RTCA Special Committee 209

Mode S Transponder MOPS Maintenance

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Trig Avionics Proposal for a Revised Whisper-Shout Requirement and Test Procedure

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SUMMARY

This Working Paper presents Trig Avionics proposal for revising the Whisper-Shout requirement and test procedure in DO-181D.

Introduction

The interaction of Airborne Collision Avoidance Systems with transponders has been discussed at previous SC-209 meetings, and a proposal has been made for a testing regime that could catch non-interoperable implementations. Whilst the proposed testing might weed out some non-interoperable transponders, we at Trig Avionics do not believe it is the right solution. It is possible to have an interoperable transponder that fails the proposed test. It is also possible to have a transponder that passes the proposed test, but does not interoperate with ACAS.

Problem Revisited

TCAS acquires targets by sending Mode C interrogations (P1 and P3). In order to manage the replies and avoid cluttering the spectrum the TCAS interrogator inserts a pulse in front of the interrogation (S1), spaced the same as a suppression pair, but at a lower power than the P1 pulse. The intent is that only a subset of the transponders in the vicinity will reply. The TCAS interrogator then progressively steps the S1/P1P3 power levels up through predetermined power levels to iteratively acquire all the potential targets.

The notional width of each interrogation band is set by the difference in power level between S1 and P1. The wider the gap between S1 and P1, the larger the set of transponders that will reply to each interrogation. The recommended whisper-shout gap is 7.5 dB.

Successive interrogation bands overlap. That is, the step from one interrogation to the next is smaller than the whisper-shout gap. This accommodates the end-cases in the transponder behaviour where either S1 or P1 is close to the MTL, because the next attempt will be less likely to be adjacent to an end case. The recommended step is 6 dB.

The success of this algorithm is based on the following three basic assumptions:

1. Transponders for which all three pulses are below the MTL will <u>not</u> reply.
2. Transponders for which the S1 pulse is below the MTL but the P1 and P3 are above the MTL <u>will</u> reply.
3. Transponders for which all three pulses are above the MTL will <u>not</u> reply.

We will refer to these as TCAS requirements 1, 2 and 3. Of these requirements, number 3 is already covered in the MOPS – that is well defined behaviour. Requirement 1 is only indirectly addressed in the MOPS, but a MOPS compliant transponder will behave satisfactorily for TCAS.

TCAS requirement 2 is not covered at all in the MOPS, and the revisions to the transponder MOPS should address that requirement.

MTL Sidebar

Certain aspects of the transponder response to signals around MTL are key to the behaviour of TCAS. It is therefore worth reviewing the MOPS treatment of MTL.

The Mode A/C MTL is defined as "the minimum input power level that results in a 90% reply ratio if the interrogation signal has all nominal spacings and widths". The MOPS also requires that the MTL for Mode C interrogations be in the range -73dBm, +/- 4dB.

There is another sensitivity requirement in the MOPS which is relevant here – there is an absolute floor specified of -81dBm, and the transponder must reply to not more than 10% of interrogations at -81dBm or below.

There is therefore an implicit function of replies in which as the interrogations get quieter, the reply rate reduces. In the range from MTL down to -81dBm the reply rate must reduce from 90% to 10% (or less). There is nothing in the current MOPS that constrains the shape of that curve; depending on how the pulse detector threshold is implemented it could be a tidy steep cliff or a raggedy slope, but all would be compliant with the MOPS, and all would satisfy TCAS requirement 1 above.

The TCAS whisper shout requirement number 2 makes an additional assumption about this sensitivity curve – it assumes that the sensitivity to S1 pulses declines with signal level quite steeply. At the heart of the original Garmin problem was the fact that this was not true – near MTL the GTX330 was better at receiving S1 pulses than it was at receiving the actual P1/P3 interrogations.

Review of Existing Proposal

The current Honeywell/Collins proposal for new requirements adds three items

1. With P1 at MTL and S1 at MTL -6 dB, the transponder shall reply to ATCRBS interrogations at least 90 % of the time.
2. With P1 at MTL and S1 at MTL -3 dB, the transponder shall reply to ATCRBS interrogations at least 70 % of the time.
3. With P1 at MTL and S1 at MTL, the transponder shall reply to no more than 10% of ATCRBS interrogations.

