ModeS-WP01-18

RTCA Special Committee 209

Working Group #1

Mode S Transponder Development / Maintenance

Meeting #1

RTCA, Washington DC
3 – 5 April 2007

ATCRBS Transponder Issue with Decoding Mode S P6 as a Result of Failure to Detect the Mode S Interrogation (preamble) P1 Pulse that Produces False Targets at Interrogators

Phillip J. Woodall
Raytheon

SUMMARY

This information is a draft technical paper that has not been coordinated nor reviewed. It is intended only to help illuminate the subject problem and assist in developing a constructive solution.

ATCRBS Transponder Issue with Decoding Mode S P6 as a Result of Failure to Detect the Mode S Interrogation (preamble) P1 Pulse that Produces False Targets at Interrogators

Overriding Statement

This information is a draft technical paper that has not been coordinated nor reviewed. It is intended only to help illuminate the subject problem and assist in developing a constructive solution.

Proposed Solutions Summary

1. Fix the fielded ATCRBS transponder exhibiting the subject problem.
2. Fix the ATCRBS MOPS to preclude future problems.
3. Improve the Mode S MOPS relative to the applying the same new ATCRBS tests.

These solutions will be specifically addressed following a general discussion of possible functional implementations that might cause the subject problem or amplify its effects.

Discussion of the Problem

From a legacy standpoint, the use of the P1 – P2 Mode S preamble with P1 = P2 amplitude was 'assumed' to suppress ATCRBS transponder decoding of any portion of P6. This was 'assumed' to preclude any Mode S P6 waveform impact on the ATCRBS transponder aside from the associated additional suppression time and its impact on transponder availability. Any need to go beyond the P1 – P2 preamble was not identified.

However, the specified 'gray region' of SLS decision thresholding is such that the P1 = P2 case does not give high confidence that the P6 preamble will strongly suppress – declare SLS – in all ATCRBS transponders. Still, the problem as currently identified indicates that the SLS loss is due to missing detections of P1, not P2. Assuming this is true, the following applies.

Unfortunately, the ATCRBS MOPS Mode A and C decoding and SLS detection requirements are pre-Mode S and decoding-SLS functional implementations can (are not constrained from) significantly affect the subject problem while meeting all ATCRBS requirements. Related to but not directly on the subject, are a number of operationally identified though minor problems that are "goings-on" on 1030 MHz that produce false target problems at interrogators. These are not controlled – specified against – in the ATCRBS MOPS. The (ATCRBS) MOPS have historically been anchored in the past because there have been few 'modernizations' compared to Mode S as a result of the data link, TCAS, and ADS-B interactions with the aircraft. That said, the following are functional implementation 'possibilities' that could affect how the ATCRBS transponder handles the P6 waveform.

First Assumption

First Assumption: ATCRBS MOPS are met but shaved to reduce production and test costs. To meet both false reply (squinter) requirements and MTL in the absence of P2, the throughput bandwidth may be reduced to the absolute minimum. Below this minimum, meeting pulse width and decoding tolerances, and sensitivities are essentially impossible. This extreme position would not be taken on an airline rated transponder because the cost savings is likely more than offset by the resulting qualification and customer satisfaction issues.

Looking at the case when this maximum bandwidth and cost reduction is instituted, thresholds must be adjusted away from theoretical nominals – raised – to achieve the objectives sought through minimized bandwidth. Typically, the objectives are met by increasing sensitivity through bandwidth reduction and then some is given back by raising the detection threshold that allows meeting the false reply squitters. SLS threshold may then also be raised to reduce false suppressions due to noise detections without failing the SLS detection requirements.

Implications of the First Assumption

The unexpected consequence of the first assumption ATCRBS transponder is that it is more likely to make detection threshold decisions during P6 than would a standard bandwidth, nominal threshold setting nominal ATCRBS mode in Mode S transponders or in conservatively designed ATCRBS only transponders. Correction (minimization) of P6 decoding by current ATCRBS and Mode S transponders would establish a baseline for further action. **Before proceeding, it should be restated that this challenging situation occurs even when the first assumption ATCRBS transponder meets existing ATCRBS MOPS requirements**. Therefore, testing of the offending ATCRBS transponders against the present ATCRBS MOPS does not seem to be a particularly useful direction to take.

