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# RESULTS OF HAZELTINE DISTANCE-MEASURING EQUIPMENT TESTS



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## ABSTRACT

A series of tests were made on a unit of experimental distance-measuring equipment (DME) built for the Civil Aeronautics Administration by the Hazeltine Electronics Corporation. These tests were designed to determine the accuracy, reliability, and general performance of the video, decoder, search and track, and range indication circuits of the airborne equipment under simulated conditions of high traffic density.

Results indicate that this equipment is capable of a high degree of range accuracy and has the ability to track at speeds far in excess of those of commercial aircraft. At high tracking speeds, however, a rather objectionable oscillation of the range indicator was observed. Under simulated conditions of high traffic density, the average number of searches before tracking is begun was found to exceed the theoretical number greatly. Also, contrary to theory, high traffic density had little effect on search and memory time, because of improper action of the video and decoder circuits under high pulse density.

## PROBLEM STATUS

This is a final report; this problem will be considered closed thirty days from the mailing date of this report unless otherwise notified by the Bureau.

## AUTHORIZATION

NRL Problem R07-37T  
BuAer Problem NRL-EL-9A-357

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## RESULTS OF HAZELTINE DISTANCE-MEASURING EQUIPMENT TESTS

### INTRODUCTION

#### General Remarks

The phenomenon of high pulse density has been the subject of considerable study by the Radar II Branch of Radio Division III, Naval Research Laboratory, especially of those phases which deal with distance-measuring equipment (DME) and beacon problems. Both theoretical and experimental investigations (1)\* have been made of this phenomenon and a wide variety of equipments (2, 3) have been designed to simulate and measure high pulse density conditions.

At the request of the Bureau of Aeronautics, this Branch has undertaken to run a series of tests on the airborne part of an experimental DME system built for the CAA. In particular, these tests are designed to determine the accuracy, reliability, and general performance of the searching and locking circuits of the airborne components.

Since the results of tests made on a single equipment, especially on the experimental model, can not be regarded as absolutely indicative of the merits or demerits of the system or the equipment, some theoretical analyses were also made in an effort to determine what performance could reasonably be expected. Attempts were made to correlate the conclusions of the analyses with the results of the tests and to compare the conclusions with those arrived at by the manufacturer (4, 5, 6).

#### Scope of Tests

Tests made on the Hazeltine DME were confined exclusively to a portion of the airborne equipment. The entire investigation was limited to a study of the behavior of the video and search unit under conditions of high pulse video input at the video input jack. No tests were made on the transmitter or on the r-f and i-f parts of the receiver, because they are more or less conventional in design and should have relatively little effect on the over-all system performance.

Although it was recognized that tests on all units might have considerable value, tests were limited to the video and search unit, because this unit may be regarded as the heart of the whole system, and its behavior under high pulse density inputs will give a fairly accurate indication of the capabilities of the whole system. There was also the practical consideration that the investigators possessed considerable experience in and had access to specialized equipments for making tests on this unit only.

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\* Numbers in parentheses indicate references at end of report.

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All tests made on the equipment were electrical, i. e., were concerned with the behavior of circuits. There were no mechanical tests, none of the effects of temperature, humidity, etc., since such tests would have little significance on an experimental equipment such as this.

At various times during the course of the tests consideration was given to modification of circuits or component values in order to obtain a possible improvement in performance. With minor exceptions, no modifications were made because it was felt that the equipment should be tested in the condition received. It was recognized also that the designers might have had good reasons for doing things in certain ways, reasons which were not obvious.

#### Test Set-Up

All tests were made on the video and search unit, of a Hazeltine DME, Model No. 1460 Serial No. 6. Since the operation of the video and search unit is practically independent of the R-F and control unit, the latter was divorced entirely from the test set-up by the following procedure:

1. Put a jumper from Pin I to Pin J in Plug J-1103 as a substitute for the interlock in the R-F and control unit.
2. Place a 22,000 ohm resistor from the video input jack to ground to obtain the correct bias for V-416. Normally, V-416 is directly coupled to V-2002 in the R-F and control unit, and derives its bias from this tube.

The control box and the range meter were connected in the normal manner.

Power supply to the equipment consists of 28 volts dc and 117 volts, 400 cps (390 cps measured) and was maintained at this level throughout the tests.

Before the tests were begun the 225-volts regulated voltage supply was checked and adjusted, the range-meter calibration was checked, and the zero set (6).

The normal pulse-repetition frequency (prf) of the equipment is 30 pulses per second (pps). For the particular equipment tested it was found to be almost 32 pps. This was considered close enough to normal so that no change was required.

### PERFORMANCE TESTS AND RESULTS

#### Preliminary Tests

##### Pulses-to-Lock Setting

CAA specifications call for search to be terminated whenever two responses are obtained to three successive interrogations. Consequently, the equipment must be adjusted so that search is terminated and track begins when transponder (beacon) efficiency is  $2/3$ . In the Hazeltine DME this switch takes place upon operation of relay K-402, which in turn depends upon the setting of potentiometer R-559 and upon the succession of pulses received during the periods of the wide gate. Figure 1 summarizes the results of a test designed to check the effect of varying the R-559 potentiometer setting.

