LOW COST VECTOR SCORING SYSTEM FOR AIRBORNE TARGETS

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ABSTRACT

Testing of airborne weapons systems often requires that a scoring system be placed on the target drone to obtain critical miss distance data. Advanced weapons utilizing directional warheads often require a scoring system which yields vector, miss distance and miss direction, information.

Scalar scoring systems currently in use are relatively simple and inexpensive. Vector scoring systems are typically complex and the cost of systems which are currently available or are being developed can be prohibitively expensive. Due to the current military budget decline, development of a low cost vector scoring system is desirable

This paper introduces a low cost vector scoring system developed for airborne target drones and based on an inexpensive scalar scoring system currently in use. To meet the low cost criteria, vector operation is achieved via minimal modifications to the existing scalar system.

KEY WORDS

Vector Scoring, AN/DSQ-37, Airborne Targets

INTRODUCTION

The development of a low cost vector scoring system based on a modified DSQ-37 scalar scoring system was proposed in FY-91 by the Miss Distance Indicator Group of the Airborne Targets Division at the Naval Air Warfare Center (NAWC) Pt. Mugu, CA. NAWC China Lake, CA designed and tested the prototype Vector Scoring system in FY-93.

The low cost vector system is needed for test and evaluation of guided missiles and consists of a modified DSQ-37 scalar scoring system. The low cost system is desirable as an alternative to similar non-cooperative systems being developed, the U.K. (ARMS) and NAVS, which are expected to be extremely costly. The system can also be used to replace the cooperative MEGS system for warhead firings.

THEORY OF OPERATION

The original DSQ-37 scoring system has one antenna which transmits radar pulses at a nominal pulse repetition frequency (PRF) of 504 kHz. The pulses are reflected off of the missile or item under test and are received by the DSQ-37 whose pulse width, receiver "ON" time, and transmitter duty cycle are adjusted such that the received pulse must be reflected from a target in a range gate of 25 to 75 ft. from the DSQ-37's antenna.

The receiver in the DSQ-37 generates an output level based on the velocity of the missile or item under test with respect to the DSQ-37 The output of the receiver is bandpass filtered such that the doppler output corresponds to velocities of 200 to 5000 ft./sec. The miss distance is then calculated by counting the number of doppler cycles which occur within the calibrated 75 ft. range gate.

The proposed vector scoring system adds 4 antennas to the current DSQ-37, each operating at 1/4 of the original DSQ-37's PRF. The antennas are switched such that each can only receive reflections from its own transmitted pulse. The received signal for each antenna is sampled, filtered and parallel processed such that a doppler signal is created for each antenna radar pulse. Thus the vector scoring system acts as four DSQ-37's with a reduced PRF of 126 kHz. The miss distance for each antenna is calculated by counting the number of doppler cycles which occur within its calibrated 75 ft range gate. The miss distance data from the four antennas is correlated on the ground to translate the scalar information from each of the four antennas to vector miss distance data.

PRELIMINARY ANALYSIS

The primary issues in determining the feasibility of modifying a DSQ-37 for vector scoring were the following.

1) Availability of sufficient transmit power to operate when 1/4 of the radar pulses were used to illuminate the missile or item under test.

2) Achievement of adequate doppler frequency miss distance determination by individual antennas operating at one-forth of the original PRF.

3) Achievement of sufficient isolation between antennas and associated processing circuitry

The DSQ-37 outputs a minimum of 3 watts peak power at a PRF of 504 kHz. A link analysis determined that the reflected radar pulse would have enough energy, when the radar was operating at 1/4 of the original PRF thru 4 antennas, for the system to operate properly. The peak power for the vector system remains a minimum of 3 watts and the main problems to be analyzed were the loss in power in the RF switch used to divide pulses between antennas and 6 dB power loss due to a reduction in the average transmitter power for each antenna to 1 /4 of the power transmitted by the original DSQ-37's single antenna.

A worst case analysis was done for a typical missile with a Radar Cross Section (RCS) of $\sigma = 0.5$. Where

$$P_r dB = P_t dB + 10 \log \{ (G^2 \lambda^2 \sigma^2) / [(4\pi)^3 R^4] \}$$

and,

P_r = Received Power in dB
P_t = Transmitted Power in dB
G = Antenna Gain
λ = Wavelength
σ = RCS of missile or item under test.

The worst case analysis indicates that the original DSQ-37's radar return would exceed the -93 dBm DSQ-37 receiver sensitivity by approximately 17 dB for a typical missile with a RCS of $\sigma = 0.5$. Calculations indicate that P_r is $\geq$ - 75.93 dBm when switch and circulator mismatches in the modified DSQ-37 are included.

