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Transponder Reply Limiting

[Unclassified Title]

WALTON B. BISHOP

Security Systems Branch
Electronics Division

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ABSTRACT

(U) The concept of causing the transponder to limit the number of replies it will make or the rate at which it will transmit them under various circumstances is explored qualitatively. It is shown that reply limiting by transponders is a potentially valuable means of improving radar-beacon system traffic capacity and reliability. Recommendations are made for more detailed studies of reply-limiting techniques so that the most effective and/or most efficient or least expensive ones can be chosen for use.

PROBLEM STATUS

This is an interim report; work is continuing on other phases of the problem.

AUTHORIZATION

NRL Problem 52R03-05.302
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TRANSPONDER REPLY LIMITING

Walton B. Bishop

1.0 INTRODUCTION

(C) Radar-beacon transponders are ordinarily designed so that they can respond to interrogations more rapidly than they are expected to need to. Since their early days, however, transponders have been equipped with safety devices designed to prevent them from trying to respond at rates that would exceed transmitter capabilities. One might expect such an overload protection circuit to be triggered by high temperature, but since any excessively high temperature could do severe damage to a transponder, automatic overload control circuits are usually triggered by some predetermined adequately-high response rate. The triggering action simply reduces the transponder receiver's sensitivity until the number of interrogations received is below the maximum-allowable response rate, i.e., the triggering level. The response-rate-limiting automatic overload control circuit also offers some improvement in the system's reliability and resistance to jamming. Recent studies concerning how the Mark XII system might be made to provide additional functions for the Federal Aviation Administration [1] and how it might perform additional Communications, Navigation and Identification (CNI) functions [2] [3], have led to the consideration of new transponder-reply-limiting techniques. Some of these new techniques, and what might be gained by using them are discussed in this report.

2.0 RESPONSE-RATE LIMITING

(U) It is not particularly difficult to determine the maximum safe rate at which a transponder's transmitter can transmit replies, if we wait until the transponder has been designed and built. To determine the maximum rate at which a transponder <u>should</u> be able to transmit replies, however, depends upon some difficult-to-determine factors. We shall not try, in this report, to determine this maximum rate, but we shall indicate some of the factors that must be considered in determining it.

(U) The exact purposes of response-rate limiting must be examined very carefully before rate determinations can be made. The problem of limiting reply rates to those which the transponder's transmitter can handle is an economic problem that has little bearing today. Once it is known how rapidly a transponder should be able to transmit replies, a transmitter can easily be designed to reach this rate. Reply transmission at rates higher than needed is wasteful and should be avoided.

2.1 To Overcome Jamming (C)

(C) The use of response-rate limiting to help overcome enemy jamming is one long-avowed purpose of Automatic Overload Control (AOC) circuits [4]. The concept is quite straightforward: If enemy jamming consists of many interrogations that look like ours, then a transponder may be overloaded seriously enough to sustain damage, or it may simply be so busy answering enemy interrogations that it has no time left to answer friendly interrogations. If friendly interrogations are stronger than the enemy interrogations, then an AOC circuit that reduces receiver sensitivity each time the response rate exceeds a certain figure will cause at least some of the enemy interrogations to be ignored, and some of the friendly interrogations to elicit replies.

(C) To counter jamming, the AOC circuit does not need to start reducing receiver sensitivity until the transponder reply rate has become considerably higher than it would be if several friendly interrogators were interrogating the transponder simultaneously. Also, the AOC circuit's reaction time does not need to be particularly rapid. Jamming that occurs for only very short intervals of time is not likely to be very effective; so the AOC circuit may adjust slowly to the high response rates produced by jamming. An AOC circuit that reduces receiver sensitivity a few tenths of a second after enemy interrogation jamming causes the transponder response rate to become excessively high should be quite adequate. Ideally, the antijamming AOC circuit should return the receiver to full sensitivity in a somewhat shorter time after the jamming ceases but, in this case too, a few tenths of a second can probably be tolerated.

(U) The actual AOC response-rate setting, thus,depends primarily upon the rates at which our interrogators interrogate and how many are likely to be trying to obtain responses from a given transponder simultaneously. The rates at which ground-based interrogators interrogate are all assigned by the FAA [5]. While use of an average figure for these rates neglects some important factors such as the chance that synchronous interference between interrogators will occur [6], and the geographical distribution of interrogation repetition frequency assignments, a conservative estimate of interrogation reception rates at a transponder can be made by using it. The same average rate may also be used to determine what portion of the interrogations reaching a transponder will elicit no replies due to the action of Interrogation-Side-Lobe-Suppression (ISLS) signals from another interrogator. The problem of determining interrogator antenna beam widths is another where average figures may be used. Consideration must be given to main-beam or response-triggering beam widths, side-lobe coverage, and even the range of reflection-suppression transmissions now being used at some installations [7].

