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Air-to-Air Mode S Surveillance Algorithms

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16. Abstract

Lincoln Laboratory is assisting the Federal Aviation Administration in developing a beacon-based airborne collision avoidance system known as the Traffic Alert and Collision Avoidance System (TCAS). The version of TCAS intended for air carrier use is called TCAS II. It provides traffic and resolution advisories and operates in the highest traffic densities predicted for the end of the century.

TCAS II extends and replaces an earlier system known as BCAS (for Beacon Collision Avoidance System). Mode S surveillance algorithms developed for BCAS are described in this report. These algorithms form the basis for TCAS algorithms now under development at Lincoln Laboratory.

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I. INTRODUCTION

Lincoln Laboratory is assisting the Federal Aviation Administration in the development of a beacon-based airborne collision avoidance system known as the Traffic Alert and Collision Avoidance System (TCAS). The version of TCAS intended for air carrier use is called TCAS II. It provides traffic and resolution advisories and operates in the highest traffic densities predicted for the end of the century.

TCAS II extends and replaces an earlier system knows as BCAS (for Beacon Collision Avoidance System). While designed to operate in a much lower traffic density, the Mode S surveillance algorithms developed for BCAS form the basis for the TCAS algorithms under development.

The purpose of this report is to give a detailed description of the Mode S surveillance processing algorithms that served as a point of departure for TCAS II.

II. MODE S SURVEILLANCE OVERVIEW

1. Objectives

The Mode S surveillance processing algorithms described herein examine the relative position of each replying aircraft and, for efficiency, track only those aircraft found to be potential threats. The surveillance processor regularly reports each aircraft's range, range rate and relative altitude to the threat detection logic. Provisions are also included for sampling the relative positions of aircraft that could not become threats in the near future. This is done in such a way that surveillance of the more immediate threats is not compromised. The algorithms are capable of operating in real-time with a wide range of aircraft densities and velocities. Validity-checking and intelligence are included to achieve high confidence that established tracks are real and that track data are continuous and accurate.

2. Surveillance Process

The surveillance process involves a series of steps in which each aircraft is assigned one of the states defined in Table 1. Briefly, the processing steps occur as follows: The presence of a Mode S aircraft is detected from its squitter transmission and it is placed in the squitter state. Once its presence has been validated, three actions are possible: (1) targets outside the maximum altitude zone (± 5000 ft) are retained in the squitter state; (2) targets within the maximum altitude zone (± 3000 ft) are placed in acquisition; (3) an altitude rate is calculated for aircraft in the ± 3000 to 5000 ft zone. If the time to coaltitude is 60 seconds or less, the aircraft state is changed to acquisition. In the acquisition state interrogations are scheduled to determine threat range. Using this range and the maximum capable head-on velocities of the two aircraft, a minimum closure time is calculated. If this time is less than or equal to 43 seconds, the target is placed in the roll-call state, and it is actively interrogated every second. Otherwise, the aircraft is placed in the dormant state for a calculated period of time. After release from the dormant state, the aircraft is returned to the squitter state. The range, range rate and relative altitude of all aircraft in the roll-call state are forwarded in "track reports" to the threat detection logic.

3. Processing Features

Validity checks are incorporated in the surveillance algorithms to prevent false addresses or false ranges from entering the track file. At least two transmissions having the same address must be detected before interrogations are scheduled to the aircraft. This requirement reduces the incidence of false addresses since an error in squitter transmission always results in a corrupted aircraft address. Validity of the range measurement of an aircraft is checked by requiring that two replies correlate in range before the aircraft ID is placed in roll-call. This action prevents a range based on a fruit reply from entering the track file.

TABLE 1 TRACK STATES

State	Aircraft Assigned To State If	Action Taken
1. Squitter State	A squitter has been received but the ID has not as yet been validated by receipt of a second squitter, or Aircraft ID is known but it does not qualify for dormancy, acquisition or roll-call states.	Aircraft is purged from surveillance processing if no squitters are received for 40 seconds after receipt of a squitter or transition into squitter state.
2. Acquisition State	Aircraft is close in altitude but its range is not yet known.	Aircraft interrogated to obtain range and determine a new state. If after six scans of interrogation no correlating replies are received target ID returned to squitter state.
3. Dormant State	Aircraft is not of immediate interest.	Aircraft made dormant for a fixed period of time during which it is not interrogated and any squitters from it are ignored.
4. Roll-Call State	Aircraft is a possible range and altitude threat.	Aircraft interrogated each scan.

Link reliability is enhanced by the use of reinterrogation in both the acquisition and roll-call states. This produces a substantially higher report reliability in areas where reply reliability is poor.

Interrogation rates and processing times are limited by: (1) scheduling interrogations only to aircraft that are near in altitude, (2) placing aircraft that do not represent a possible range threat into the dormant state for a calculated period of time, and (3) limiting the reinterrogations to aircraft in the acquisition or roll-call state through the use of interrogation control tables.

III. SURVEILLANCE SCAN PROCESSING TASKS

The surveillance update cycle is designated a "scan" and is of one-second duration. After ATCRBS scheduling and reply processing have been completed, surveillance processing operates on all Mode S aircraft whose IDs are known to the system and processes any squitters that are received during the scan. Upon completion of the scan, track reports for all aircraft with established roll-call status are passed to the CAS logic. A track is not considered established until ranging is successful in two separate scans, i.e., the range rate has been determined. The surveillance scan processing tasks are shown in Fig. 1.

Surveillance processing involves the use of various parameters, counters, flags and variables. These are defined in Figs. 2, 3 and 4. Figure 5 summarizes the track state transitions that are permitted to take place during a scan for target IDs previously known to surveillance processing. Figure 6 summarizes the action that takes place when a squitter is received. Figure 7 presents the track file information required by each track state.

A. Squitter Processing Upon Receipt of Squitter

Upon receipt of any unsolicited preamble detections and associated Mode S message bits, certain filtering should be applied to the message bits. This is done in order to reduce the number of garbled DABS messages as well as false Mode S messages caused by ATCRBS fruit that can enter surveillance processing. This filtering may be done in hardware or software and is described in detail in the Appendix.

The filtering consists in assuring that the 5-bit DF field in the data block is that of an altitude-reporting Mode S surveillance reply, and that no illegal altitude bits or bit combinations are present in the altitude field. Additional reduction in erroneous squitters can be achieved by applying an upper acceptance threshold to the number of low confidence bits associated with the 56 data bits in the message.

Flow charts for the squitter processing that follows this filtering appear in Figs. 8 and 9. Upon receipt of a squitter, squitter processing calculates the altitude difference and determines whether a track state has previously been established for this ID. If the ID exists in dormant, acquisition, or roll-call track state, the squitter is ignored. If it does not exist in any state, a track entry is made assigning a squitter track state to the ID along with altitude differences and time-of-arrival. The squitter drop counter, "counter c", is initialized at 40 and the acquisition failure counter, "counter j", is set to 0.

If the ID already exists in the squitter state, counter c is reinitialized at 40 and a determination made of the relative altitude zone with which the aircraft should be associated. If the aircraft's altitude is outside the maximum altitude zone (± 5000 feet), the track state remains squitter and the track data is updated with the new squitter time and altitude difference.

