

RTCA Special Committee 209
ATCRBS / Mode S Transponder
Meeting #3

RTCA, Washington DC
8 – 9 August 2006

Review of P1-P3-P4
Accept / Reject Requirements
In Response to Action Item 2-7

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SUMMARY
The intent of this document is to address remaining issues regarding conflict between the SARPs and RTCA DO-181X in regards to the detection of the P4 pulse in Mode-S All-Call Interrogations.

Introduction:

This document is a continuation of work initiated in Eurocae WG49 Working Paper WG49N6-06, Action Item A5/05 as addressed by Mr. Tom Pagano. As such, the original working text presented in Eurocae WG49N6-06 is retained in “Black” Font. Additional text has been added by the author of this document and is in “Blue” Font. Likewise, all figures have been added by the author of this document.

The intent of this document is to address remaining issues regarding conflict between the SARPs and RTCA DO-181X in regards to the detection of the P4 pulse in Mode-S All-Call Interrogations.

Note that all commented information and figures were preliminary when discussed at Eurocae WG-49 Meeting #7 in Paris on July 4-5, 2006. The intent herein is to update the preliminary information and figures where needed and attempt to draw final correlation between RTCA DO-181X, Eurocae ED-73X and ICAO Annex 10.

EUROCAE WG49N6 Action (A5/05)	Working Paper WG49N6-06 AGENDA Item 4
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Description of differences in ATCRBS/Mode S All Call Interrogation P4 pulse duration tolerance between SARPS and DO-181C/ED-73B MOPS

It was recognized and discussed at the December 2005 Meeting of EUROCAE Working Group 49, that there exists differences between the SARPS and MOPS in the area of P4 pulse duration requirements for a Mode S Transponder acceptance and rejection of an ATCRBS/Mode S All Call interrogation. This paper details the applicable SARPS and MOPS paragraphs which define P4 pulse duration requirements.

SARPS vs MOPS

The SARPS contains requirements in Volume 4 for interrogation pulse characteristics, including pulse amplitude, duration and timing tolerances. The paragraphs which pertain to interrogation pulse characteristics for ATCRBS/Mode S All Call interrogation acceptance and rejection in a Mode S Transponder are §3.1.2.4.1.1.2 (which has references to §3.1.2.1.5.1) and §3.1.2.4.1.2. The paragraph that directly relates to P4 duration tolerances is §3.1.2.4.1.2.2.1. The SARPS levies requirements on P4 pulse duration by referencing the trail edge of P4 to the lead edge of P3. Since the MOPS levies requirements for P4 pulse duration to the lead edge of P4, translation of the SARPS requirements to the MOPS requirements is necessary. Since there is an allowed tolerance on P3 to P4 lead edge, the SARPS and MOPS requirements are not exactly the same so assumptions have to be made to relate the two. In the SARPS, §3.1.2.1.5.1.3 defines the acceptance criteria for P3 to P4 pulse position tolerance as +/- .050 microseconds, which needs to be considered when relating the requirement to the MOPS P4 pulse duration tolerance.

Must Accept Requirement

The SARPS ATCRBS/Mode S All Call acceptance criteria for the trail edge of P4, per §3.1.2.4.1.2.2.1 requires acceptance if the P4 trail edge is between 3.45 to 3.75 microseconds after the P3 lead edge. At nominal P3 to P4 lead edge time of 2.0 microseconds, this is equivalent to P4 pulse durations from 1.45 to 1.75 microseconds. To determine the minimum must accept P4 pulse duration equivalent to the SARPS 3.45 microsecond requirement, the maximum allowed P3 to P4 lead edge to lead edge spacing would be applied, i.e. the minimum pulse duration for P4 results when P4 is .050 microseconds late relative to nominal P3-P4 spacing. In this case, P4 lead edge is at 2.050 microseconds relative to P3 lead edge and this is equivalent to a 1.40 microsecond P4 pulse duration. To determine the maximum must accept P4 pulse duration equivalent to the SARPS 3.75 microsecond requirement, the minimum allowed P3 to P4 lead edge to lead edge spacing would be applied, i.e. the maximum pulse duration for P4 results when P4 is .050 microseconds early relative to nominal P3-P4 spacing. In this case, P4 lead edge is at 1.95 microseconds relative to P3 lead edge and this is equivalent to a 1.80 microsecond P4 pulse duration. Therefore, the MOPS would need to require a must accept range for P4 pulse duration of 1.40 to 1.80 microseconds to accept in all cases required by the SARPS. In DO-181C, the P4 must accept pulse duration is defined in 2.2.6.3.a with an acceptance range of 1.5 to 1.7 microseconds. The MOPS defines a narrower range of P4 pulse duration must accept range than the SARPS.