Proposal number 3 above is a restatement of an existing MOPS requirement (DO181C paragraph 2.2.5.1 c), so this is already true for all transponders. Fortunately DO-181C paragraph 2.2.5.1, parts a and c is also a complete answer for TCAS requirement number 3 so the good news is that we all meet TCAS requirement number 3 without any other work.

Proposal number 1 above is closest to being a useful statement of TCAS requirement number 2, but has a couple of weaknesses. It uses 6dB between S1 and P1, which is slightly less than TCAS generally uses, although it could be argued that this is erring on the conservative side. More importantly it pegs the P1 level at MTL, and is therefore a single point test which is not necessarily the most critical case for the TCAS algorithm – we are more interested in cases that bracket MTL, rather than hit it head on. In fact, since the TCAS stair-step algorithm uses overlapping windows of interrogation amplitude, the special case where one or other of the pulses happens to coincide with the receiver MTL is actually a "don't care" point for the TCAS algorithm – it doesn't really matter whether the transponder behaves as though the pulse in question were below or above MTL, because it will try again shortly with all the levels stepped up.

Finally, a detailed objection – as was noted in the discussion of MTL above, the MTL point is defined to be the level of P1/P3 which returns exactly 90% replies. Unless you anticipate that inserting S1 actually improves the reply rate, then the reply rate under test number one can never be more than 90%; it can only be less than or equal to 90%, so the wording of the requirement is incorrect.

Proposal number 2 above is only very indirectly testing the compatibility with TCAS. It doesn't address any of the TCAS requirements, but what it does measure is the effective sensitivity slope for the detection of S1. Since the reply rate at MTL without the S1 present was 90%, asserting that the reply rate with S1 at MTL-3dB is 70% or better implies that we are seeing at most 22% of the S1 pulses when the S1 pulses are at MTL-3dB, and therefore give an implicit slope for the pulse detector. That's a bit of a stretch without knowing the internal workings of the transponder, and whilst it might be true that a transponder which passes that test is more likely to work correctly with TCAS, it does not directly address the TCAS requirements.