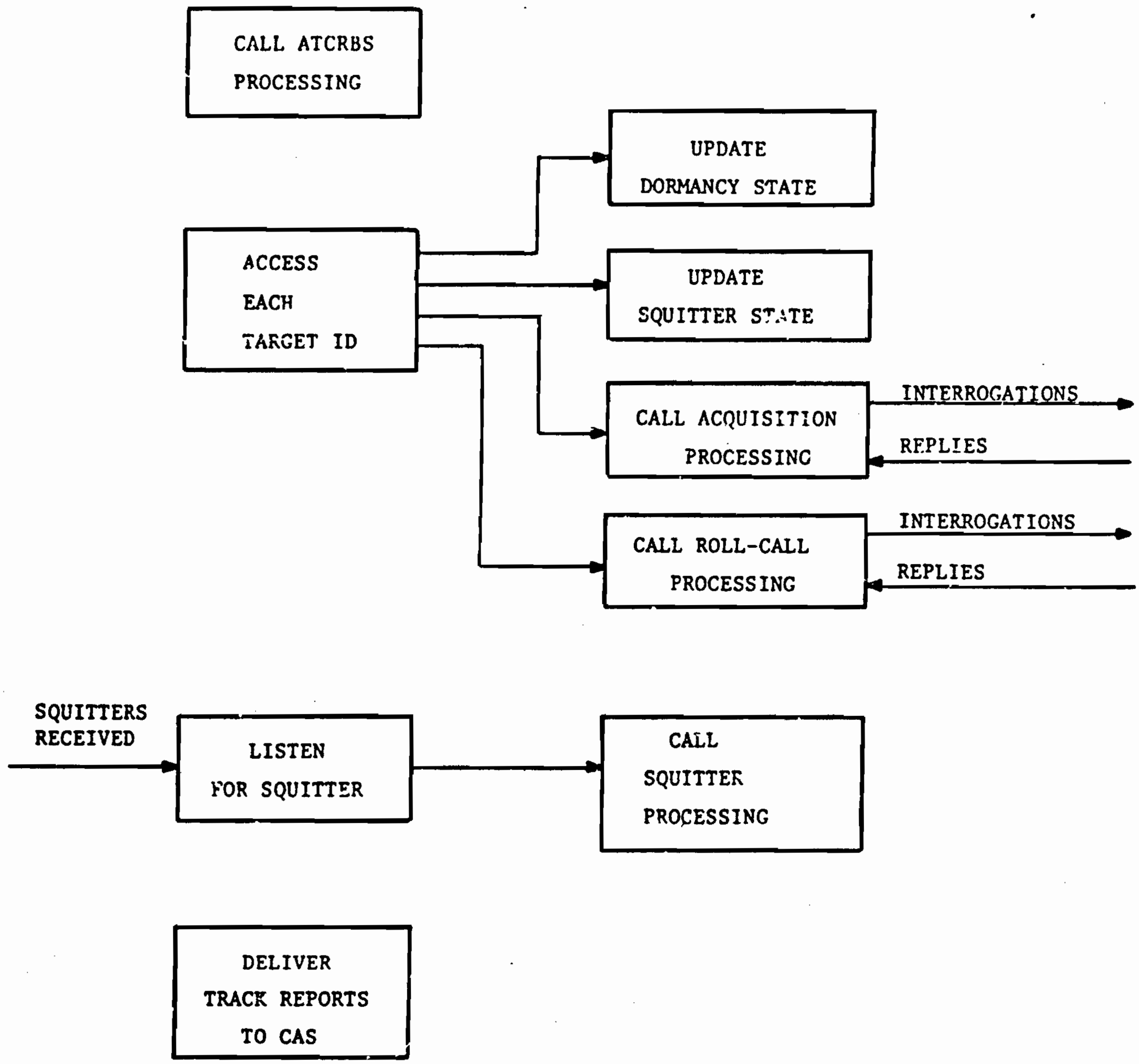

Fig. 1. Mode S Surveillance Scan Processing Tasks

Symbol	Name	Purpose	Value	Reference
AMAX	Max. alt. zone	Altitude limit for altitude and/or range tracking	5000 ft.	Roll-Call Processing Acquisition Processing Squitter Processing
AMIN	Min. alt. zone	Used to limit surveillance in altitude	3000 ft.	Squitter Processing
AT	Altitude Min Tau	Used to limit surveillance in altitude	60 sec.	Squittter Processing
F	Coast Limit	Controls number of scans with no reply permitted in Roll-Call before track is dropped	10	Roll-Ca[illegible]cessing
D	Min. alt. change	Controls updating of squitter altitude	200 ft.	Squitter Processing
N(f)	Roll-Call Interrogation Control Table	Limits number of interrogations per scan for target in Roll-Call State	Fig. 18	Roll-Call Processing
N(i,j)	Acq. Interrogation Control	Limits number of interrogations per scan for target in Acquision State	Fig. 11	Acquisition Processing
RT	Range Min. Tau	Used to limit surveillance in range	40 sec.	Acquisition Processing Roll-Call Processing

Fig. 2 Parameters Used in Mode S Surveillance Algorithms

Symbol	Name	Purpose	Initial Value	Reference
c	Squitter Drop Counter	Determines time in squitter state. Reset upon receipt of squitter. Decremented by 1 each scan.	40	Squitter purging Squitter Processing Acquisition Processing
f	Track Firmness	Counts track coasts. Parameter in Roll-Call interrogation control table. Parameter in listening window size.	1	Roll-Call Processing Roll-Call Interrogation
g	Track History Firmness	Counts previous track coasts. Parameter in listening window size	3	Roll-Call Processing Roll-Call Interrogation
i	Acquisition Drop Counter	Limits number of scans in Acquisition State. Parameter in Acq. Interrogation Control table.	6	Acquisition Processing
j	Acquisition Failure Counter	Counts transitions from Acq. to Squitter state. Used as parameter in Acq. Interrogation Control table.	0	Acqisition Processing
ℓ	Reply Counter	Counts replies in Scan for correlation purposes	4	Acquisition Processing
n	Interrogation Counter	Initialized from interrogation control tables. Decremented upon unsuccessful interrogation.	N	Acquisition Processing Roll-Call Processing
w	Antenna Switching Counter	Controls switching between top and bottom antenna. Reinitiated each scan.	2	Roll-Call Processing Acquisition Processing

Fig. 3 Counters Used in Mode S Surveillance Processing

Symbol	Definition
ALT	Altitude of aircraft
ALTO	Own altitude
AN	Antenna flag. Designates top or bottom antenna
CP	Correlation pending flag
H	Altitude difference = ALT-ALTO
ID	Address of target aircraft
RACQ	Range obtained during acquisition state
RCW	Range for closing range window
RDSM	Range rate
RM	Measured range
ROW	Range for opening range window
RPR	Predicted range
RSM	Smoothed range
SMO	Max capable speed of own aircraft
SMT	Max capable speed of target aircraft
T	Time of receipt of squitter or reply
TE	Time to endanger
TR	Time in dormancy
TSA	Time to same altitude
URE	Early range adjustment
URL	Late range adjustment

Fig. 4 Variables and Flags Used in Mode S Surveillance Processing

CURRENT TRACK STATE OF ID	PROCESSING	CONDITIONS	NEW STATE
SQUITTER	Decrement time (c) in squitter file	c > 0 c = 0	No change Remove
DORMANT	Decrement time in dormancy (TR)	TR > 0 TR = 0	No change SQUITTER
ACQUISITION	Perform acquisition processing	Successful ranging No alt. threat No range threat Range threat Unsuccessful ranging i > 0 i = 0	 SQUITTER DORMANT ROLL/CALL No change SQUITTER
ROLL/CALL	Perform Roll/Call Processing	Successful ranging No alt. threat No range threat Range threat Unsuccessful ranging f < F f = F	 SQUITTER DORMANCY No change No change SQUITTER

Fig. 5. Scan Processing of each ID in Surveillance Processing

TRACK STATE OF TARGET	PROCESSING	CONDITIONS	NEW STATE
UNKNOWN			SQUITTER
SQUITTER	Perform squitter processing	Alt. threat no Alt. threat	ACQUISITION No change
ACQUISITION	No action		No change
ROLL/CALL	No action		No change
DORMANT	No action		No change

Fig. 6. Track State Transitions Resulting from Receipt of Squitter.

SQUITTER

ID	address of target
T	time of measurement
H	altitude difference
c	squitter drop counter
j	acquisition failure counter

DORMANT

ID	address of target
T	time of measurement
H	altitude difference
TR	time in dormancy

ACQUISITION

ID	address of target
T	time of measurement
H	altitude difference
RACQ	interim range
AN	antenna
w	antenna switching counter
i	acquisition drop counter
j	acquisition failure counter

ROLL-CALL

ID	address of target
T	time of measurement
H	altitude difference
RSM	smoothed range
RDSM	range dot
AN	antenna
NT	new track flag
w	antenna switching counter
f	track firmness
g	track history firmness

Fig. 7 Track File Information Required by Each Track State.

