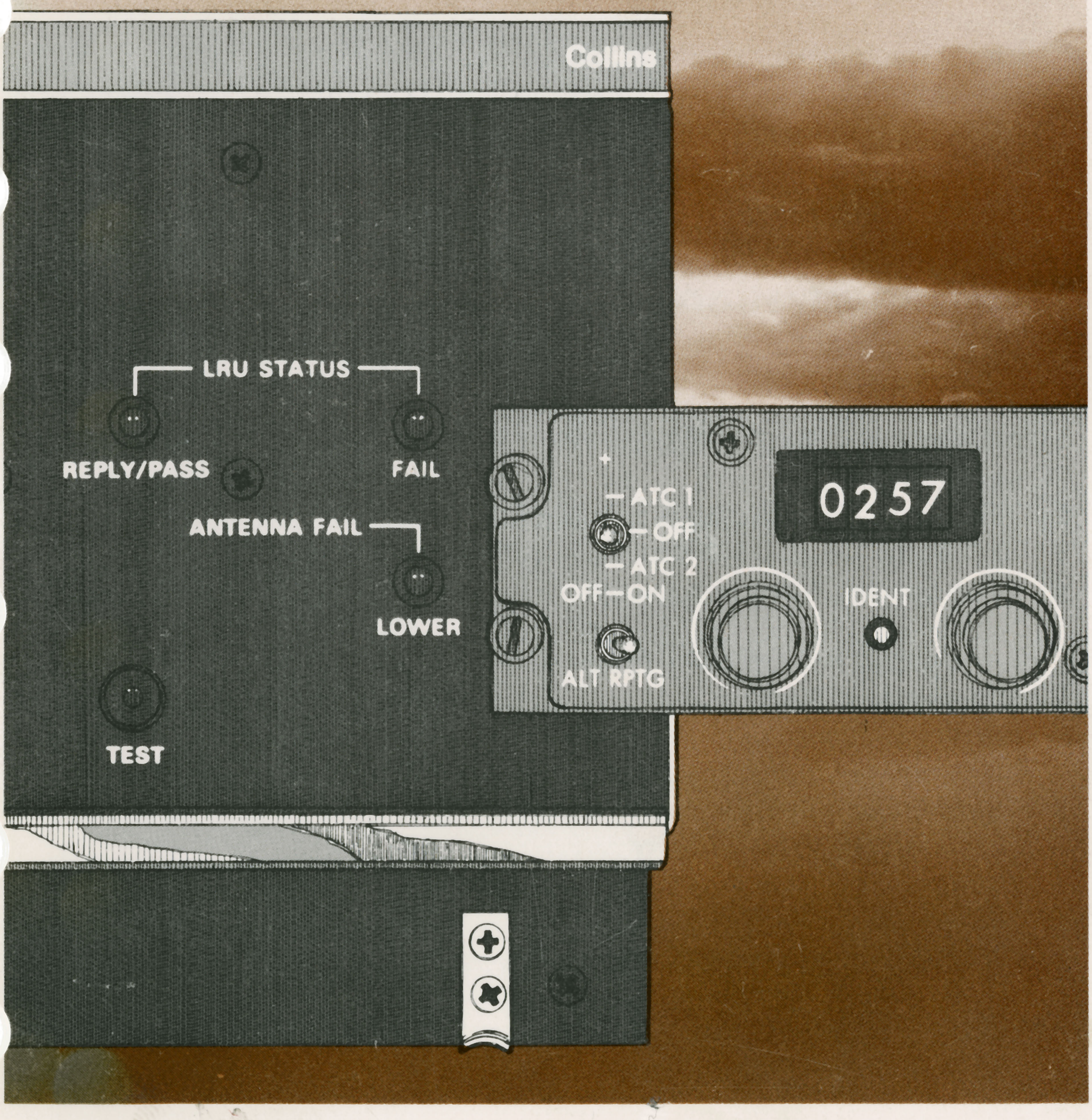
instruction guide

Collins Air Transport Division

What Is a Transponder?