Alternative Proposal

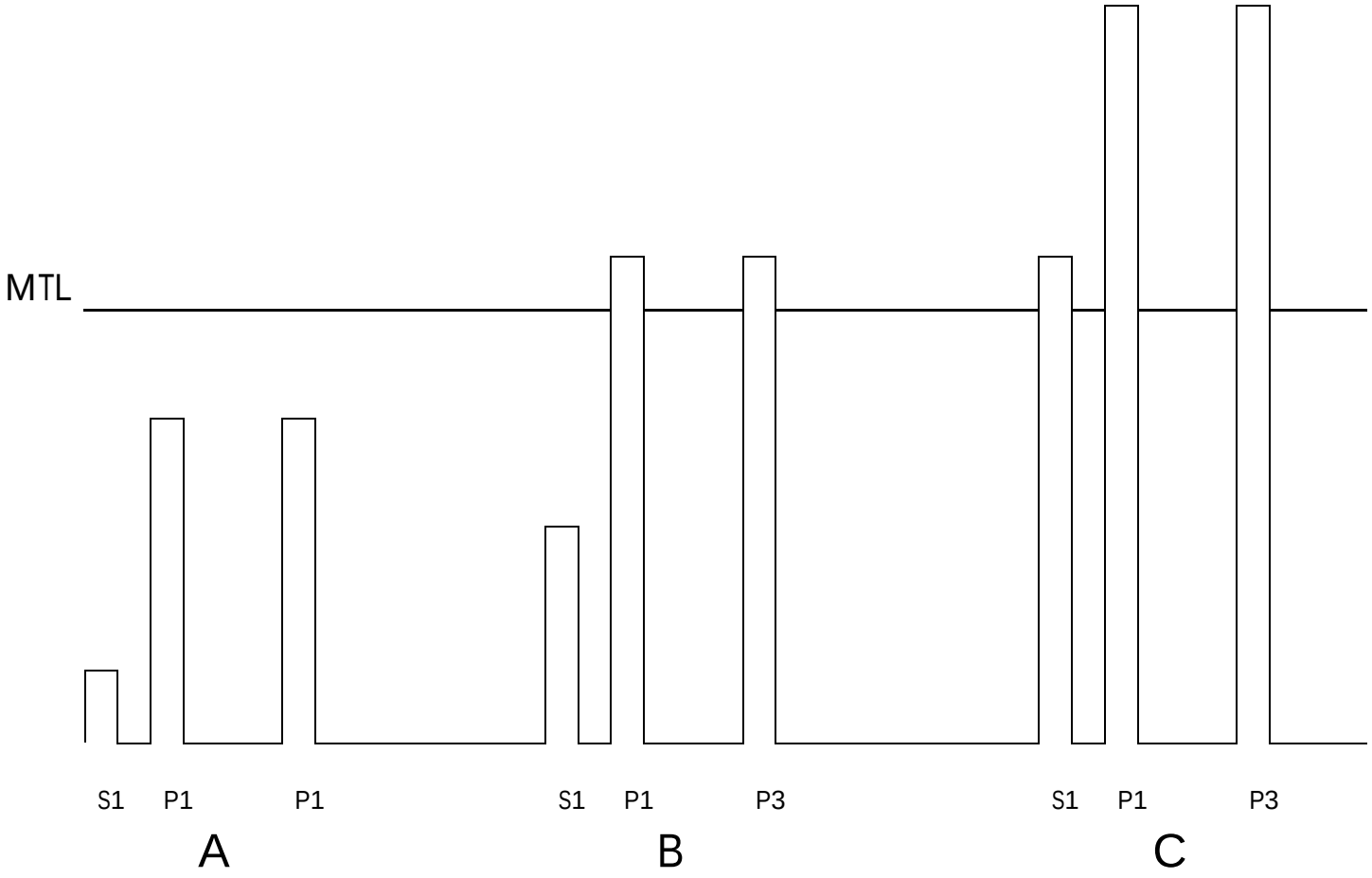
The TCAS requirement is that when S1 and P1/P3 bracket the MTL, the transponder will reply with high probability for all power levels within the non-overlapping portion of the interrogator window. Rephrased as a requirement on the transponder, this would be:

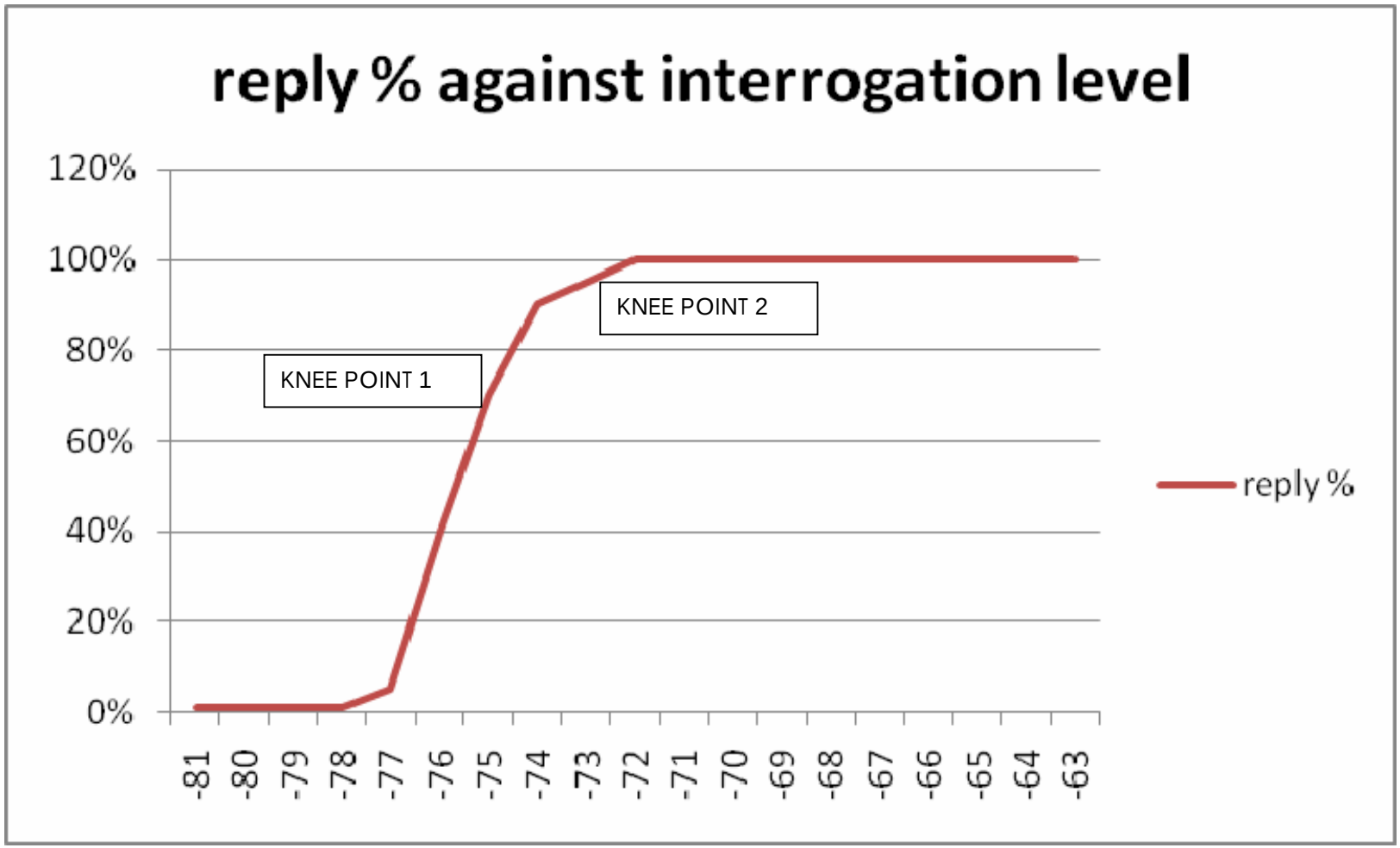
With an S1 pulse 7.5 dB below the P1 pulse, the reply ratio to Mode C interrogations shall be not less than 70% for all levels of P1 between MTL and MTL+6dB.

Discussion

Our analysis shows that the hardest part of this new requirement for many transponders is not the reply ratio when P1/P3 is at MTL and S1 is at MTL-7.5dB. Since the S1 pulse is well below the pulse detector threshold, that is not particularly different to the original MOPS requirement for MTL. (Even the erroneous GTX330 replies to that test point). The harder part is maintaining the reply rate when the interrogation is at the **upper** end of the window. When the P1/P3 pair are at MTL+6dB the S1 pulse is only MTL-1.5dB, and depending on the receiver design quite a few of those pulses will be recognised. That is why the success criteria is set at only 70%, rather than the more usual 90%.

Example Whisper Shout operation




reply % against interrogation level
120%
100%
80%
60%
40%
20%
0%
KNEE POINT 1
KNEE POINT 2
-81
-80
-79
-78
-77
-76
-75
-74
-73
-72
-71
-70
-69
-68
-67
-66
-65
-64
-63
reply %