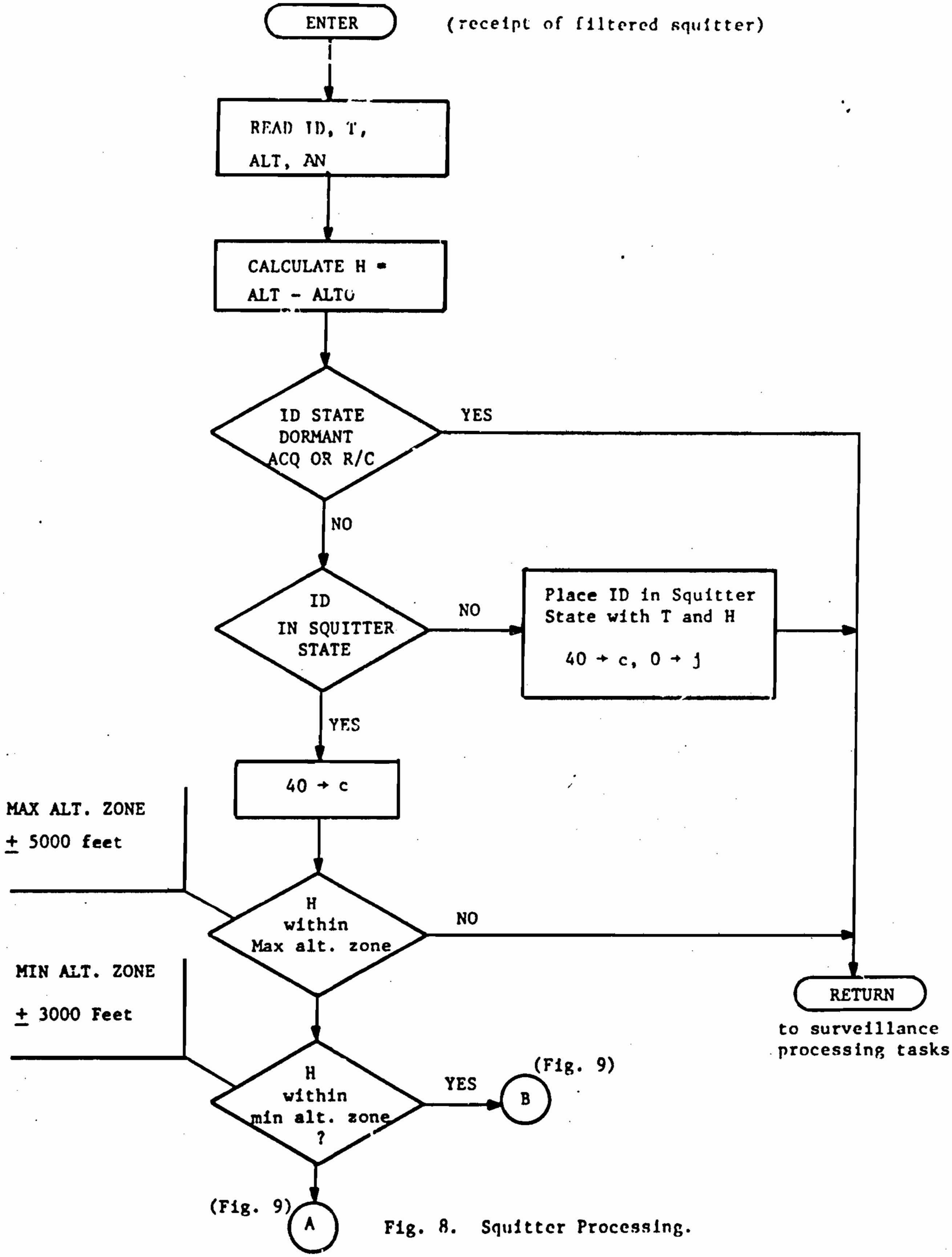

Fig. 8. Squitter Processing.

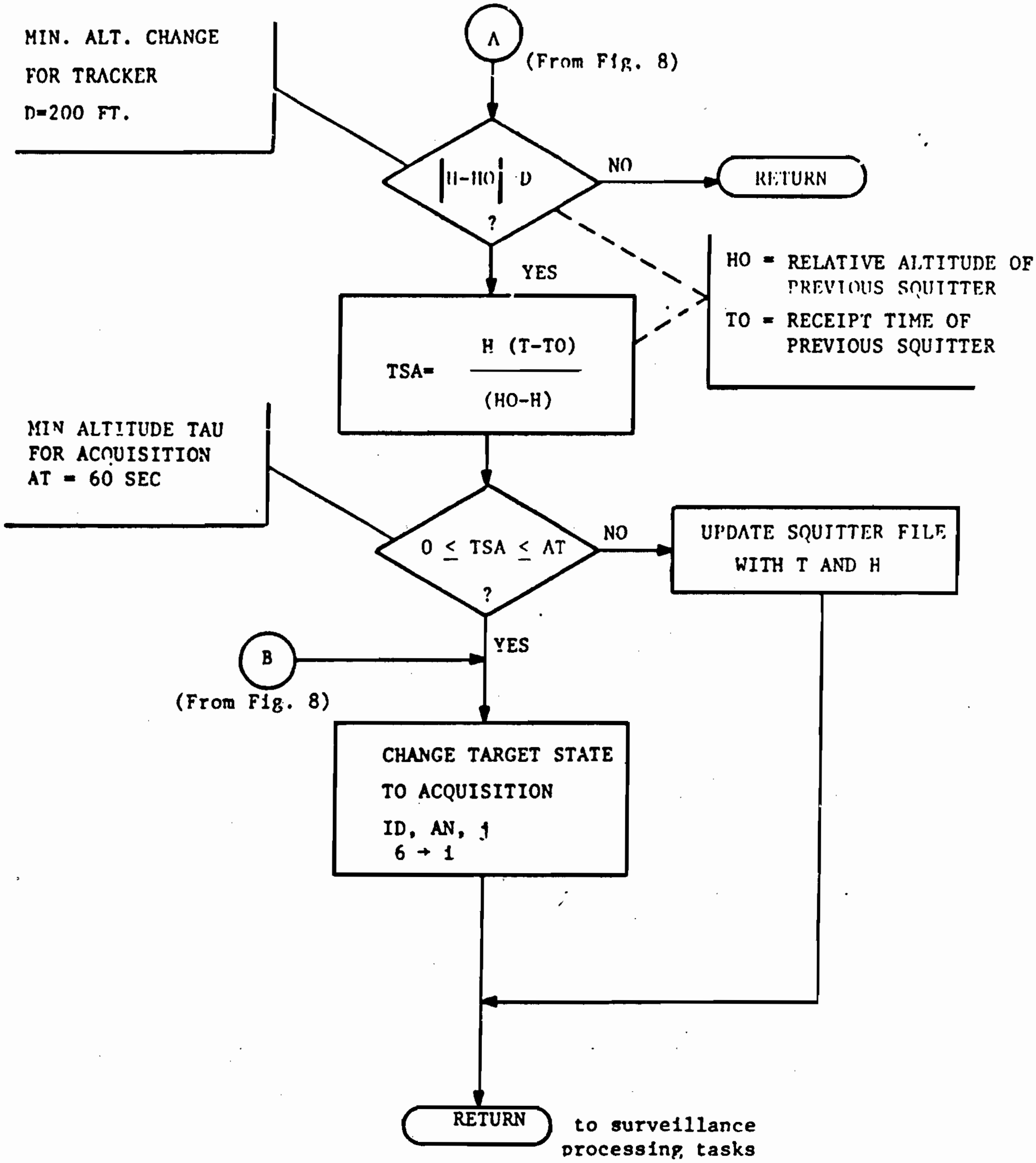

Fig. 9. Squitter Processing. (End)

If the target is within the minimum altitude zone (± 3000 feet), its track state is changed to acquisition. AN is set to indicate the antenna that received the squitter and the acquisition drop counter, "counter i", is initialized at 6.

If the target relative altitude (H) is between the minimum and maximum altitude zones, the estimated time to same altitude, TSA is computed, provided H has changed by at least D (± 200 feet). If D is not satisfied, the squitter is ignored.

If TSA is less than 0 or greater than AT (60 sec.), the relative altitude and time-of-arrival are updated with the new information. If the minimum tau criterion is satisfied, the target track state is changed to acquisition.

B. Processing of Target in Squitter State

The squitter state is assigned to a target if its ID is not yet validated by receipt of a second squitter, or if it is not currently an altitude threat, or if it has made a track state transition from dormancy, acquisition, or roll-call. A target both enters and exits surveillance processing by way of the squitter state.

Counter c (associated with the ID) is decremented by 1 each scan, and if reduced to 0, the ID and any information associated with this ID are removed from memory.

C. Processing of Target in Dormant State

A target is placed in the dormant state if it is sufficiently distant not to be of immediate interest. In this case the time to endanger (TE), calculated in acquisition processing or roll-call processing, has been found sufficiently large to safely ignore the target for a time TR.

Each scan, TR is decremented by 1, and when reduced to 0, the target state is changed to squitter state.

D. Acquisition Processing

The acquisition processing algorithms are exercised each scan for each target in the acquisition state. Acquisition processing schedules interrogations to a target, sends a formatted message to the modulation control unit (MCU) and operates upon replies passed from the reply processor.

Upon entry to acquisition processing with a target ID, the antenna switching counter, w, associated with that ID is initialized at 2 (Fig. 10). If this is the first scan of the acquisition state (i=6), the intermediate range RACQ is set to zero. The maximum number of permitted unsuccessful interrogations, N, is obtained from the acquisition interrogation control table using the acquisition drop counter i and acquisition failure counter j as entries. The acquisition interrogation control table is given in Fig. 11. The counter n is initialized with the value from the table. The correlation pending flag is initialized at zero and the counter ℓ initialized at 4.