Start RHS Commentary on P4 Acceptance:

Review of the Figure 1 provided at the end of this document indicates the following:

First, the figure contain Reference Bubbles shown as Red Ellipses with the number/letter inside.

- a. Referring to Bubble 1a on the figure, if the reference time is established at the earliest possible leading edge of P3 which is at 7.8 microseconds after the leading edge of P1, then add minimum of 1.95 microseconds for the minimum spacing to the leading edge of P4, then add 1.5 microseconds for the minimum P4 duration, you have 11.25 microseconds (Mode-A) for the least possible trailing edge time of P4, or 3.45 microseconds after the leading edge of P3. (**Reference Bubble 1d and 1h**)

This same result appears to be obtained directly in ICAO by adding 3.45 microseconds to the earliest leading edge of P3 at 7.8 microseconds, resulting in 11.25 microseconds to the earliest possible trailing edge of P4 for Mode-A interrogations. (**Reference Bubble 1g and 1h**)

- b. Likewise, but referring to Bubble 1b on the figure, if the reference time is established at the latest possible leading edge of P3 which is 8.2 microseconds after the leading edge of P1, then add the maximum of 2.05 microseconds for the maximum spacing to the leading edge of P4, then add 1.7 microseconds for the maximum P4 duration, you have 11.95 microseconds (Mode-A) for the most possible trailing edge time of P4, or 3.75 microseconds after the leading edge of P3. (**Reference Bubble 1e and 1h**)

This same result appears to be obtained directly in ICAO by adding 3.75 microseconds to the latest leading edge of P3 at 8.2 microseconds, resulting in 11.95 microseconds to the latest possible trailing edge of P4 for Mode-A interrogations. (**Reference Bubble 1g and 1h**)

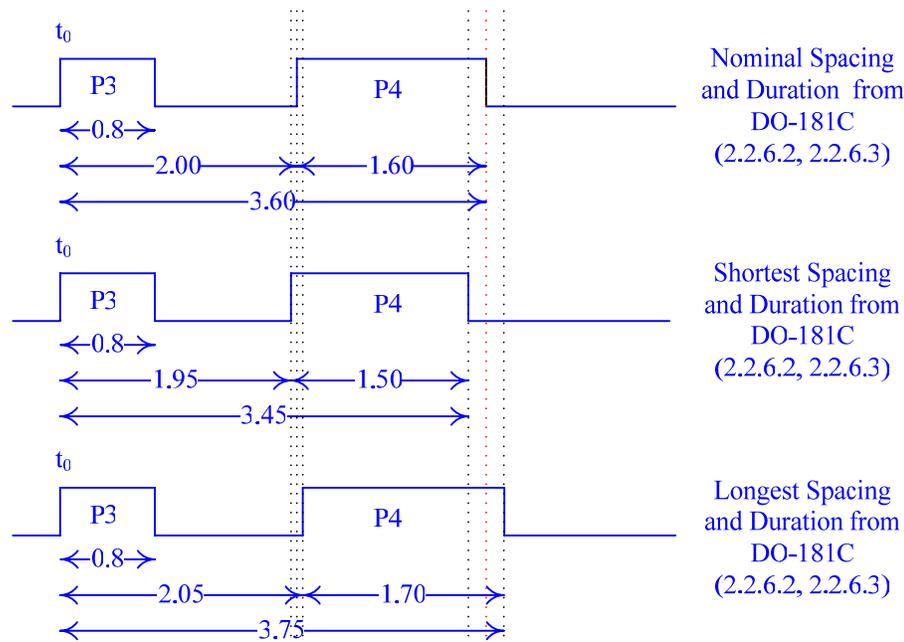
Note: *The time of 4.15 microseconds shown for Bubble 1h is actually 3.75 microseconds after the latest leading edge of P3 which occurs at 8.2 microseconds.*

c. Therefore, it is relatively easy to correlate the **Must Accept** criteria for P4 trailing edge as the trailing edges of P4 line up in both subparagraph “a” and “b” above. One just has to observe that the SARPs appear to be taking into consideration where the leading edge of P3 can occur +/- 0.2 microseconds of nominal.