This value is reduced to -81.93 dBm when the 6 dB loss in average power due to operation at 1/4 PRF is factored in, and therefore the current DSQ-37 radar should be sufficient for vector scoring system operation.

The second area of concern was missile doppler frequency determination by each antenna of the vector system while operating at 1/4 of the original PRF. Determination of miss distance during operation at 1/4 of the original PRF is basically equivalent to four synchronized radars operating at 1/4 of the original PRF.

The system must work for closing velocities of 200 to 5000 ft/sec. Therefore,

$$f_d = 2v_m / \lambda = 2v_m f_o / c$$

where,

f_d = doppler frequency
v_m = missile closing velocity
f_o = radar frequency
c = speed of light.

Thus,

$$f_{d\ max} = [\ 2\ (5000\ \text{ft/sec})\ (1775\ \text{MHZ})\ ]\ /\ (9.84\text{x}10^8\ \text{ft/sec})$$
$$= 18.04\ \text{kHz}.$$

Since the original PRF was 504 kHz the vector system will have a PRF of 1/4 or 126 kHz for each antenna. A PRF of 126 kHz results in $\geq$ 6.98 samples per doppler cycle at the max doppler frequency of 18 kHz, therefore, the doppler can be reconstructed by each antenna individually and the four reconstructed signals will enable miss distance calculations for each antenna and vector operation.

The final concern was isolation between the returns from the four antennas and maintaining system signal to noise specifications at the DSQ-37 level in order to enable detection of small test items.

The main concern of Pt. Mugu was channel isolation in the RF switch. Tests were run on an RF switch previously procured by Pt. Mugu and they indicated that isolation between channels in the switch was on the order of 50 dB. Bench tests indicated that this value is sufficient to provide the required channel isolation at the switch.

Another concern in the system design was maintaining the system noise level of the original DSQ-37. The DSQ-37 has a receiver video noise level requirement of $\leq$ -32 dBm (@+25°C). The prototype system was constructed to maintain as much isolation between antenna channel circuitry as possible. However, being a breadboard prototype the video noise level realized was 8-10 dB above the original DSQ-37 specification requirement. If production of the vector scoring system modification is pursued the units can be designed to attain the -32 dBm requirement.

Thus the preliminary analysis indicates that the vector scoring modification to the DSQ-37 is feasible.

DESIGN APPROACH

The system design of the vector scoring system is outlined in Figure 1. The major components are the DSQ-37, 4:1 RF switch, controller, quad switch; sample/hold; filter banks and telemetry system.