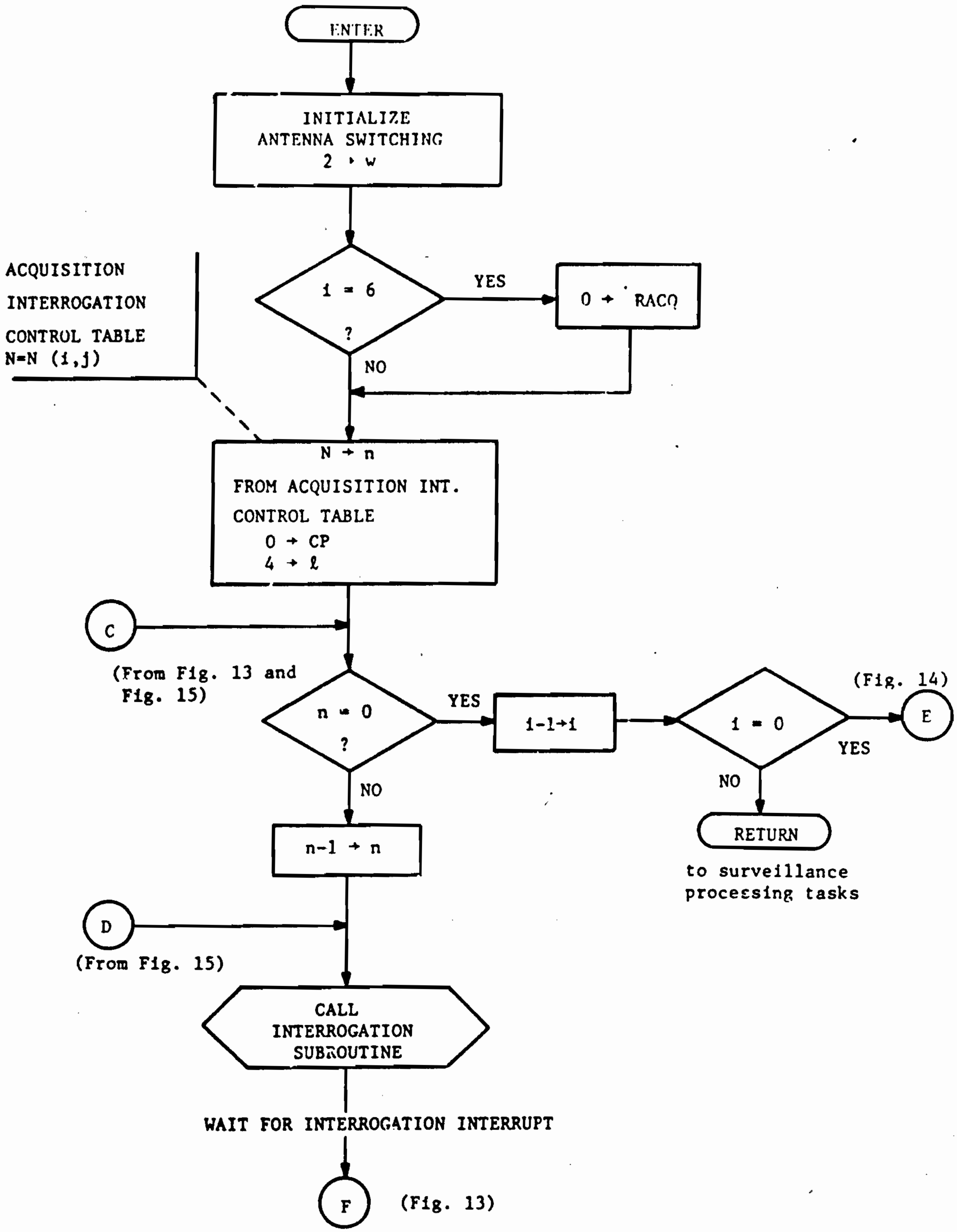

Fig. 10. Acquisition Processing (Begin).

N(i,j) = Maximum number of interrogations with no reply permitted in 1 scan.

i = acq. drop counter
j = acq. failure counter

i	j = 0	j = 1	j = 2	j = 3
6	3	2	1	1
5	3	2	1	0
4	3	2	1	0
3	0	0	0	0
2	0	0	0	0
1	0	0	0	0

Fig. 11. Acquisition Interrogation Control Table

If the counter n is non-zero, it is decremented by 1 and an interrogation is scheduled to the target by the interrogation subroutine (Fig. 12). The reply processor operates on any replies to this interrogation and interfaces back to acquisition processing at point F (Fig. 13) where correlation tests are performed if the reply is a valid one. Correlation tests consist in determining whether an earlier reply has been received during the scan with a received range within 0.5 nmi of the current reply. A correlating pair of replies must be received in the same scan for successful acquisition to be accomplished. This is done to prevent fruit or multipath returns from being accepted and causing tracks to be initiated based on false ranges. If the interrogation fails or does not produce a correlating reply, the program returns to point C (Fig. 10) where n is again decremented by 1, if it is still non-zero, and another interrogation is scheduled.

If a reply was received but further correlation is necessary (Fig. 15), the interrogation subroutine is called immediately without decrementing n.

Interrogations are scheduled to the target until either a satisfactory correlation is found or counter n is decremented to 0.

1. Acquisition Processing - Interrogation Subroutine

This subroutine is called by acquisition processing each time an interrogation is to be transmitted for acquisition purposes (Fig. 12).

The range window is opened from zero-range out to a maximum range of 60 nmi. The interrogation message is formatted and sent to the modulation control unit. The aircraft ID and window ranges are sent to the reply processor which returns control to acquisition processing after completing its task of processing replies to the interrogation. The interrogation is transmitted on the antenna indicated by AN.

2. Unsuccessful Acquisition

In the event that the reply processor does not return a valid reply at point (F), the antenna switching counter w is decremented by 1 and if w=0, the antenna flag AN is changed to the other antenna, and the switching counter w is initialized at 2. Processing returns to point C (Fig. 10) where the counter n is compared to 0. If n ≠ 0, another interrogation is scheduled.

If n = 0, the acquisition drop counter, i is decremented by 1. If i ≠ 0, the ID is kept in the acquisition state, and interrogations will be scheduled when the ID is accessed during the next scan by acquisition processing.

Should the counter i be decremented to 0, the acquisition phase has been unsuccessful and a track state transition takes place. (Fig. 14)

If RACQ ≠ 0, at least 1 reply was received during the total acquisition period of 6 scans. The time-to-endanger (TE) is calculated based on this range. If TE > 43 seconds, (RT + 3), the target state is changed to dormancy with TR = (TE - RT) seconds. If TE < 43 seconds, the target state is changed to squitter.