Contents

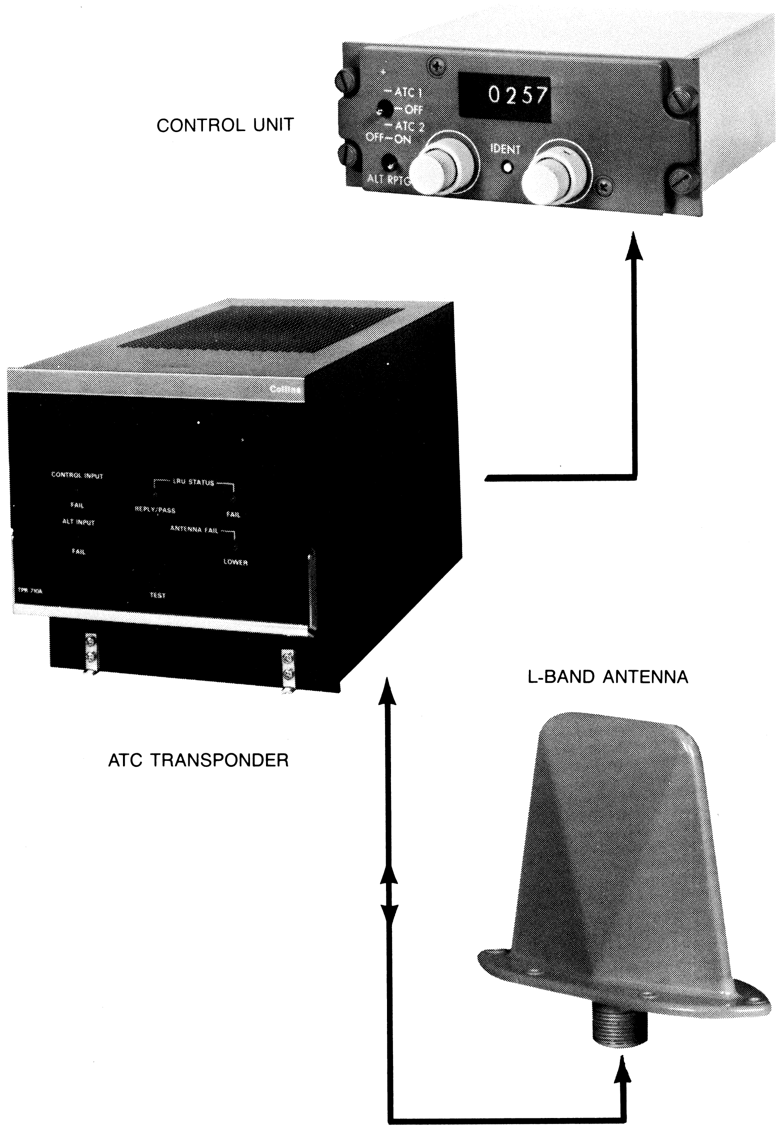
List of Illustrations

Glossary

ATC	Acronym for air traffic control.
DME	Acronym for distance measuring equipment. A system that provides distance information from a ground station to an aircraft.
Framing Pulse	A pulse that is used to mark the beginning or end of the coded reply pulses.
GCA	Acronym for ground-controlled approach. A system that uses a ground-based controller to control the approach of an aircraft by transmitting instructions to the pilot.
Ident	The action of the transponder transmitting an extra pulse along with its identification code (at the request of a controller).
IF (if)	Abbreviation for intermediate frequency. A frequency that a signal is shifted to as an intermediate step in transmission or reception of a signal.
L-Band	A radio-frequency band from 390 to 1550 MHz.
Mode A	The pulse format for an identification code interrogation.
Mode B	An optional mode for transponder interrogation.
Mode C	The pulse format for an altitude information interrogation.

Mode D	An unassigned, optional transponder mode.
MTI	Abbreviation for moving target indicator. This type of radar display will show only moving targets. The motion is measured relative to the radar antenna.
Nautical Mile	Equivalent to 6076.1 feet or approximately 1.15 statute miles. Abbreviated nmi.
PAR	Abbreviation for precision approach radar. An X-band radar which scans a limited area and is part of the ground-controlled approach system.
PPI	Abbreviation for planned position indicator. A type of radar display which shows aircraft positions and airways chart on the same display.
PSR	Abbreviation for primary surveillance radar. The part of the ATC system that determines the range and azimuth of an aircraft in a controlled airspace.
Radar	Acronym for radio detecting and ranging. A system that measures distance and bearing to an object.
Radar Mile	The time interval (approximately 12.359 microseconds) required for radio waves to travel 1 nautical mile and return (total of 2 nmi).
RF (rf)	Abbreviation for radio frequency. A general term for the range of frequencies above 150 kHz to the infrared region (10^{12} Hz).

SLS (sls)	Abbreviation for side-lobe suppression. A system that prevents a transponder from replying to the side-lobe interrogations of the SSR. Replying to side-lobe interrogations would supply false replies to the ATC ground station and obscure the aircraft location.
SPIP	Another designation for ident pulse.
Squawk	Reply to interrogation signal.
SSR	Acronym for secondary surveillance radar. A radar-type system that requires a transponder to transmit a reply signal.
Stage 1 Service	A radar traffic service that provides the pilot with traffic information and limited vectoring, on a workload-permitted basis.
Stage 2 Service	Same as stage 1 service except the sequencing of aircraft into the traffic pattern is added to the services.
Stage 3 Service	Stage 3 radar traffic service provides radar vectoring, sequencing of aircraft into the traffic pattern, and separation between participating VFR aircraft and all IFR aircraft operating within the controlled airspace.
Suppressor Pulse	A pulse used to disable avionics during the transmitting period of a piece of airborne equipment. It prevents the other avionics aboard the aircraft from being damaged or interfered with by the transmission and any noise associated with that transmission.