This is due to the fact that important parameters affecting the problem have not been controlled in the current ATCRBS MOPS. Consider a specific possibility. If the IF bandwidth of a transponder is minimized, particularly if the filter characteristic is selected only for noise equivalent bandwidth and not for controlled group delay – as would be needed in a Mode S transponder design – the amplitude ripple produced by the P6 BPSK phase modulation will be accentuated prior to envelope and then threshold detections. Once accentuated, it can’t be filtered out in the simple sense. Detection of the accentuated ripples is further accentuated by the higher detection threshold setting. This is notionally illustrated in figure 1.

The specification view of the potential ATCRBS decodes is shown in figure 1(a). The first option (A) is for P2 detection as a P1 and P6 ripple coming 8 or 21 μs later causing P3 detection. The second option (B) is for the detection of the leading edge of P6 as P1 and P6 ripple as a Mode A or C decode. Finally, there's option (C) that can occur anywhere over a short P6 for Mode A and over P6 long for Mode A and C.

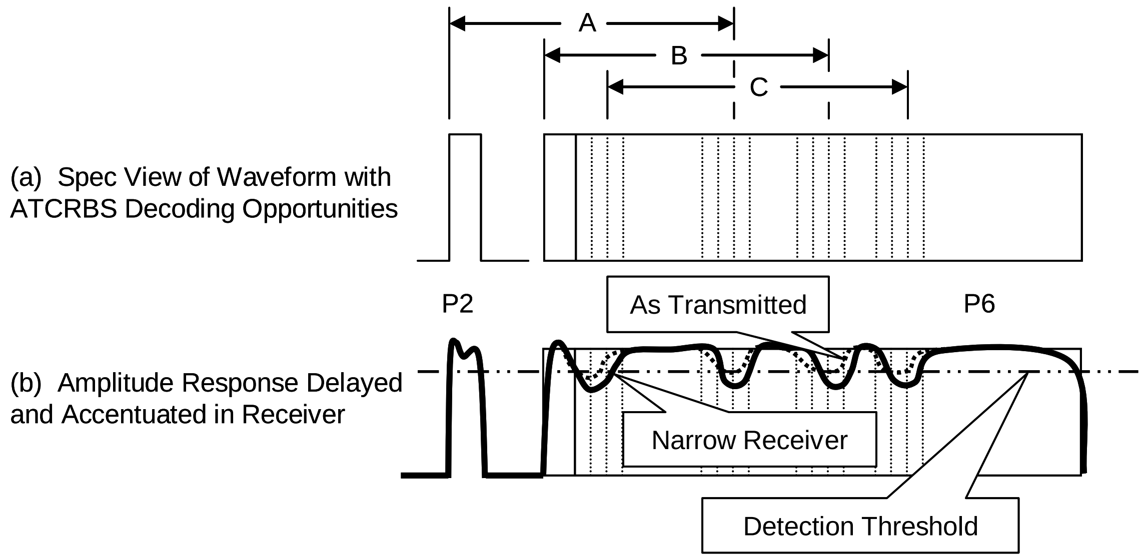

Figure 1. P2 and P6 Waveforms and Amplitude Envelopes

In figure 1(b), the RF waveform envelope (single sided) is shown. The as-transmitted waveform has ripple but should be at or less than the conservative threshold setting for ATCRBS decoding (dashed waveform) in Mode S transponders. The heavy line is the waveform envelope at the point of detection in the receiver, after it has been (may be) delayed and accentuated by the narrow, non-optimal IF (and possibly) RF filtering. In the latter case, ripple detection is more likely, particularly with a high threshold setting.

At this point it is observed that it would be effective to implement a Constant False Alarm Rate (CFAR) function that identifies a P6 from its signal density function as is done in spread spectrum radar and IFF receivers, and to use this CFAR to desensitize the ATCRBS decoding during receipt of P6 to augment the SLS suppression function. This is immediately recognizable as having considerable potential impact on existing designs of either ATCRBS or Mode S transponders and does not seem to be warranted based on extensive operational use of most designs over quite a period of time. A more appropriate response seems to be to weed out the offending designs and fix the hole in the fence.

Some Additional, Related Technical Details

Controlling P6 Ripples – When a P6 BPSK waveform is passed through a bandwidth limiting filter – to remove spectrum sidebands during transmission – amplitude ripples are produced. Mode S interrogators produce amplitude ripples in P6. It is assumed that all Mode S interrogators do not produce excessive P6 ripples. DO-185A for the TCAS Mode S interrogator function provides a simple way of defining what is acceptable P6 ripple and how it can conveniently be measured. As the transponder receive filter is in series with the transmitted ripple, the depth of the ripple and its duration is unfortunately increased. Inadvertently putting a poor phase response filter in an ATCRBS transponder will further increase the potential for the subject problem. The bulk of existing transponders do not appear to have this problem.