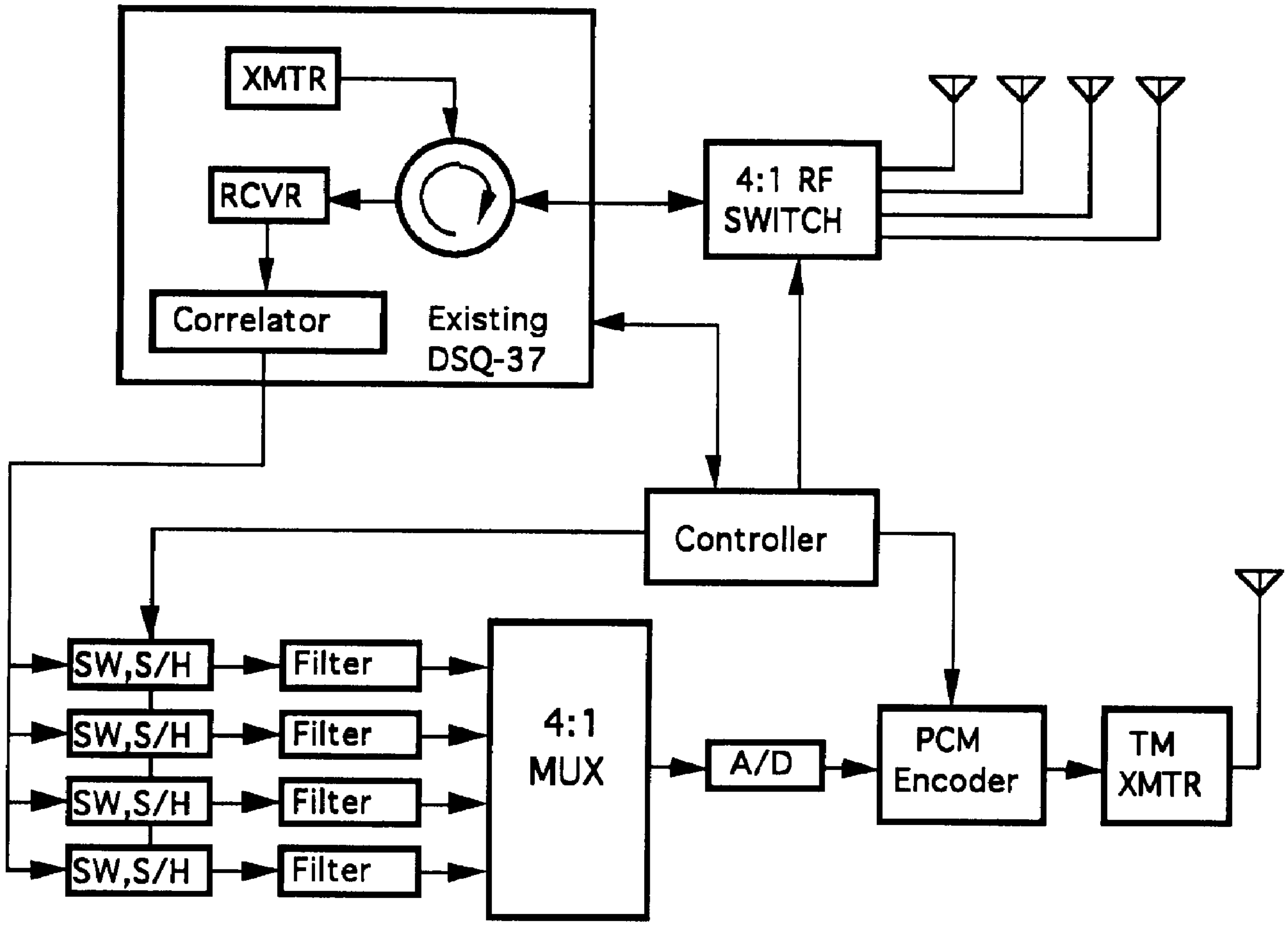

FIGURE 1: Vector Scoring System Block Diagram

The controller receives the 504 kHz PRF signal from the DSQ-37 and generates synchronizing signals for the RF switch turning on antennas 1 thru 4 in order that each operates at a PRF of 126 kHz. The controller routes the receiver video sample pulse from the DSQ-37 through the appropriate switch/sample/hold/filter bank.

The switch, sample/hold, filter banks are similar to the switch, sample/hold and active filter circuits used to recover the doppler frequency in the original DSQ-37. By feeding each antenna's received signal into the filter banks, the returns for each antenna are parallel processed to derive miss distance doppler information at the output of each of the four filters.

The controller also uses the 504 kHz PRF signal from the DSQ-37 to derive the telemetry system bit clock and word clock.

The telemetry system digitizes and multiplexes the four doppler signals, inserts frame sync and transmits the data to a ground station receiver as a PCM data stream. On the ground, the data is received and decommutated to recover miss distance information from each antenna which is correlated to yield miss distance and direction data.

PRELIMINARY TESTING

The prototype vector scoring system was tested at the NAWC, China Lake, SNORT track during a series of sled and monorail tests. The first tests were conducted with a large sled and were setup as shown in figure 2.

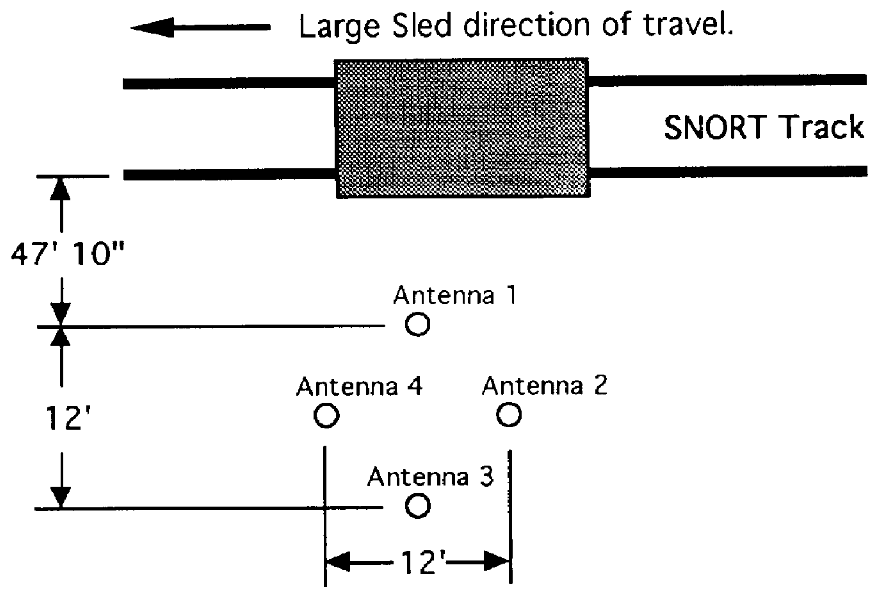

Figure 2: Large Sled Test Setup

The large sled was greater than 20ft in length and it was expected to obtain only qualitative data, mainly due to the fact that since both the vector scoring system array and sled are near ground level multipath was expected to be significant.