Airborne ATC Beacon Radar Equipment
Figure 1

Introduction

The airborne transponder is an important part of the air traffic control system being used today. The safety of passengers, aircraft, and crew depends on the ability of air traffic controllers to accurately identify and locate aircraft within the controlled airspace. This instruction guide presents the theory and principles of transponder operation and answers common questions about transponder operation.

What Is a Transponder?

A transponder is the airborne receiver-transmitter (rt) portion of the ATC Beacon Radar System that sends an identifying coded signal, in response to a transmitted interrogation from a ground-based radar station, in order to locate and identify the aircraft.

Why Use a Transponder?

Air traffic controllers use the coded identification replies of transponders to differentiate between the targets (aircraft) displayed on their radar screens. Being able to identify the aircraft aids the controller in maintaining aircraft separation, collision avoidance, and distinguishing types of aircraft.

The ATC Beacon Radar System

The ATC Beacon Radar System consists of airborne and ground-based equipment. The airborne equipment consists of a transponder (receiver-transmitter), a control unit, an antenna, and a digitizer. The airborne equipment is illustrated in figure 1. The ground based equipment is comprised of a primary radar system and a secondary surveillance radar (SSR) system. The primary radar system consists of an antenna, a receiver-transmitter (rt), and an indicator. The SSR system consists of an antenna, a receiver-transmitter, and the necessary interface and control equipment for the ground station.

Airborne Equipment

Transponder (Receiver-Transmitter)

The receiver portion of the transponder contains the necessary circuitry to receive, demodulate, amplify, and decode the interrogation signal. The transmitter section of the transponder is comprised of the circuits necessary to encode, modulate, amplify, and transmit the coded reply signal. The transponder also contains the circuitry required for checking the validity of the received interrogation signal and monitoring the integrity of the transponder.

Control Unit

The control unit contains the circuits and controls necessary to select the identifying code. It also contains the controls necessary for selecting an altitude source, initiating a self-test condition, and selecting the transponder reply mode. Indicators on the front panel of the control will also display a system fault and the code selected.

Digitizer

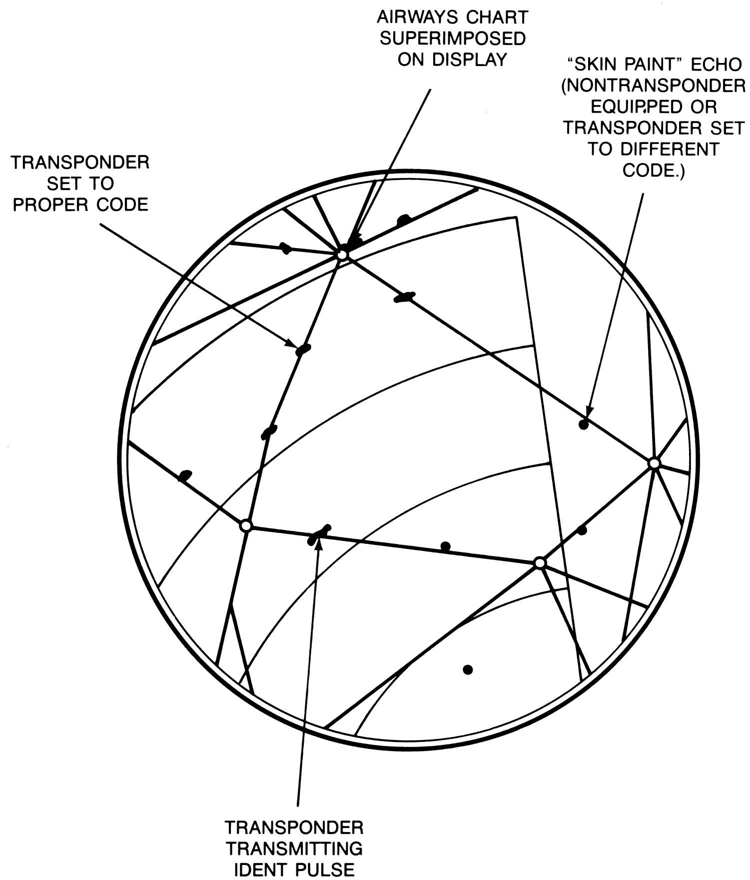
The digitizer is a simple converter that converts an analog signal, representing barometric altitude, to a digital format. The digitized barometric altitude can then be encoded and shipped as part of the reply signal. The digitizer circuit could also be part of the rt in some ATC Beacon Radar Systems.

Antenna

The antenna is an L-band, monopole blade-type antenna. The antenna is usually mounted in an area of the aircraft that will not be shielded from interrogation. This prevents the aircraft's identification from disappearing from the controller's radar screen.