P1 – P3 and P1 – P2 Detection

The question is, what mechanism allows SLS detection failures to expose the undesirable P6 decodes when P6 is transmitted at the same amplitude as its associated P1 and P2? Looking first at the MTL, P1 – P3, detection process, as the signal level is reduced below a 100% reply rate the failure to threshold by either P1 or P3 produces the reduced reply rate. As the reply rate approaches 0%, the loss of both P1 and P3 dominate. In the region between say 30% to 90%, it is still likely that either P1 or P3 don’t threshold. Similarly for P1 = P2 amplitudes, it is likely that P1 will fail to detect as for P2 to detect. At a signal level equivalent to 50% reply rate, 50% of the time P1 is not detected, which is equivalent to 25% failure to produce a SLS, opening the door for a false P6 decode. The possibility of a P2 to P6 decode exists that would add to the possibility of a false target being generated at the interrogator.

One can not improve the sharpness of MTL and P1 – P2 detection unless the threshold is raised much higher, improving the signal-to-noise ratio at the thresholding point but with the attendant reduction in MTL sensitivity. Not possible. Therefore, as the Mode S waveform (preamble plus P6) comes out of noise, it is likely that there will be failures to detect the P1 – P2 pair by the first assumption ATCRBS transponder while it still decodes P6 ripple and falsely replies at rates that sometime produce false targets.

Further to the problem, in situations where lateral multipath causes a delayed or attenuated version of P6 to reach the offending transponder, the conditions for false target generation are magnified. Here again, the most assured solution is to accept the fact that SLS failures will occur and therefore minimizing P6 decoding as the more fruitful avenue to pursue.

Conclusions

1. If excessive P6 ripples exist in an ATCRBS transponder pre-detection and the pseudo-leading edge timing allows Mode A or C decodes, SLS decode failures guarantee the subject problem will exist.
2. In the vicinity of MTL, loss of SLS detections due to the loss of P1 or P2 pulses is significantly probable even in strong implementations.
3. The detection statistics of the ATCRBS transponder waveforms are such that noisy SLS detections occur in the vicinity of MTL. Further, MTL in ATRBS transponders can occur over a 9 dB signal range, which is a considerable target distance (radial range) variation where the problem might manifest.

4. If a Mode S interrogator has excessive transmitted ripple or it employs a Mode S – ATCRBS supermode operation, false target generation potential will be aggravated.
5. There is no ATCRBS MOPS requirement to limit the probability of P6 ripple induced ATCRBS replies in the absence of a SLS, with or without P2 detection. Testing of P6 decodes without a P1-P2 suppression pair is not a current requirement but should not present a monumental challenge.
6. Marginal implementations may greatly increase the probability of this undesirable operating condition.
7. Future ATCRBS only transponders should be specified to minimize all of the characteristics that lead to false P6 ATCRBS decodes and replies in the absence of SLS P1-P2 pairs. Likewise, future Mode S transponders might insure that the ATCRBS mode of operation is optimized against the subject problem.

Proposed Solutions

The laws of physics limit the opportunities for resolving the subject problem. That is, there is the potential for it happening with a well designed ATCRBS transponder that simply has not been required to address P6 decoding suppression through conventional design adjustments. The following is proposed as one near optimal approach, but one that requires a state of serious concern before it is undertaken. While additional testing of offending transponder designs may be useful, current requirements and TSO minimums are unlikely to "get them off the street." The proposals:

1. **Fix the fielded ATCRBS transponder problem.**

   Identify the offending transponder types. It is assumed that this will demonstrate that a particular transponder type or types are the culprit and that a particular type Mode S interrogator or it operations are not implicated in the problem. Review the TSO data. If the TSO data is compliant with the requirements, the responsible Government will replace the defective units with either conforming units, see 2, below, or the original units that are aligned or modified to meet the, new conforming TSO. [Other Nations but not the US.]

2. **Fix the ATCRBS MOPS to preclude future problems.**

   Develop a small set of P6 waveforms having valid data that produce optimal opportunities for undesired Mode A (and Mode C) decoding. Add the requirement to test the ATCRBS transponder with the above identified test BPSK P6 waveforms with both no P1 – P2 pulses and no P1 pulse inserted over the range from -80 dBm to -21 dBm with no more than 1% false replies being produced in either Modes A or C.

3. **Improve the Mode S MOPS relative to applying the same new ATCRBS tests.**

   Incorporate an appropriate version of the ATCRBS MOPS revisions in the ATCRBS section of the Mode S MOPS for consistency of operation.

– End –