d. **Simplified Approach:**

As illustrated in the following Figure 2, you could also take nominal P3-P4 spacing of 2.0 microseconds and nominal P4 duration of 1.6 microseconds, to get 3.6 microseconds. Then subtract 1.0 microseconds for the shortest P4 (1.5), subtract 0.05 microseconds for the shortest P4 spacing (1.95), and you get $3.6 - 1.0 - 0.5 = 3.45$ microseconds.

Likewise, take the same nominal 3.6 microseconds, add 1.0 microseconds for the longest P4 (1.7), add 0.05 for the longest P4 spacing (2.05), and you get $3.6 + 1.0 + 0.05 = 3.75$ microseconds.



SARPs 3.1.2.4.1.2.2.1 places must accept requirement on P4 leading edge at 3.45 to 3.75 microseconds from the leading edge of P3. As such, the SARPs are placing the trailing edge at the same place that the DO-181C MOPs are as indicated in the above figures.

Figure 2: Simplified P4 Acceptance

End RHS Commentary on P4 Acceptance:

Must Reject Requirement

A similar analysis is required for the SARPS ATCRBS/Mode S All Call rejection criteria, The SARPS specifies for the trail edge of P4, as per §3.1.2.4.1.2.2.1, rejection if the P4 trail edge is less than 3.30 microseconds or greater than 4.20 microseconds after the P3 lead edge. At nominal P3 to P4 lead edge time of 2.0 microseconds, this is equivalent to P4 pulse duration of 1.30 microseconds on the narrow end and 2.20 microseconds on the wide end. To adhere to the must reject SARPS requirement for all cases, the maximum must reject P4 pulse duration equivalent to the SARPS 4.2 microsecond P4 trail edge requirement would be determined by applying the minimum allowed P3 to P4 lead edge to lead edge rejection spacing, i.e. the

maximum pulse duration for P4 results when P4 is required to be rejected when P4 lead edge is 1.7 microseconds or less relative to P3 lead edge and P4 trail edge is required to be rejected at 4.2 microseconds or more relative to P3 lead edge. This is equivalent to a 2.50 microsecond P4 pulse duration. Therefore, the MOPS would need to require a must reject range for P4 pulse duration of 2.50 microseconds and more for the wide pulse rejection criteria to be equivalent to the SARPS. This is indeed the case as per DO-181C §2.2.6.3.b. Looking at the narrow pulse rejection requirement, the minimum must reject pulse width results from the maximum allowed P3 to P4 lead edge rejection timing, i.e. 2.3 microseconds and the low end must reject P4 trail edge timing, 3.30 microseconds. This results in a minimum pulse width for rejection of 1.0 microseconds. In DO-181C, the P4 must reject pulse duration is defined in 2.2.6.3.b with a reject value of 1.2 microseconds on the narrow side. The MOPS requirements tend to reject less often than the SARPS requirements.

Conclusion

The SARPS and MOPS requirements are not equivalent. In the must accept case, the SARPS may be advantageous and in the must reject case the MOPS may have an advantage if acceptance of an interrogation is the preferred outcome. Solutions include: 1) change the MOPS requirements to be consistent with the SARPS and make the requirements relative to P3 lead edge instead of P4 lead edge; 2) change the SARPS to be consistent with the MOPS and define P4 pulse durations; 3) ignore the differences.

Start RHS Commentary on P4 Rejection:

a. Attempts to Correlate Trailing Edge of P4

Referring to Figure 1, below, lines indicated by bubble **3** were inserted to show the duration of P4 in accordance with RTCA DO-181C. Lines indicated by bubble **4** were inserted to show the trailing edge of P4 in accordance with ICAO Annex 10.