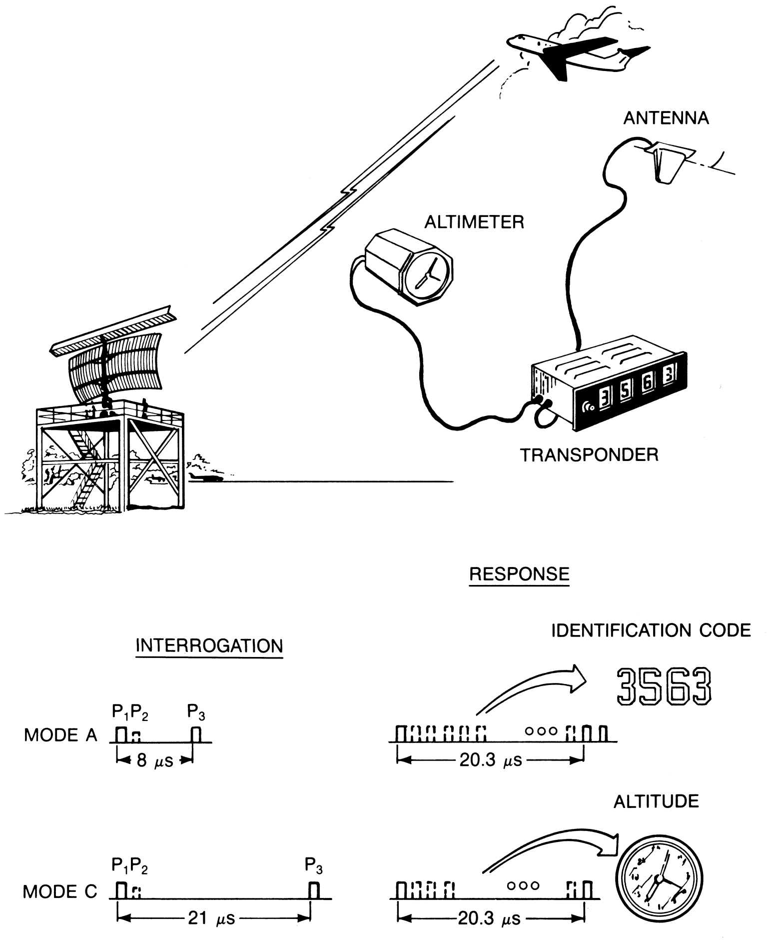
Ground Facilities

The ground facilities consist of a primary radar system and the secondary surveillance radar system. The primary radar system works like other radar systems. A narrow rf type beam, transmitted through a rotating antenna, is reflected by any targets in its path and returned to the antenna. By calculating the elapsed time between transmission and reception of the rf beam, the distance to target is determined. The angle of the antenna is also noted so that the bearing of the target can be determined. This information is displayed on a 2-dimensional radar screen. Refer to figure 2.



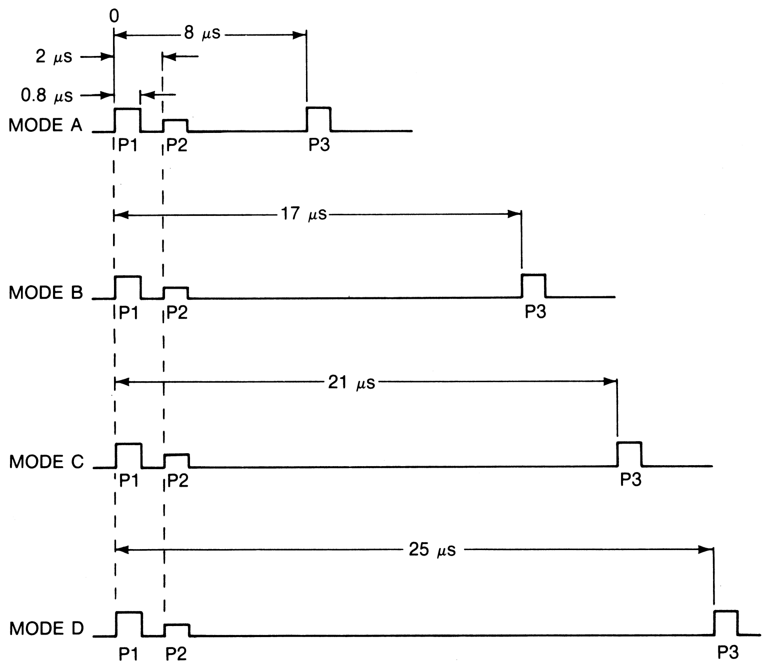
ATC Radarscope Display
Figure 2

The problem with this type of display is that it does not separate aircraft by altitude. To get this type of information to the air traffic controller, the secondary surveillance radar (SSR) system was developed. The SSR system uses an antenna that is mounted directly to the primary radar antenna and pointed in the same direction or synchronized with the same rotation as the primary radar.