Floor level	-81	dBm
Reply rate at and below floor	1%	

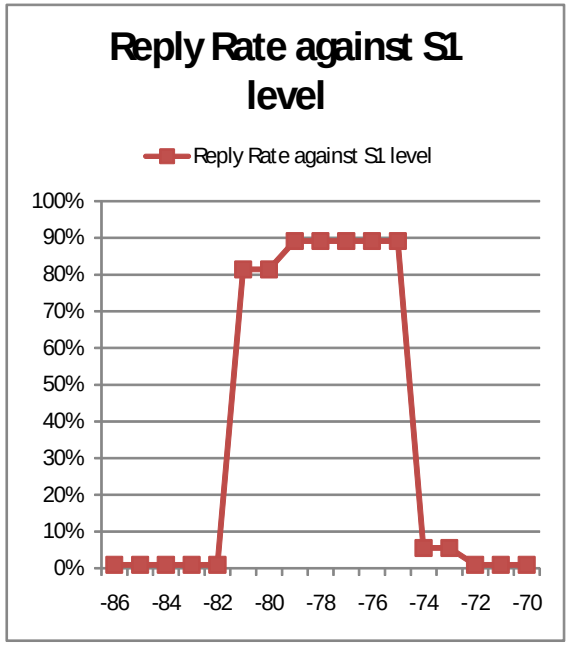
knee1 point	-75	dBm
reply rate at knee1	1%	

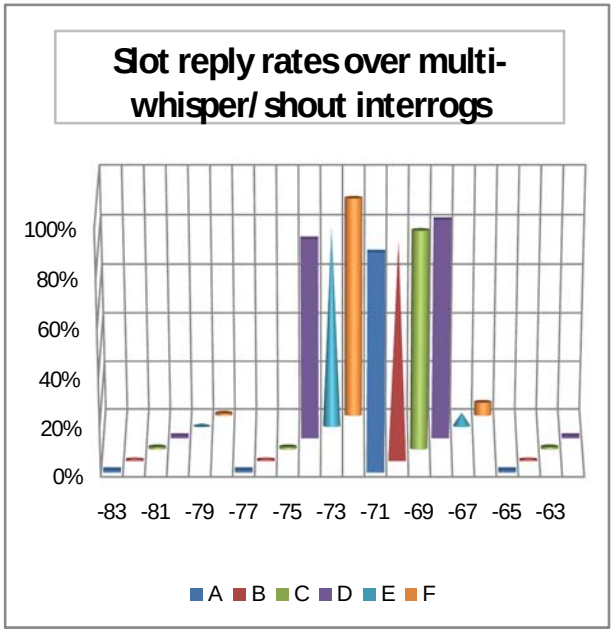
MTL	-74	dBm
MTL reply rate	90%	

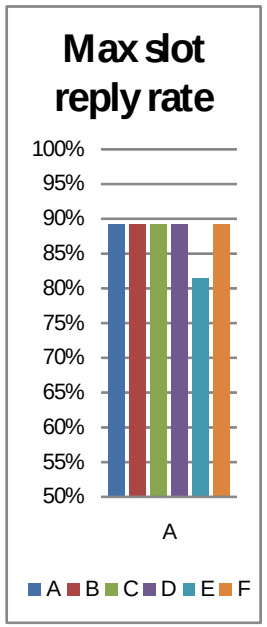
knee point2 (above MTL)	-72	dBm
reply rate at knee2	99%	