The vector scoring system test results with the large sled indicated that the sled was traveling in the proper direction and approximately the correct distance from the array. However, a large target offers multiple returns for which it is difficult to resolve an accurate miss distance.

The prototype vector scoring system was next tested during small target monorail tests at SNORT. The test setup, shown in figure 3, placed the antenna array across the track from the small target, this was necessitated due to limited locations of available power.

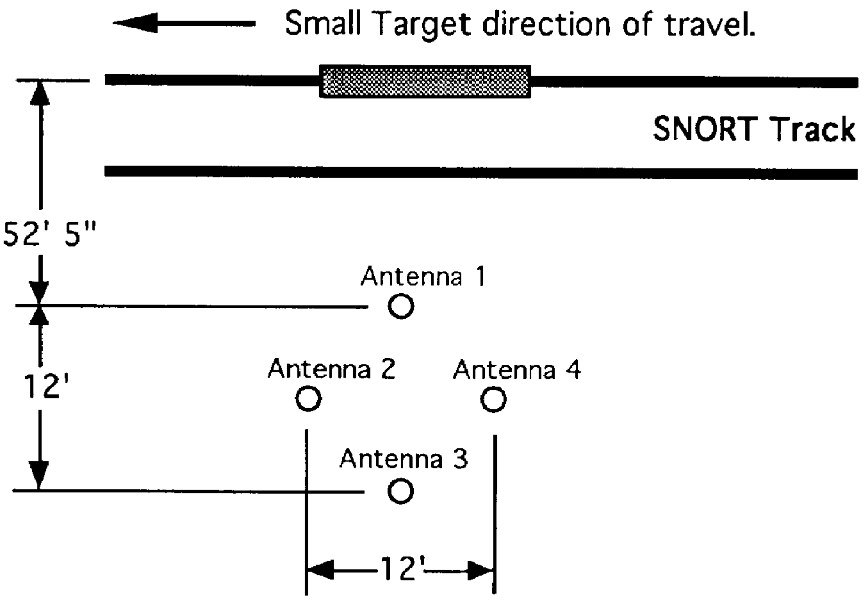

Figure 3: Small Target Test Setup

The preliminary test data indicated that the antennas received a return from the target and that the antennas picked up the target in the expected order - Antl, Ant 4, Ant 3, Ant 2- which properly indicated where the target was with respect to the array.

Detailed analysis of the monorail test data was performed at Pt. Mugu to determine miss distance as the signal to noise ratio was lower than the previous large sled shots and couldn't be directly interpreted at the test site.

CONCLUSIONS

Strip chart data taken during SNORT tests indicated that the system worked properly. Analysis of the large sled test data performed at Pt. Mugu provided accurate miss distance calculations for all four antennas and therefore confirmed proper operation as a vector system. The large sled size yielded a diffused return and therefore miss distance accuracy was somewhat greater than ±1 ft., however, this is also typical of the original DSQ-37's operation with large targets.

The small target was 52.5 ft. away from the nearest vector system antenna and was on the furthest rail from the system as shown. The system and track were both within 6 ft. of the ground thus problems were anticipated due to multipath. Because of these two factors, it was not anticipated that accurate miss distance data for the small target shots would be obtained. The strip chart data taken at SNORT indicated that the vector system "saw" the target, however, no real-time miss distance information could be obtained due to limited data reduction equipment availability.

Nonetheless, later sonagraph analysis of the small target data tapes processed at Pt. Mugu did yield accurate miss distance information, within ± 2 ft, for each antenna thus confirming the systems ability to operate as a vector scoring system. DSQ-37 data analysis personnel at Pt. Mugu indicated that the small target was typically difficult for the original DSQ-37 to determine accurate miss distance data and that the new system yielded data as good or better than that typically obtained during DSQ-37 scalar system missile tests. They also indicated that a miss of 50 ft. was considered a far miss and that the DSQ-37 system accuracy of ±1 ft. was typically not realized for these types of misses.

DSQ-37 data analysis personnel at Pt. Mugu are satisfied with the test results, especially considering the difficulty of the test scenarios at SNORT. Five inch gun tests scheduled in FY-94 at closer miss distances will confirm system accuracy to the ±1 ft specification.

In conclusion, the Low Cost Vector Scoring project has been successful at providing a low cost alternative for future vector scoring system requirements.

REFERENCES

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