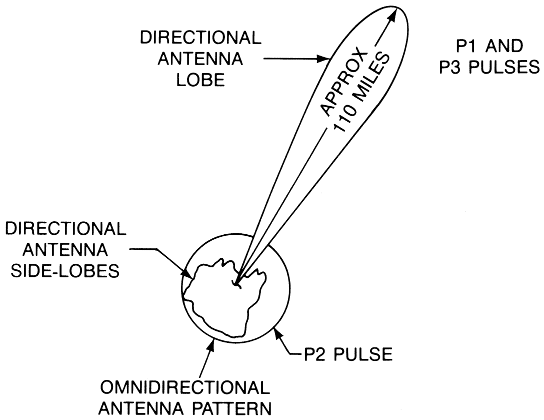
ATC Radar Beacon System
Figure 3

The secondary surveillance radar (SSR) system interrogates the aircraft about its identity and altitude by transmitting two sets of pulses. The first set of pulses is called Mode A and the second set is called Mode C. The Mode A pulses are spaced 8 microseconds apart and interrogate the transponder about the identity of the aircraft. The Mode C pulses are 21 microseconds apart and interrogate the transponder about the altitude of the aircraft. The pulses in both modes are identical except for the spacing of the pulses. There are two other modes (Mode B and Mode D) which are optional modes for transmitting the identification and altitude information. Refer to figure 4. The ground station assumes that the reply signal it receives after an interrogation is in response to that interrogation. The interrogation set of pulses consists of three pulses. The rotating directional antenna radiates two pulses, designated P1 and P3. The P1 and P3 pulses are spaced according to the SSR mode of operation. A pulse designated P2 is radiated by an omnidirectional antenna 2 μs after the P1 pulse from the directional antenna. The P2 pulse is a reference pulse for side-lobe suppression (sls) with an amplitude the same as that of the maximum side-lobe



Pulse Spacing for Interrogation Signals
Figure 4

pulse from the directional antenna. All pulses are 0.8 μs wide. Figure 5 illustrates the propagation pattern from the SSR. The transmitted interrogations from the ground station are at a frequency of 1030 MHz. The received reply signals are at a frequency of 1090 MHz.



Propagation Pattern for 3-Pulse Interrogation Signal
Figure 5

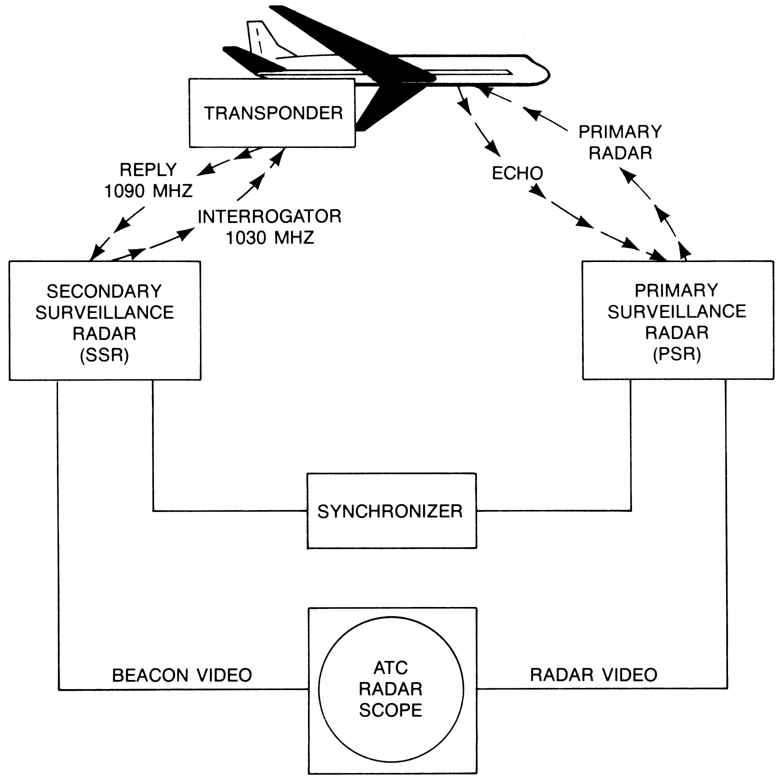
The received signal from the airborne transponder is electronically encoded so it can be displayed on a controller's radar screen. The type of radar screen used is called a planned position indicator (PPI). The images presented on a PPI remain on the screen till the next sweep of the screen. In this way the controller does not have to remember where the aircraft is between sweeps. The replies processed by the SSR system will produce either a single or double slash for the target. The number of slashes depends on what the controller has selected. The ground controller selects which identification codes will be displayed on the PPI. If the controller is not interested in a particular aircraft, the identification code of that reply signal will be ignored. In some cases the controller may be able to display only those aircraft returning a transponder signal, instead of all primary radar targets.

The code is selected by flight personnel and, in case of emergencies, there are codes that can identify the aircraft as being in an emergency situation.

An emergency identification code (7700 or 7777) causes the slashes to appear wider and brighter in addition to initiating an aural warning to the controller. Code 7600 is selected when the aircraft's vhf transceiver is not operational.

Typical Operation

1. The pilot selects an identification code or is instructed to select a certain identification code from the air traffic controller.
2. The SSR system transmits a coded interrogation signal (at 1030 MHz) as the primary radar system detects the aircraft.
3. The interrogation signal is received, detected, and decoded by the airborne transponder.
4. The transponder then encodes and transmits a set of reply signals (depending upon mode and code selected).
5. The reply signal is then received, decoded, and displayed at the ATC ground station.