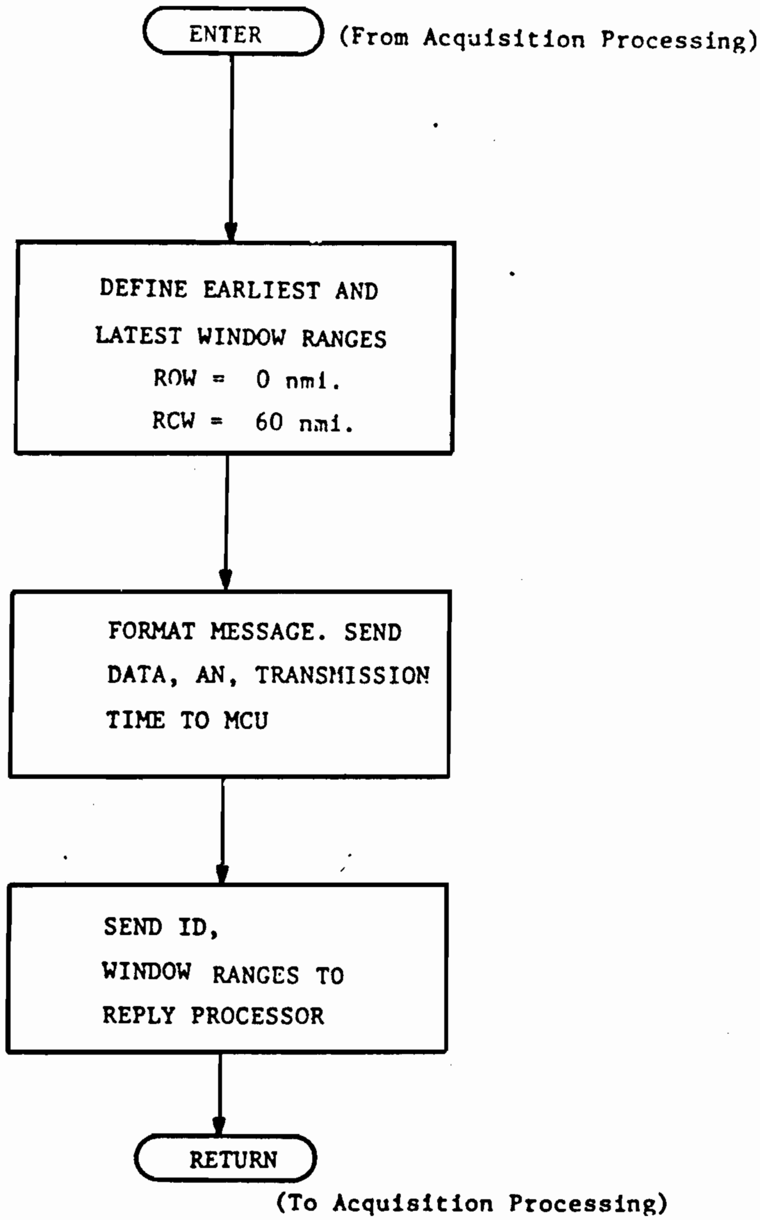

Fig. 12. Acquisition Processing-Interrogation Subroutine

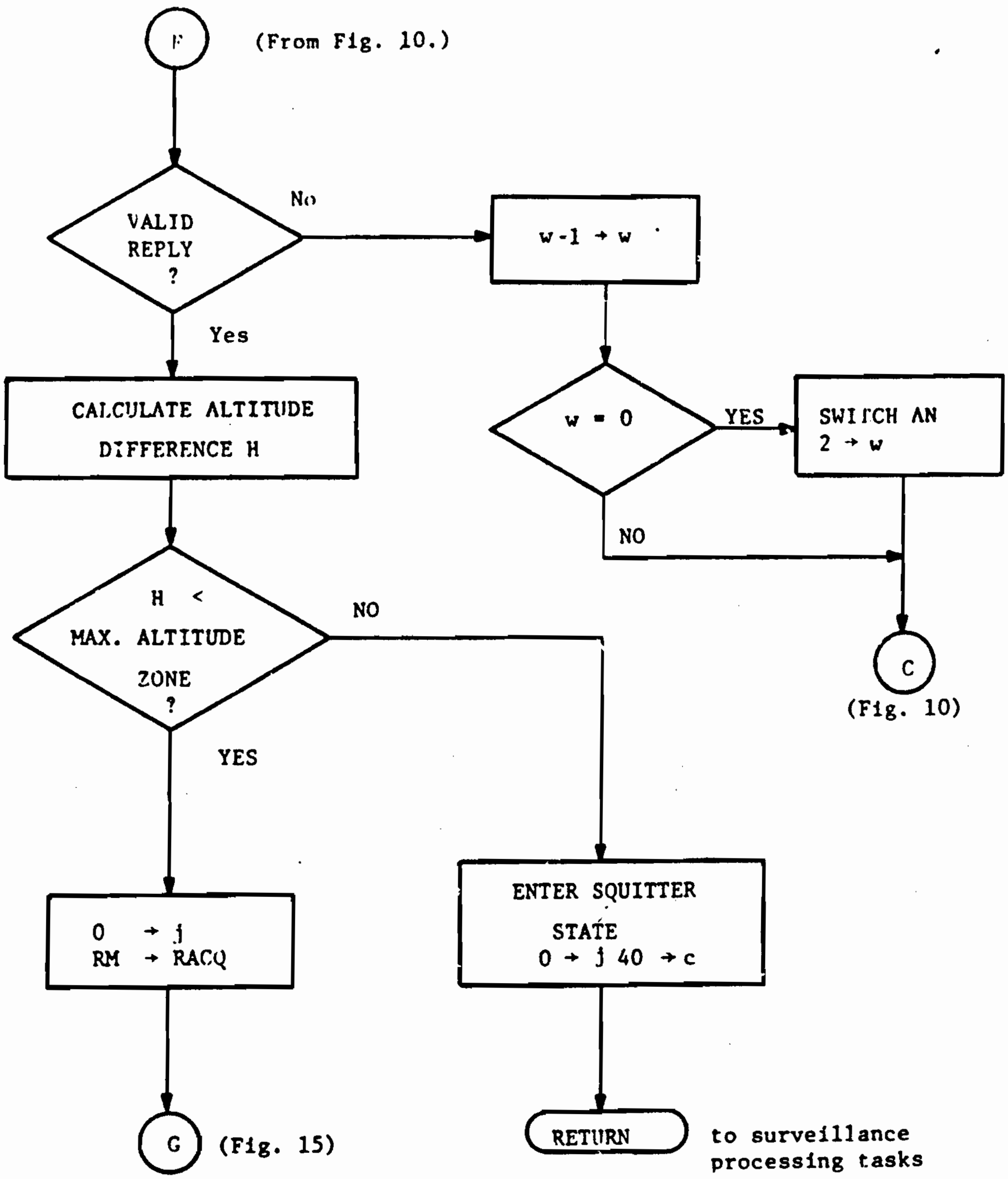

Fig. 13. Acquisition Processing (Cont.).

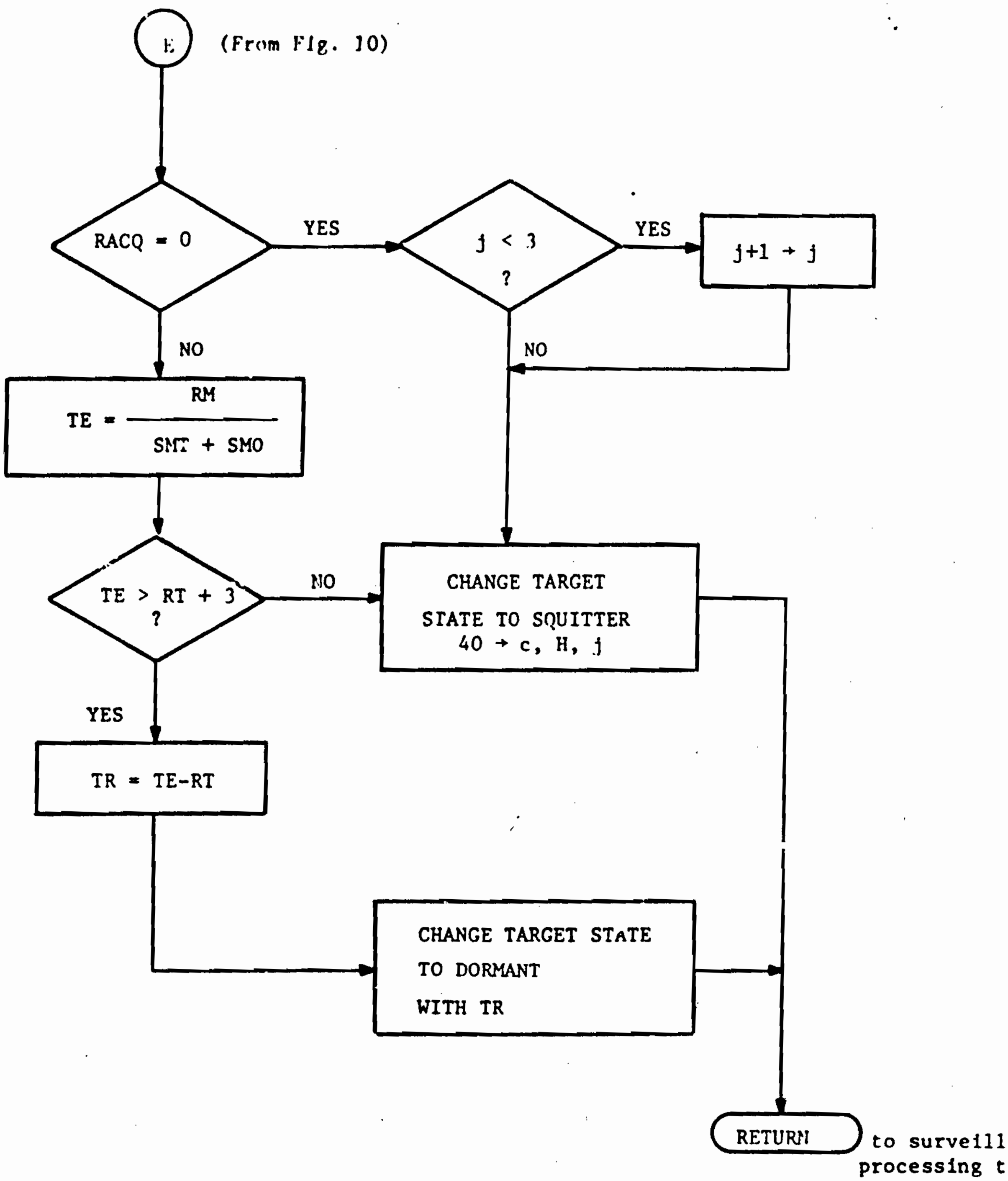

Fig. 14. Acquisition Processing (Cont.).

If RACQ = 0, no replies were received during the total acquisition period. The acquisition failure counter j is incremented by 1 and the target state changed to squitter. The acquisition failure counter is used to reduce the number of acquisition interrogations scheduled to targets habitually failing in acquisition. Generally, such targets are beyond the 60 mile range window, and if this is the case, cannot be acquired.

3. Successful Acquisition

Successful acquisition is accomplished if two replies having ranges within 0.5 nmi of each other are received from interrogations made during the same scan. Two replies satisfying this requirement are referred to as a correlating pair.

If an interrogation elicits more than 1 valid reply, any later replies are assumed to be either multipath or fruit and therefore ignored.

When a valid reply is received from the reply processor at Point F (Fig. 13), the altitude difference is calculated. If the target is outside the maximum altitude zone, the target state is changed back to squitter with the acquisition failure counter, "counter j" initialized at 0 and the squitter drop counter initialized at 40.

Should the target be within the maximum relative altitude zone, the range is stored in RACQ, and in the temporary range buffer so that correlation checks may be made (Fig. 15), and counter ℓ decremented by 1.

If this is the first valid reply this scan for the target ($\ell = 3$), processing returns to Point D (Fig. 10) to schedule another interrogation.

If the reply correlates with a previous reply, and this is the second valid reply ($\ell = 2$), the range is considered to be correlated. Processing moves to Point H (Fig. 16).

If the reply correlates, $\ell \neq 2$, and the correlation pending flag has been set (CP $\neq$ 0), this last correlating range is accepted as correct.

Should the correlating pending flag CP = 0 and the earlier uncorrelating range be greater than the correlating pair, the correlating range is accepted.

Should the earlier uncorrelating range be shorter than the correlating pair, and CP = 0, the correlation pending flag CP is set to 1 and processing returns to Point D to schedule another interrogation.

If the altitude of the correlating reply (ALT) is less than 10,000 feet, the maximum capable speed of the target, SMT, is limited to 300 knots. Similarly if own altitude (ALTO) is less than 10,000 feet, own maximum speed, SMO, is limited to 300 knots. The minimum time to endanger is then calculated. This is the earliest possible time a collision could take place (assumes head-on encounter with both flying at maximum capable speeds).

If TE > 43 seconds, (RT + 3), the target state is made dormant, and TR is set to (TE - RT) seconds.