(C) Although ISLS and anti-reflection signals do not elicit responses, they may be used to help determine when a transponder's receiver should have its sensitivity reduced as a mutual interference reducing or as an anti-jamming measure.

(C) Our discussion thus far serves only to indicate that the use of a response-rate limiting technique to overcome a particular type of possible enemy jamming is not a simple matter. More detailed consideration of AOC triggering levels may be found in a separate report [8].

2.2 To Increase Reliability

(C) If the response-rate-limiting AOC circuitry is intended primarily for increasing the radar-beacon system's reliability and/or capacity, some additional difficult-to-determine factors must be considered. For example, not only must we know the probability that some number of our interrogators will have their response-triggering beams aimed toward a particular transponder, but we must also know the average length of time this situation will continue once it starts. Further, we need to know the minimum acceptable round reliability that will permit satisfactory (reliable) operation of the system. We assume that an antijamming technique might be worthwhile even if it does not permit fully satisfactory operation for all prospective users in the presence of jamming. Reasonably good operation for a few is usually considered better than no operation at all. This concept is open to question, however. There are a number of ways in which the ATCRBS could be improved before resorting to AOC action. Most of these possible improvements would have a marked effect upon the choice of AOC triggering levels, reaction times, and the types of circuits that could be used for AOC. (1) Antenna improvements: Better directivity for interrogator antennas and better omnidirectional coverage for transponder antennas top the list of improvements needed. Current antennas and current interrogation repetition frequencies cause us to pollute the interrogation frequency with far more transmissions than are needed. (2) In most ground installations, more efficient use could be made of data received. This too offers a possible reduction in transmissions. (3) For Military IFF systems, from ten to twenty replies from each transponder during each interrogator scan past it appears to be adequate [9]. A reduction to similar numbers for nonmilitary radar-beacon uses would result in a tremendous increase in the system's air traffic capacity and/or reliability.

(U) If the AOC circuit is to increase the reliability of the air traffic control feature of the system, then priority should be given to nearby and hence, hopefully, interrogators that achieve greater signal strength at the transponder. But if the AOC circuit is adjusted to give maximum reliability to FAA interrogators, then some military interrogators (those that are farther away and/or of lower power) are likely to be discriminated against. This problem is further complicated by the fact that interrogator antenna installations differ widely, and the manner in which ISLS and antireflection transmissions are used is not uniform. Both power levels and azimuth coverages vary.

(U) In spite of the fact that there are many factors to be considered in determining what the reply-rate-limiting AOC circuit triggering level and reaction times should be, and many of these factors cannot be determined accurately, there are a number of simplifying assumptions that can be used to obtain a reasonable estimate of what the AOC parameters should be. Since the factors which determine how the reply-rate-limiting AOC should function are certain to change as the Mark XII comes into wider use, continued testing and evaluation of AOC action is in order, and the AOC circuit should most certainly be built so that its reply-rate triggering level, sometimes called its threshold, can be adjusted to compensate for future variations. Many of these future variations can be anticipated now; so it should not be too difficult to determine how much range the threshold adjustment should have [8].

3.0 INTERROGATOR-ASPECT LIMITING

(C) The desirability of having a transponder capable of responding to interrogators located in a particular area or portion of space has been recognized by Military users of radar-beacons for almost 30 years*. The development of diversity antennas [10] would now make it rather easy to cause a transponder to limit its responses to either those interrogators above a certain angle or those below a somewhat different angle. The dividing line between top-and-bottom-antenna coverage is not sharp; so certainly there would be some positions from which an interrogator would elicit a response regardless of which antenna happened to be in use.

(C) It would also be quite possible to use forward-and/or backward-directed antennas to limit responses. The value of forward-backward aspect limiting in areas where our aircraft frequently fly <u>into</u> and then <u>out of</u> enemy territory is obvious. A combination of forward-backward and up-down aspect limiting would offer still more military advantages.

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* See files of World War II Combined Research Group

(U) The simple hemisphere-directive type of interrogator-aspect reply limiting described above, probably has no place in commercial use of a radar-beacon system. The use of phased array antennas, however, which could provide much sharper interrogator-aspect reply limiting for military users, might also be very valuable for nonmilitary users. It would permit a transponder to give priority to interrogators in any chosen location at will. The development of airborne phased-array antennas is not too far from reality [11], [12] to warrant overlooking its possibilities for future radar-beacon systems.

4.0 THE ADEQUATE-RESPONSE PRINCIPLE

(U) A radar-beacon system operates on the master-slave principle. The interrogator, as master, demands responses; the transponder, as slave, responds dutifully unless prevented from doing so by circumstances beyond its control. As in any master-slave situation, difficulties arise when two or more masters make conflicting demands upon the same slave. At present, most interrogators demand far more responses from transponders than they really need. These excessive demands are usually excused by the reasoning that unless the interrogator obtains as many responses as possible from all transponders, then some transponders will provide far too few. Little consideration is given to the fact that it is the excessively high interrogation rates of so many interrogators that actually prevents some transponders from satisfying the demands of interrogators.