Primary and Secondary Surveillance Radar System, Block Diagram
Figure 6

Principles of Transponder Operation

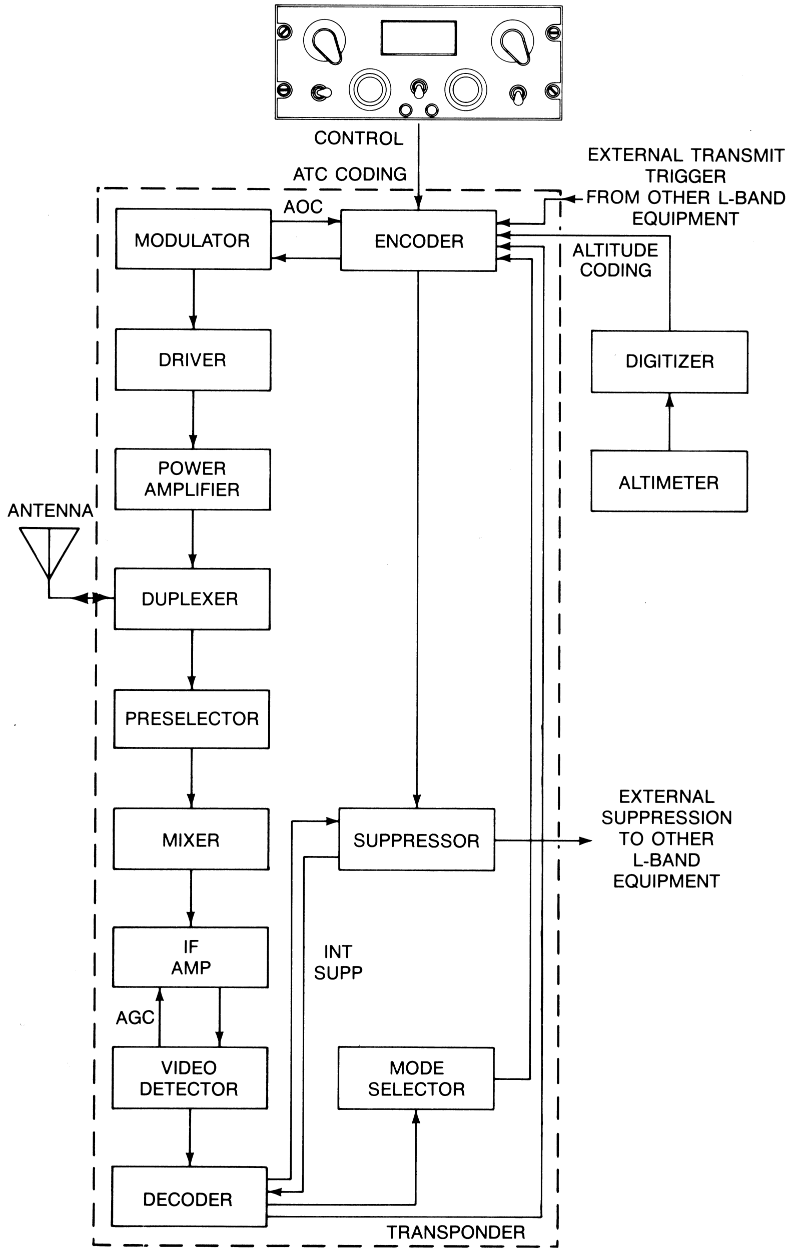
How a Transponder Identifies an Aircraft

A transponder identifies an aircraft by producing a unique coded reply in response to a group of transmitted pulses (interrogation) from a ground station. The transmitted pulses from the ground station are radiated from a directional SSR antenna mounted with the primary radar antenna. The transponder is interrogated every time the radar scans the airspace it occupies.

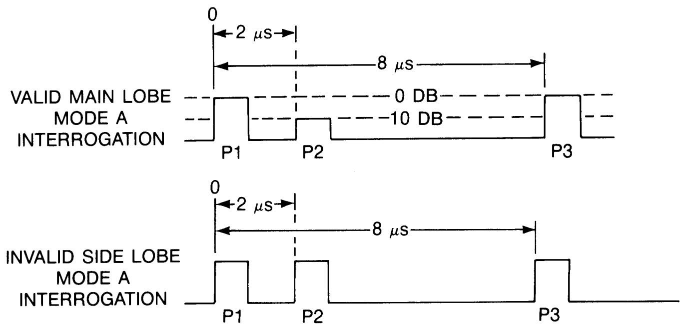
The transponder receives, detects, and decodes these pulses. Depending on the spacing of the pulses, a set of pulses is initiated encoding the selected identification code and/or the barometric altitude of the aircraft. These reply pulses are then transmitted back to the SSR antenna, where they are decoded and applied to the PPI as part of the video signal. The plane is then located by range, identifying code, and altitude (if the aircraft is equipped to reply to a Mode C interrogation).