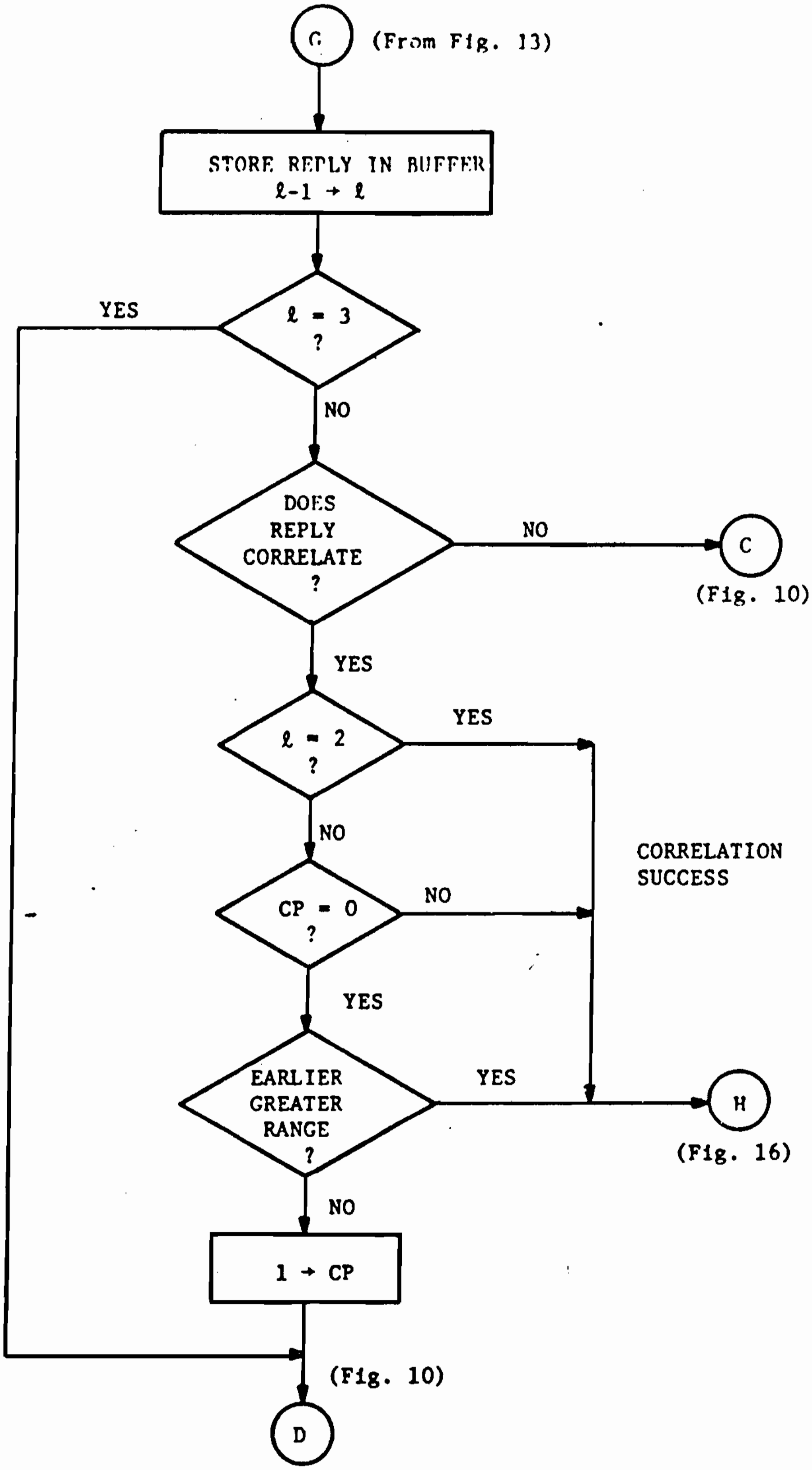

Fig. 15. Acquisition Processing (Cont.)

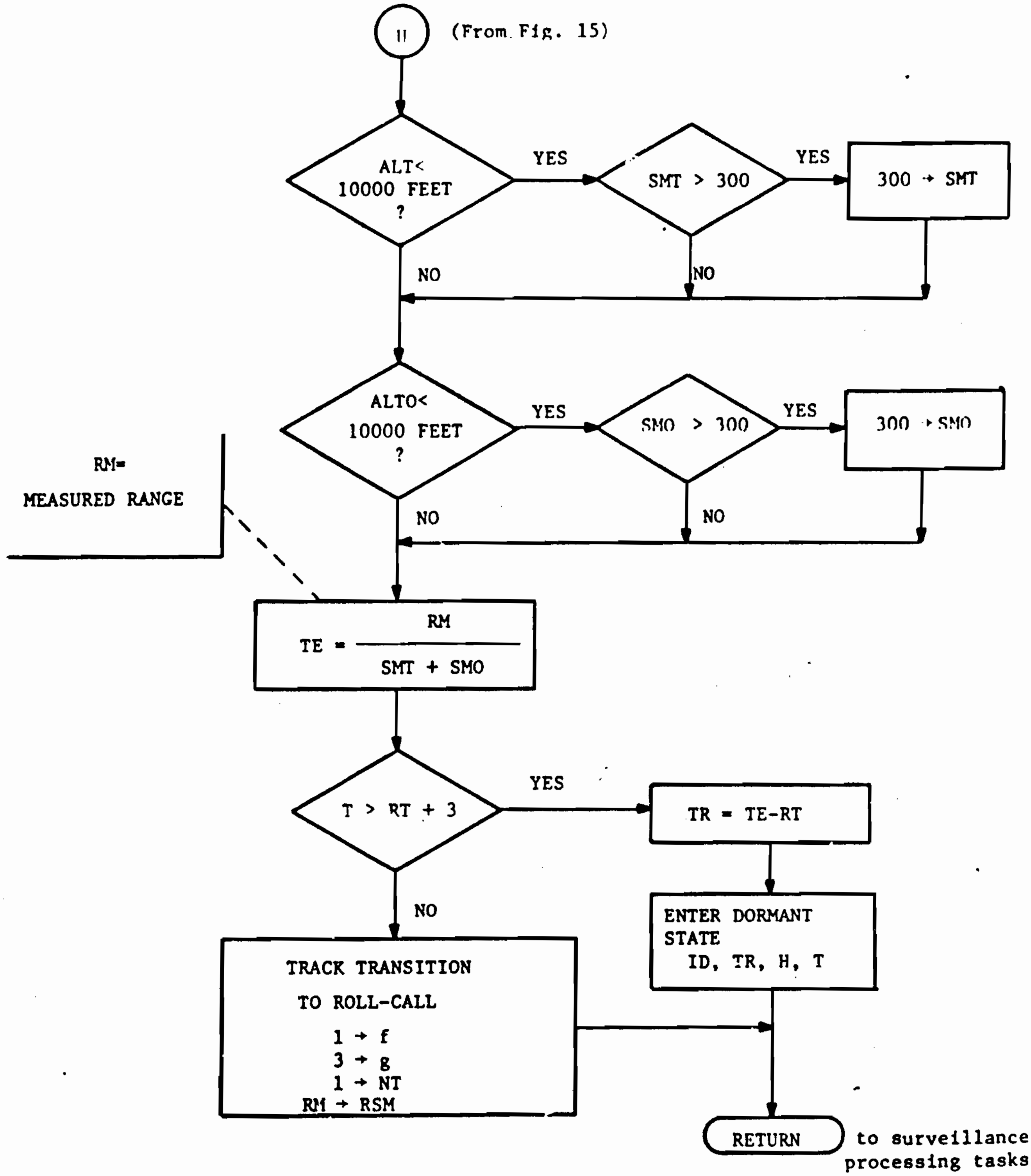

Fig. 16. Acquisition Processing (End)

If TE < 43 seconds, the target is placed in the roll-call track state. The track firmness f is set to 1, the track history firmness g is set to 3 and the new track flag NT is set to 1. Interrogations are scheduled on the next scan to this target by roll-call processing.

E. Roll-Call Processing

The roll-call processing algorithms are exercised each scan for each target ID having roll-call track status.

Upon entry to roll-call processing, the antenna switching counter w is initialized at 2 (See Fig. 17). The maximum number of interrogations permitted this scan N(f) is accessed from the roll-call interrogation control table (Fig. 18) and the roll-call interrogation counter n is initialized at N(f).

If n ≠ 0, it is decremented by 1, and the roll-call interrogation subroutine is called to schedule an interrogation to the target.

1. Roll-Call Interrogation Subroutine

This subroutine is called by roll-call processing each time an interrogation is to be sent out for tracking purposes. (Fig. 19)

If this is a new target (NT≠0), the acquisition range is used as the predicted range, and the early and late range adjustments are each set at 1.6 nmi. If this is not a new target (NT=0), the predicted range is extrapolated from the previous range using the range dot RDSM. The early and late range adjustments are computed using the track firmness f and the track history firmness g. The constant A used in the equation is a function of the target altitude and range.

The message is formatted and sent to the MCU along with time of transmission and antenna flag AN.