Virtually all possible combinations were tried in order to get the Must Reject Criteria to line up with those of ICAO Annex 10, but to no avail. In fact, the line indicated by bubble **5b** would indicate that the trailing edge of P4 could occur anywhere between 2.90 and 4.60 microseconds after the leading edge of P3. Needless to say, this does not agree with ICAO Annex 10 which requires that the trailing edge occur between 3.30 and 4.20 microseconds after the leading edge of P3, as indicated by the Figure 1 lines indicated by bubble **4**.

b. Final Resort

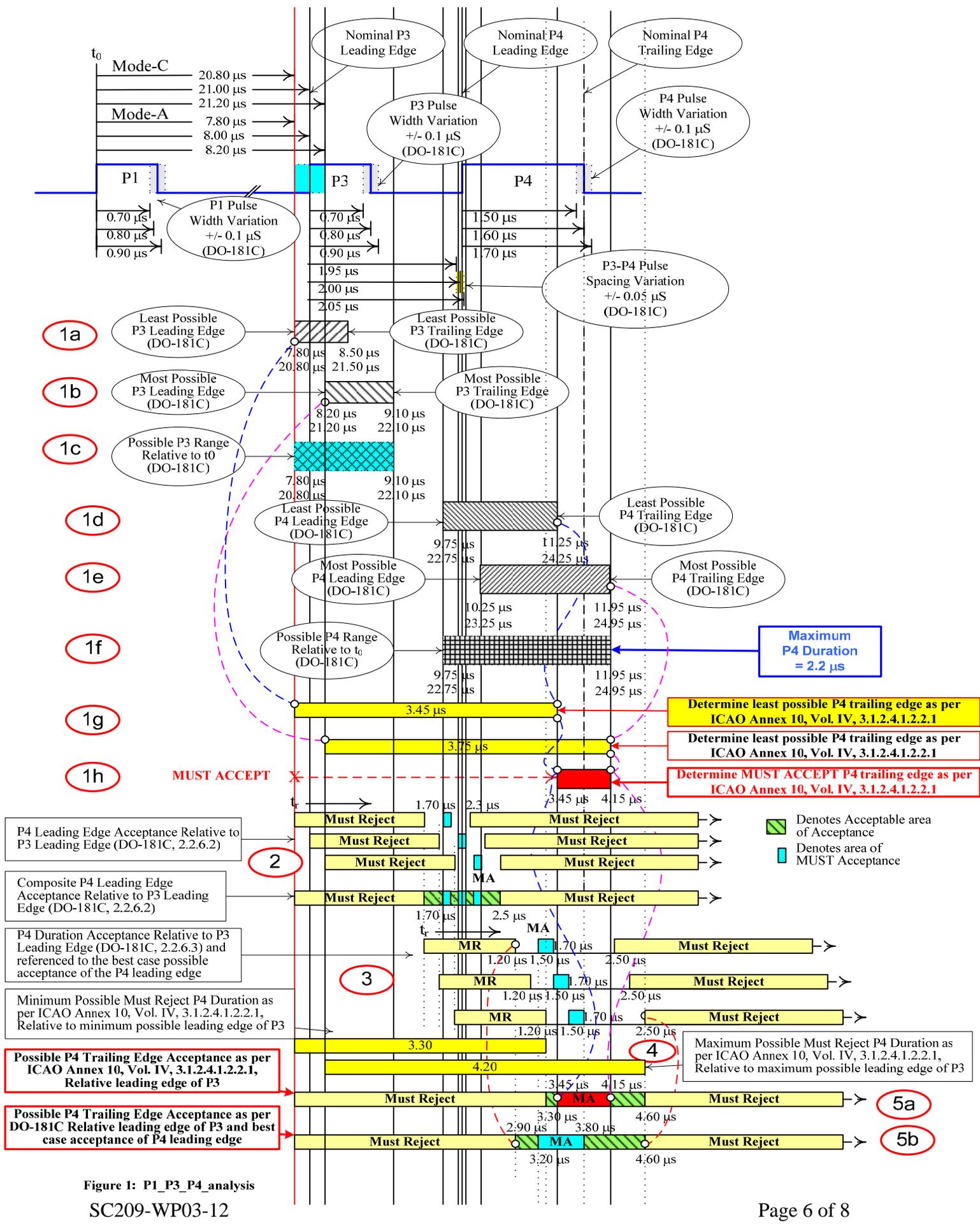
As a final resort during the discussions at Eurocae WG-47, Meeting 7, it was suggested that rising edge and falling edge requirements be taken into consideration when attempting to establish the ICAO Annex 10 P4 Trailing Edge requirement numbers. As there was no further time left during the meetings to pursue this possibility, the following addresses the proposed case.