How a Transponder Works

Refer to figure 7. The transponder receives the interrogation pulses at a frequency of 1030 MHz. The signals are then passed through a duplexer, a device that switches the antenna from receive to transmit at the proper time. From the duplexer, the received signal is sent to a preselector that amplifies and filters the 1030-MHz signal. The filtered 1030-MHz signal is mixed to produce an electrically manageable signal that is amplified and applied to the detector. The detector checks the validity of the pulses and separates them from the carrier frequency. To prevent an invalid interrogation by the side lobes of the SSR, a side-lobe suppression (sls) system is incorporated in the transponder. Refer to figure 8. The detector checks for the pulse amplitude and spacing before it is applied to the decoder as a valid interrogation. The valid interrogation signal generates an internal suppression pulse which brackets the transmission pulses. If the interrogation pulses are determined to be invalid, the decoder circuits are disabled and the transponder will not reply.



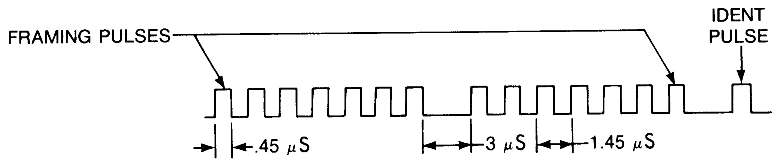
Transponder Block Diagram
Figure 7



Interrogation Signal Validity
Figure 8

The pulses are then shipped to a pulse decoder. The pulse decoder measures the amount of time between pulses and determines whether the pulses are Mode A, Mode B, or Mode D. The decoder then applies a trigger signal to the encoder and the mode selector. The valid interrogation signal also generates a suppression pulse to be applied to other L-band equipment when the transponder is transmitting. Suppressor pulses protect the receiver portions of the L-band equipment aboard the aircraft by temporarily preventing the equipment from receiving during the brief transmission period of the transponder.

The mode selector chooses what group of reply pulses will be sent. If a Mode A is selected, only the identification will be transmitted. If a Mode C is selected, the identification and the altitude information are both encoded. The pulses shown in figure 9 are for an identification code of 7777. The "ident" pulse, or SPIP, is transmitted when the ident button is pressed on the control. This causes the slashes (representing the aircraft) to enlarge, so it can easily be distinguished from the other returns. This is the maximum number of pulses that would be transmitted.



Transponder Reply Pulses
Figure 9

After encoding the identification code and the altitude information, the reply pulses are sent to the modulator to be added to the carrier signal. A feedback signal from the modulator, called the automatic overload control voltage, is sent back to the encoder to prevent the transmitter from being triggered by more than 2000 interrogation signals/second. The carrier signal is multiplied up to the transmit frequency of 1090 MHz and applied to a power amplifier before transmission.

The duplexer switches the antenna from the receiving mode to the transmit mode and the reply signal is sent back to the SSR system. The reply signal is sent two microseconds after the initial interrogation pulse is received. The ground radar system then decodes the received pulses and displays the information on the controller's radar screen.

The transponder also contains monitoring circuits that check for unit reliability and protect against over-interrogation. The transponder will respond to only 2000 interrogations/second. Most radar stations interrogate at 400 interrogations/second. If there are more interrogations, the transponder limits its sensitivity to respond to the strongest 2000 interrogations.

Troubleshooting

The basic idea of troubleshooting avionics equipment is to isolate the trouble to a single component or circuit that can be replaced or repaired. Two methods are commonly used to accomplish this.

One method is to start at the antenna or input and check components along the signal path until the faulty one is found. The other method is to troubleshoot the equipment in sections and work by halves. This is done by locating the trouble in one half of the unit or the other half, then dividing the troubled half in half to isolate the trouble even further.

This second technique is especially useful for avionics equipment. The typical avionics unit can usually be divided into two or three sections: receiver, computation, and/or transmitter.

The transmitter of a transponder can usually be checked by noting whether the reply lamp on the control lights. This indicates that the transmitter has transmitted a signal. To test the other two sections, most transponders have a self-test capability for checking the receiver and pulse decode/encode section.

The interrogation rate might affect the transponder's performance. At higher interrogation rates, the transponder could start to reply randomly instead of to each interrogation. Transponders that are used in areas where there are a number of SSR systems should be checked at several interrogation rates.

When complaints are received about transponder operation, the details of the problem should be noted. For example, if a transponder is not responding properly, does this happen on all the codes or just a particular code? This information would pinpoint a problem to either the code selector or the control. Intermittent reception of replies by the ground station could be the result of improper pulse spacing or shape, which the ground station would reject.

The antenna installation may also cause poor reception in some directions but not others. The installation of the antenna should be checked to ensure that the antenna pattern is not interfered with.

A problem that occurs in avionics equipment using high voltages, such as a transponder, is that at high altitudes it is easier for sparks to jump across terminals. After repairing a transponder, precautions should be taken to ensure that sharp points and other possible sparking points are eliminated. Postcoating of circuits after repair is another way of preventing sparking at higher altitudes.