The range window limits are then calculated using the early and late adjustments about the predicted range. Any Mode S preamble decoded during this window will result in either a valid or invalid reply.

The target ID and window ranges are sent to the reply processor which will process any replies received. Upon completion of its tasks, the reply processor returns control to roll call processing at Point K, Figure 20.

2. Unsuccessful Interrogation

In the event that the reply processor does not return a valid reply at point K, the antenna switching counter w is decremented by 1. If w = 0, the antenna flag AN is changed to the other antenna, and the switching counter w is initialized at 2. Processing returns to Point J (Fig. 17).

If n ≠ 0, it is decremented by 1 and another interrogation is scheduled to the target.

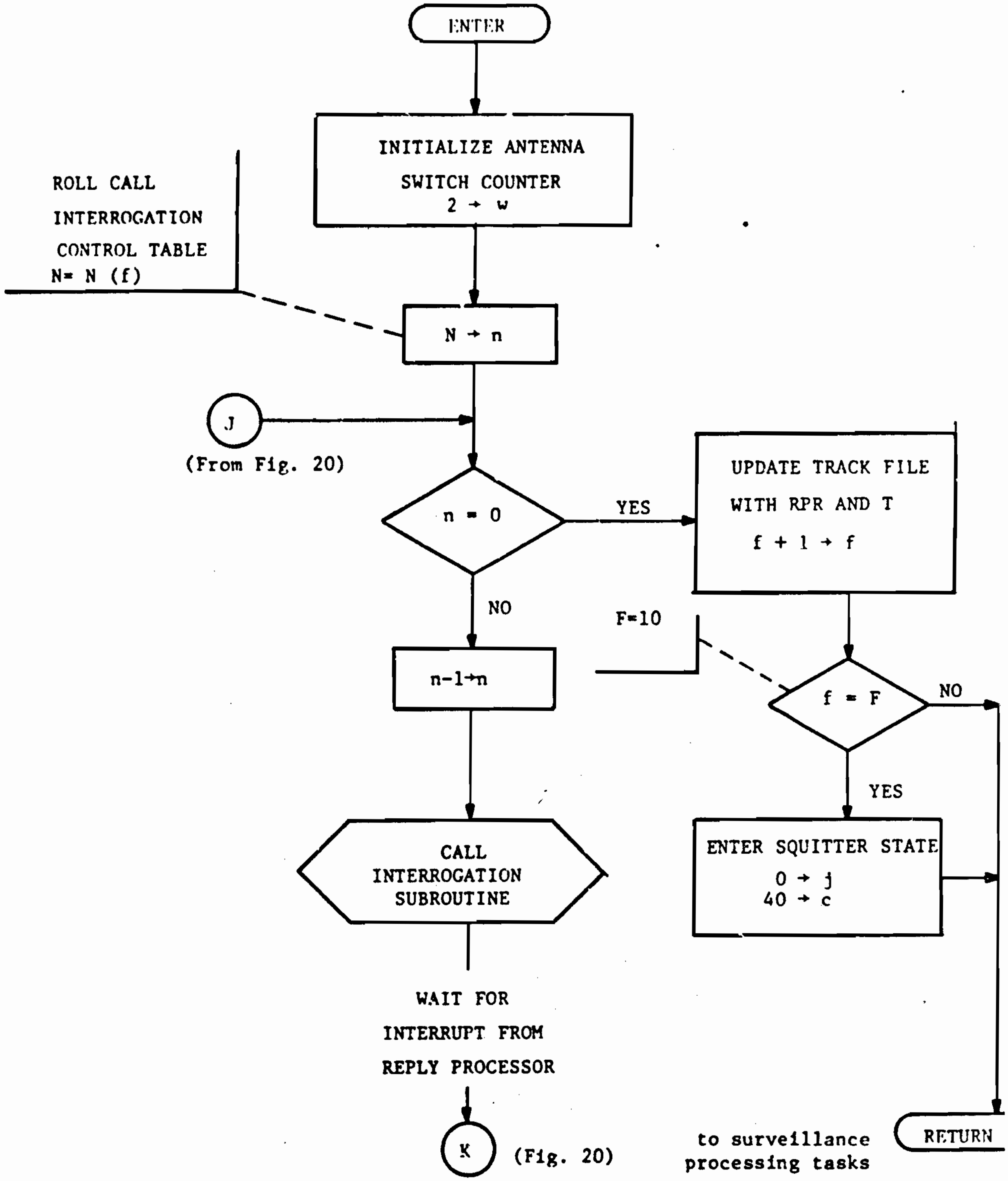

Fig. 17. Roll Call Processing (Begin).

f	N
1	5
2	4
3	3
4	2
5	2
6	2
7	2
8	2
9	2
10	2

N = maximum number of interrogations permitted in 1 scan.

f = track firmness

Fig. 18. Roll-Call Interrogation Control Table.

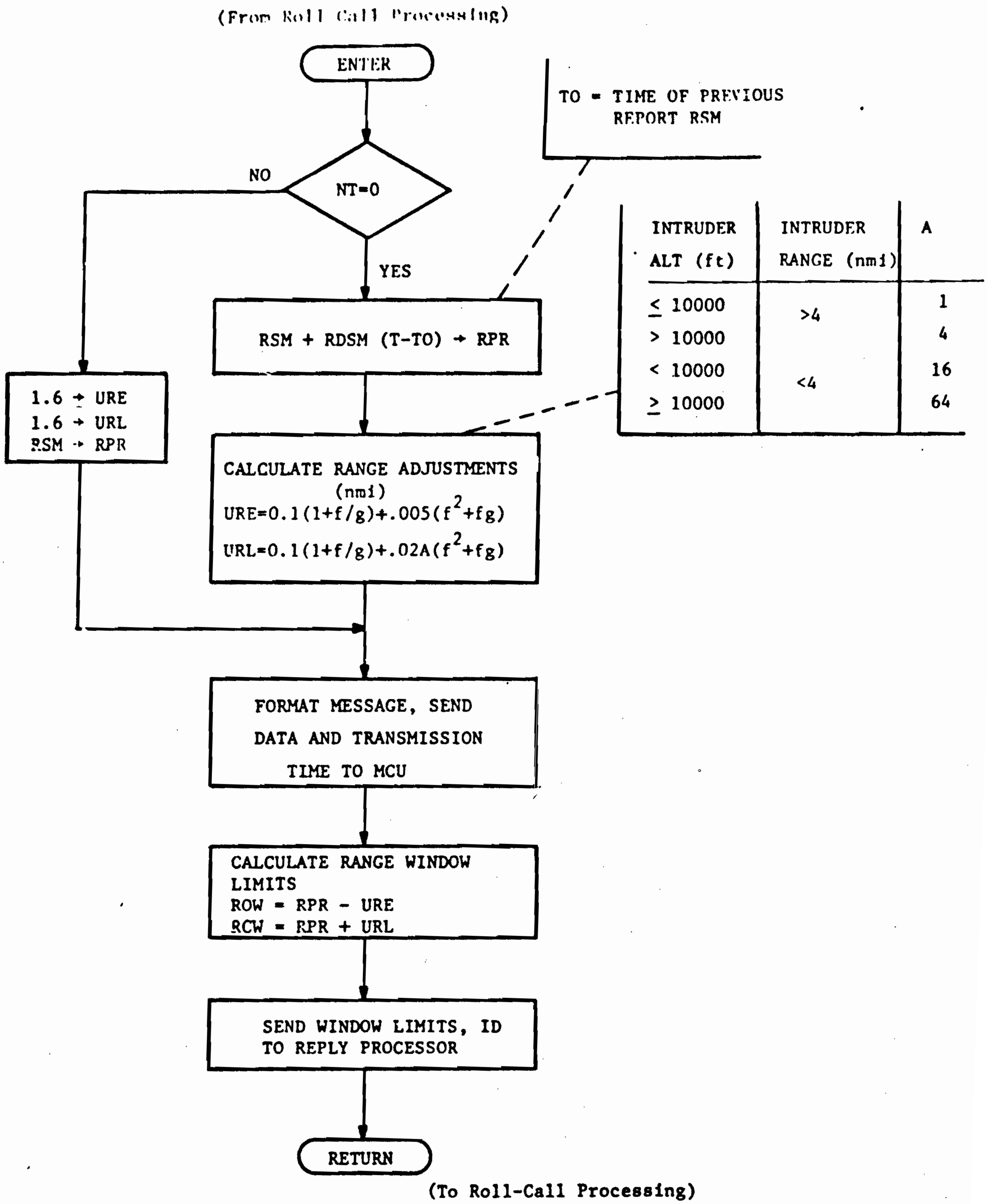

Fig. 19. Roll Call Processing - Interrogation Subroutine.