- (1). Consider NOMINAL P3—P4 leading edge spacing of 2.0 microseconds

Add 1.2 microseconds for Minimum Duration of P4 in accordance with RTCA DO-181C and the result is 3.2 microseconds.

Add Minimum Rise and Fall Times of P4 of 0.05 microseconds and the result is 3.3 microseconds to the trailing edge of P4 as per ICAO Annex 10.

$$[2.0 + 1.2 + 0.05 + 0.05 = 3.30]$$



- (2). Consider NOMINAL P3-P4 leading edge spacing of 2.0 microseconds, once more Add 2.5 microseconds for Maximum Duration of P4 in accordance with RTCA DO-181C and the result is 4.5 microseconds.

Subtract Maximum Rise Time of 0.1 microseconds and Maximum Fall Time of 0.2 microseconds, and the result is 4.2 microseconds to the trailing edge of P4 as per ICAO Annex 10.

Therefore, the establishment of the P4 trailing edge rejection criteria by ICAO Annex 10 can at least be explained.

End RHS Commentary on P4 Rejection:

Conclusions:

This document has been able to correlate the Must Accept Criteria for the Trailing edge of P4 relative to P3 between ICAO Annex 10 and RTCA DO-181C. Likewise, this document demonstrates where the P4 trailing edge rejection criteria may have been established by ICAO Annex 10. However, the analysis would indicate that implementation consistent with the ICAO P4 trailing edge rejection criteria could result in appropriate P4 pulses being rejected which could result in loss of transponder replies to Mode-S All-Call Interrogations.

Furthermore, use of the trailing edge for acceptance and rejection of the P4 pulse is inconsistent with the time line of events which must be processed by the transponder, as follows:

Assuming that a valid P1—P3 pair has been detected by the transponder:

- a. First, the transponder must enable the transmitter in order to be ready to reply with either a Mode-A or Mode-C reply in the event that no P4 leading edge is detected. Note that the reply must be started within 3.0 +/- 0.5 microseconds relative to the leading edge of P3.
- a. Next, it must detect the leading edge of P4 within the allowable must accept and must reject requirements,
- b. Next, it must determine that P4 meets the minimum pulse width of 0.3 microseconds:
 - (1). If not, the entire interrogation must be rejected, and the transponder must immediately recover in order to process another incoming interrogation
 - (2). If minimum pulse width is met, then the transponder continues to process the P4 pulse for duration. Note that the transmitter can be disabled at this time since the transponder will either not reply or will have 128 +/- 0.25 microseconds to reply, depending on the duration of P4.
- c. Next, if the P4 Pulse proves to be a short pulse, e.g., 0.8 microseconds, the transponder must reject the entire interrogation, reset, and be ready to process the next incoming interrogation,
- d. If the duration of P4 proves to be acceptable, then the transponder replies with a DF=11 reply within 128 +/- 0.25 microseconds of the leading edge of P3.
- e. Otherwise, the entire interrogation is rejected and the transponder must be prepared to process the next incoming interrogation.

As such, most modern transponders do not establish accept and reject criteria of the P4 pulse based on the trailing edge as suggested by ICAO Annex 10. Rather, acceptance / rejection is established on first having the proper leading edge of P4 followed by the proper duration.

As demonstrated in this document, the ICAO Annex 10 P4 requirements cannot easily be correlated to those used in RTCA DO-181C. In fact, the ICAO Annex10 requirements tend to confuse the P3-P4 decoding process and could thereby lead to poor interrogation decoding performance. Therefore, it is recommended that strong consideration be given to amend the ICAO Annex 10 SARPs to be more consistent with those of RTCA DO-181C.