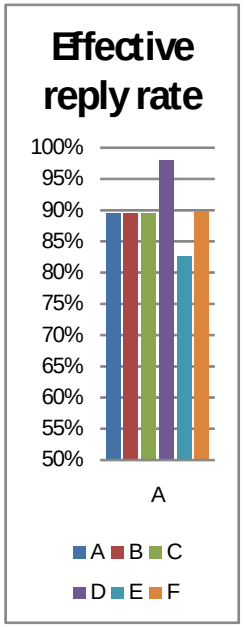
S1-P1 spacing	7

Average effective reply rate	90%









Floor level	-81	dBm
Reply rate at and below floor	1%	

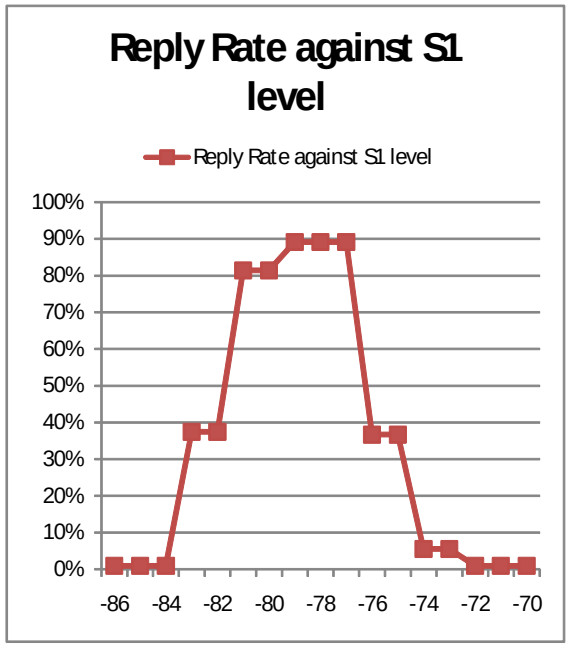
knee1 point	-76	dBm
reply rate at knee1	40%	

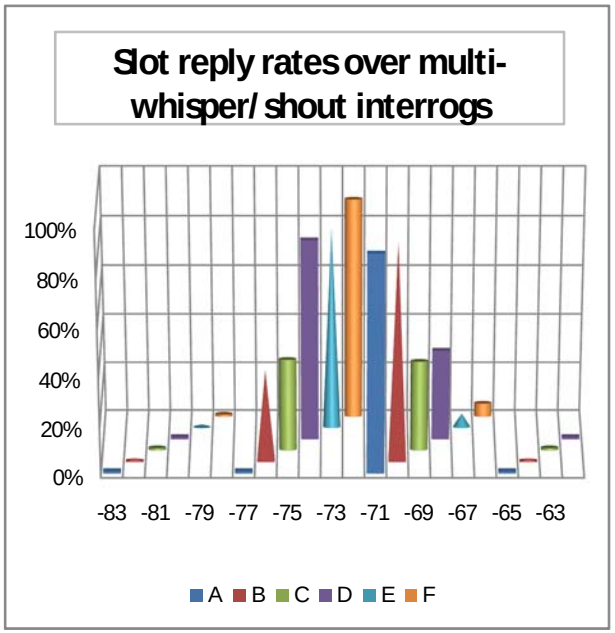
MTL	-74	dBm
MTL reply rate	90%	

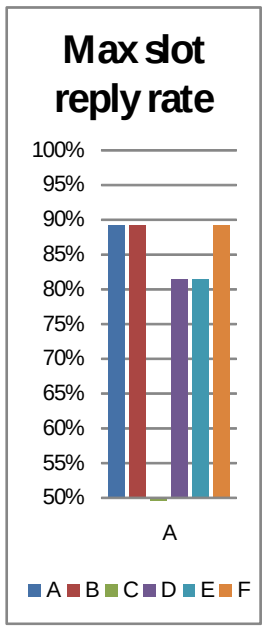
knee point2 (above MTL)	-72	dBm
reply rate at knee2	99%	

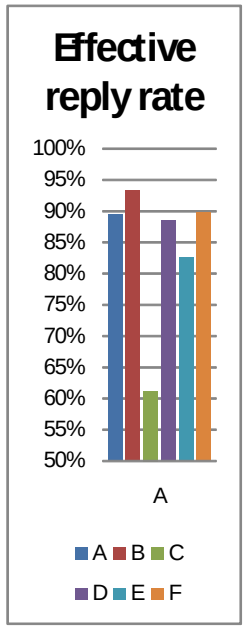
S1-P1 spacing	7

Average effective reply rate	84%









Proposed test:

With an S1 pulse 7.5 dB below the P1 pulse, the effective reply ratio of a pair of Mode C interrogations spaced at interrogation levels spaced 6dB apart shall be not less than 60% for all levels of P1 between MTL-3 and MTL+9dB.
The effective reply ratio is (1 – ((1-reply ratio1) x (1 – reply ratio 2))).

Note:
The effective reply ratio of a pair of interrogations 6dB apart measures the reply rate experienced by the interrogator after both interrogations have been completed, as this gives the overall visibility of the interrogated system to the interrogator. This is required as the interrogator steps may just catch the edge of transponder reply sensitivity change around MTL respond at a lower reply rate to two interrogations, rather than responding at a high level one interrogation.