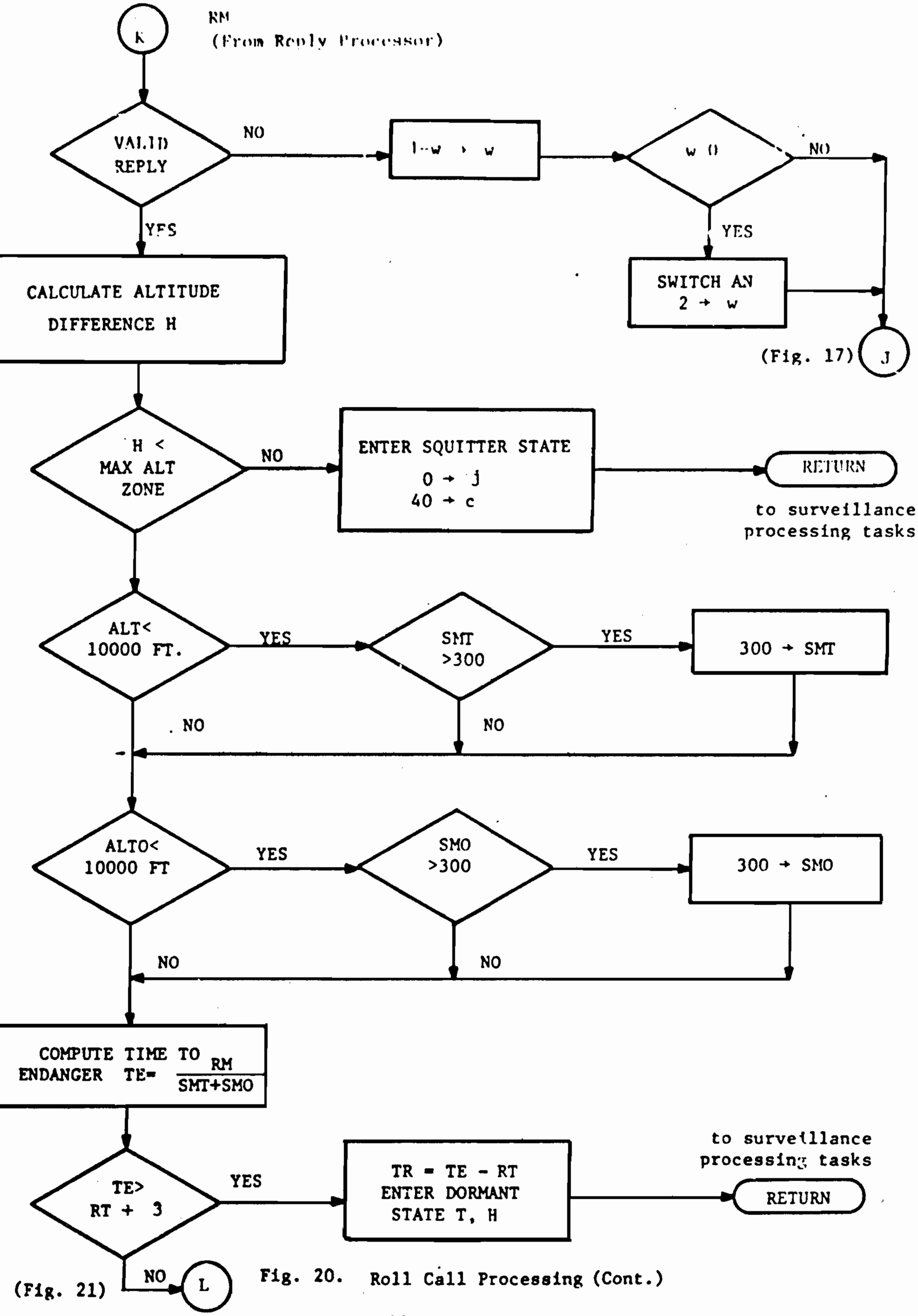

Fig. 20. Roll Call Processing (Cont.)

If n = 0, roll-call processing has failed this scan. The track firmness f is incremented by 1, and if f = F, the track is dropped and its state is changed to squitter. The squitter drop counter c is initialized at 40 and the acquisition failure counter j initialized at 0.

In the event that n = 0 and f ≠ F, the target retains its roll call state, the range being updated by RPR, the predicted range. Interrogations to this target will be scheduled again the next scan by roll-call processing.

3. Successful Interrogation

When the reply processor returns a valid reply to an interrogation, roll-call processing calculates the altitude difference. Should the target be outside the maximum altitude zone, the track state is changed to squitter state with counters j and c initialized at 0 and 40.

Should the altitude difference fall within the maximum altitude and the altitude of target be less than 10,000 feet, the maximum capable speed of the target SMT is limited to 300 knots. Similarly, if own altitude is below 10,000 feet, own maximum capable speed SMO is limited to 300 knots.

The time to endanger TE is calculated, and if greater than 43 seconds (RT + 3), the target is dropped from the roll-call state. The track state is changed to dormancy with a time in dormancy set at TR = (TE - RT) seconds.

Should the time to endanger be less than or equal to 43 seconds, the range rate is calculated (Fig. 21). The track history firmness g is set to f, the track firmness f set to 1, and NT set to zero. A target report on this target ID is then available for issuance to the threat detection logic.

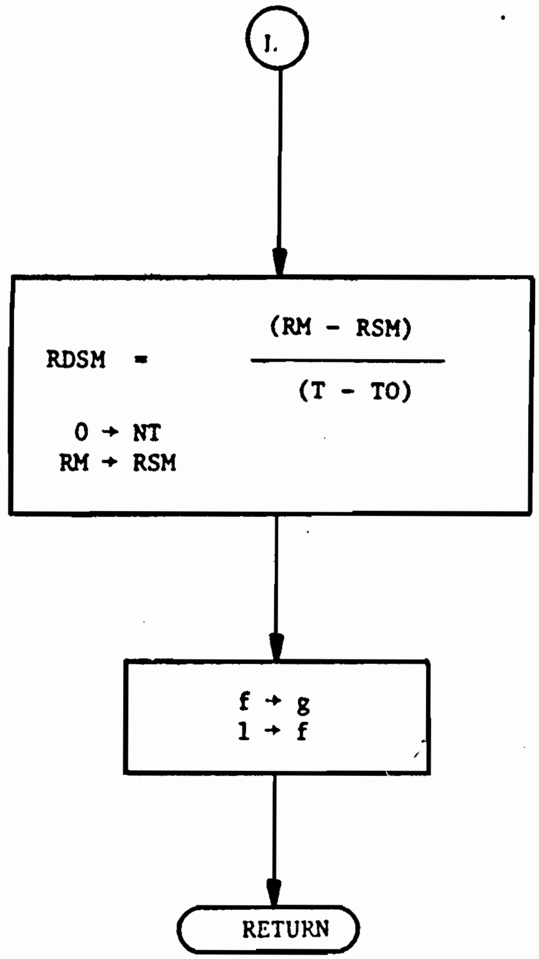

Fig. 21. Roll Call Processing (End)

APPENDIX - MODE S REPLY PROCESSING

This appendix contains a general description of the Mode S reply structure and the reply processing which supply range and data information for Mode S equipped targets to the TCAS surveillance processor. Details of the Mode S signal-in-space formats including the message structures may be found in the Mode S National Standard.

Mode S Reply

The Mode S received signal consists of a preamble and a data block.

The preamble is made up of four 0.5 microseconds pulses that are spaced 1.0, 3.5 and 4.5 microseconds respectively from the first preamble pulse.

The data block begins 8 microseconds after the first preamble pulse and contains either 56 or 112 one-microsecond bit intervals. Surveillance processing is concerned only with 56-bit data formats.

A pulse width of 0.5 microseconds is transmitted in the first half of a bit interval to indicate a binary one and in the second half of an interval to indicate a binary zero.

Preamble Detector

The preamble detector senses the presence of an incoming reply and synchronizes the receiver for the purpose of range measurement and data demodulation.

Data Bit Declaration

The data bit is declared by comparing the pulse amplitude in the first half of the bit interval to the pulse amplitude in the second half.

Confidence Bit Declaration

The comparisons of the pulse amplitudes in the first and second half of the bit interval are made a number of times during each interval. Each bit declaration is assigned high- or low-confidence depending upon the consistency of the sampling results.

Error Detection

The last 24 data bits in the Mode S data block contain the address of the aircraft and an encoding parity that is overlapped in the same field by the transponder.

When the message is decoded by the reply processor, the parity is removed, and if the message is received as it was transmitted, the resulting address field contains only the address of the Mode S aircraft.

If any corruption of the data block has taken place since the transmission, a non-zero error syndrome (i.e., set or combination of error-indicating bits) will appear superimposed on the address.

In the case where the Mode S message is a reply to own interrogation, the aircraft address is known and errors are therefore immediately apparent.

In the case where the Mode S message follows a preamble detection that was obtained while listening for squitters, the aircraft address is not known and it is impossible to determine whether a non-zero error syndrome is present.

Rejection of Invalid Squitters

The probability of accepting a squitter with a corrupted address is substantially reduced by rejecting messages that contain data bits known to be incorrect or that have too many low confidence bit declarations associated with the data block.

Squitters are rejected if any of the following conditions exist:

1) Inappropriate DF Field. The first 5 bits of the data block do not contain the code 00100 which designates an altitude reporting standard Mode S surveillance reply.

2) Illegal altitude code. The D1 bit (bit 28) in data block has been declared a one, or C1 C2 C4 (bits 20, 22 and 24) assume one of the illegal combinations 000, 101 or 111.

3) Excessive number of low-confidence bits. More than 34 of the 56 data bit declarations have been assigned low confidence.

END

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