While these troubleshooting hints do not cover all possible problems, they do indicate information and troubleshooting clues to look for. More specific troubleshooting aids are discussed in the overhaul manual of each particular piece of equipment.

Questions and Answers

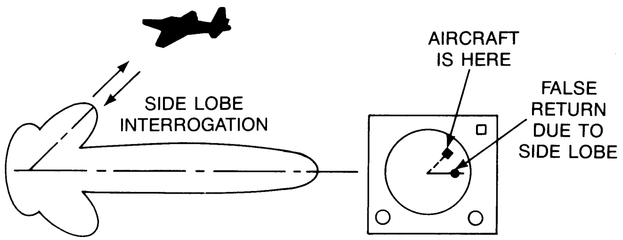
This section is intended to answer commonly asked questions about transponder operation and transponder principles.

Q. What is the operating range of a transponder?

A. The operating range of the transponder depends upon line-of-sight distance between aircraft and station and the transmitter section of the transponder. The minimum power output is approximately 125 watts. In this case, the operating range is about 100 nautical miles. Line-of-sight range is 100 nautical miles at 10 000 feet. Most transponders, though, operate as far out as 200 nautical miles (at an altitude of 30 000 feet).

Q. What is a LO-SENS?

A. A LO-SENS is an operating mode of the transponder. In the LO-SENS mode, the receiver section sensitivity is decreased so that only a strong signal will interrogate the transponder. The air traffic controller usually requests that the pilot switch his transponder to LO-SENS when the aircraft is close to a ground station and the transponder is responding to side-lobe interrogations. This is in addition to the sls circuits already incorporated in the transponder. Refer to figure 10. LO-SENS is also requested when the ground station radar may be overworked by the return of too many aircraft in high-traffic areas.



Side-Lobe Interrogations
Figure 10

Q. What specifications must a transponder meet?

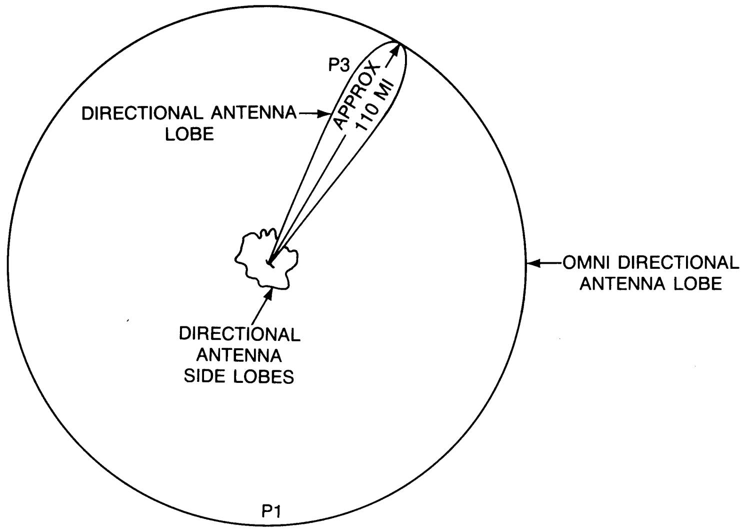
A. Transponder specifications are governed by RTCA documents DO-138, DO-160, and ARINC specifications 572 and 730. These documents define the operating parameters and environment of an airborne transponder system.

Q. What is the difference between primary and secondary radar?

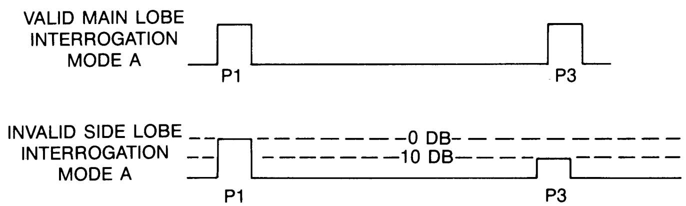
A. The difference between primary and secondary radar is the return signal. The return signal is reflected from the target for primary radar, while in secondary radar the incident signal triggers a response from a transponder.

Q. What is the 2-pulse interrogation system?

A. The 2-pulse interrogation system is another method of propagating the interrogation signals. Refer to figure 11. The pulse-pair interrogations from the SSR are a composite of both the rotating directional and fixed omnidirectional antenna radiations. There is no P2 pulse, as there is in the 3-pulse system. The first pulse, P1, is transmitted by the omnidirectional antenna. The last pulse, P3, is transmitted by the directional rotating antenna and is used in amplitude comparison with P1 to determine whether or not the interrogation is valid. Figure 12 illustrates a valid and invalid interrogation signal for a 2-pulse system.



Propagation of Interrogation Signal (2-Pulse System)
Figure 11



Interrogation Signal Validity (2-Pulse System)
Figure 12

This instruction guide has been prepared to provide a basic understanding of transponder systems. We welcome your comments concerning the contents of this instruction guide. Although every effort has been made to keep it free from errors, some may occur. When reporting a specific problem, describe it briefly and include the instruction guide part number (523-0773764), the figure number, and the page number.

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