(U) If we can determine how many responses each interrogator actually needs during each scan of its antenna past a transponder, then the transponder can be made to limit its replies so that no interrogator can obtain more than that number during any scan, regardless of how many interrogations it sends to the transponder during the scan. This type of reply limiting is based upon what we call the "Adequate Response Principle". The author is of the firm opinion that the maximum number of responses allowed per scan for each interrogator should not be greater than twenty [9]. Improved data processing equipment at interrogator sites may be needed however, before this number will be fully acceptable to all users.

4.1 Interrogator Personal Identification Code Recognition (IPICOR)

(U) There are a number of ways in which an Interrogator Personal Identification (IPI) code might be included in each interrogation [13]. Mode 4 of the Mark XII, of course, already carries far more information than an IPI code would require. For air traffic control use, a five-bit code would be adequate. There should never be as many as 32 interrogators within range of any single transponder.

(U) A few more bits might be required for military IPI codes. This would especially be true if the system is used by airborne as well as shipborne interrogators. The need for more than an 8-bit IPI code is difficult to imagine, however, and an 8-bit IPI code would be very simple to provide [13].

(U) Recognition of IPI codes by transponders could easily be made automatic. The problem of counting how many interrogations containing each IPI code have been received in order to determine when responses should be stopped is not so simple but, with today's integrated circuits, could probably be solved. The transponder would have to be capable of recognizing, counting, and storing any of the possible IPI codes for the duration of a scan and also of refusing more than a specified number of responses to any code until sufficient time had elapsed for another scan to be starting. It is the fact that a number of these IPI codes might be interleaved at a transponder which makes the transponder storage problem difficult. But for this, IPI codes would probably have been in use many years ago.

(C) If the IPI code could be enciphered, then military transponders might use it to determine which interrogations are from friends and thereby determine when an enemy is trying to elicit responses. The cryptographic encipherment of IPI codes can become a rather involved subject [13]. It will not be discussed further here. It is sufficient to say that Interrogator Personal Identification Code Recognition (IPICOR) offers some very interesting reply-limiting capabilities.

4.2 Recognition of Fixed Interrogation Repetition Periods (ROFIRP)

(U) If interrogation repetition periods are fixed accurately, controlled, and so chosen that synchronous interference between interrogations cannot occur [6], then transponders can be made to recognize interrogators by measuring the periods between interrogations received. This method of reply limiting appears to be quite complicated at first glance. However, the circuits required to provide Recognition of Fixed Interrogation Repetition Periods (ROFIRP)[14] are subject to the same integration techniques as those for IPICOR reply limiting, and it is difficult to say which is the simpler overall. It may well be that use should be made of both IPICOR and ROFIRP reply limiting if the full capabilities of the radar-beacon system are to be realized.

(C) ROFIRP reply-limiting offers some unique anti-jamming features, some of which may have wide applications.

4.3 Beam Centering

(U) Regardless of how an adequate response is determined, reply limiters based on the adequate-response principle are likely to interfere with some of the techniques now being used to determine the exact azimuth of a transponder. These techniques, often called "beam-splitting" [15], determine the angle at which replies start and the angle at which they stop. The center of the beam is then marked as half-way between the start and stop points. Both the IPICOR and the ROFIRP reply-limiting techniques would tend to shift this "beam center" toward the leading edge of the beam for all interrogators that transmit more interrogations than needed. If this shift turns out to be too erratic and, hence, might cause an automatic tracking system to lose track of a target, the reply limiting might have to be changed to reply reduction. In other words, the transponder might continue transmitting replies, but at a reduced rate, after an adequate response for all purposes but beam centering had been completed.

5.0 CONCLUSIONS

(U) This qualitative discussion of transponder reply limiting indicates that at least three types of reply limiting offer possible improvements in radar-beacon operation:

(1) Response rate limiting, now used by Automatic Overload Control circuitry, is very sensitive to the response rates at which it is triggered and the time such circuitry requires to change receiver sensitivity, but can perform some useful functions.

(2) Interrogator-aspect reply limiting offers some very important advantages, but awaits antenna developments before any wide usage can be made. Some very simple restrictions upon replies to interrogators located in certain regions (at certain aspects from the transponder) could perhaps be implemented earlier than some of the other reply-limiting techniques, but they would require new antenna installations [16].

(3) The adequate-response principle for reply limiting is a new technique that resulted from studies of how replies are used by interrogator-responsors. Two possible ways of using the adequate-response principle are suggested. Further study and some testing of the Adequate-Response Principle are needed.

(U) References [8], [13] and [14] provide details concerning current response-rate limiting techniques and limiting based upon the adequate-response principle.

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13. ABSTRACT

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Non-Synchronous Interrogation Repetition Periods						
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Edward E. Maine

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Associate Superintendent
Radar Division

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