It can be seen (Figure 1) that the reception of any single pulse will cause relay K-402 to operate if potentiometer R-559 is set at 66 volts or lower. Above 86 volts a very high percentage response is required. Further examination will show that a potential 68 to 69 volts is the proper setting, because replies to any two of three successive interrogations will terminate search when R-559 is set at this voltage.

It can also be observed that this potentiometer setting is quite critical; a change of only a few volts in setting will affect the search-to-track characteristics markedly. Potentiometer R-559 has a range of 150 volts and is fed from an unregulated supply. It seems quite probable that in the course of normal operation the voltage at the tap might easily change as much as one or two volts, which represents a change of only a few percent in the unregulated supply voltage.

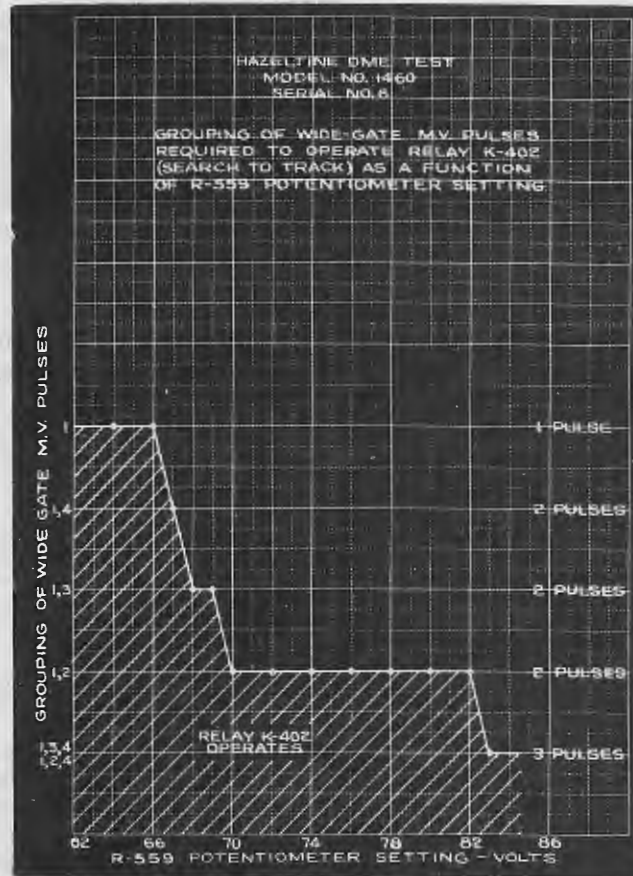


Figure 1

#### Searches-to-Lock as a Function of R-559 Potentiometer Setting

Much of the equipment set-up (Figure 2) for the test "Searches-to-Lock as a Function of the R-559 Potentiometer Setting" is not standard test equipment. This equipment is used extensively in subsequent tests.

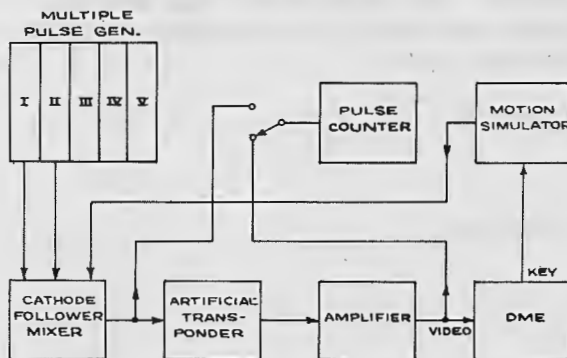


Figure 2 - Test set-up for searches-to-lock as a function of R-559 potentiometer setting

The multiple pulse generator is a device which is capable of simulating from 1 to 300 independent pulse sources. The pulse length and repetition rate of all 300 generators are controllable as a group—the pulse length from 0.4  $\mu$ sec to 8.0  $\mu$ sec, and the repetition rate from 22 to 350 pps. The outputs of these 300 generators are mixed and are available from a single jack, but, if desired, the generators may be split into as many as 5 groups of 60 generators, each group being controllable separately. Figure 2 indicates that only two of the five available groups are being employed

and only 20 generators in the second group are used in this test. In the test under discussion the multiple pulse generator simulates the output of the decoder circuit in the ground beacon transponder.

The artificial transponder is essentially a keyed, double-pulse generator whose pulse separation and recovery time may be controlled. The pulse separation may therefore be set to correspond to the type of pulse coding used in the proposed DME system and the recovery time may be adjusted to give the correct beacon count-down. Pulse length and amplitude are also variable.

The moving interrogator simulator (called motion simulator on Figure 2), is a delayed pulse generator which produces output pulses whose time delay from corresponding input or trigger pulses is made to vary at some predetermined rate, thus giving the illusion of variation in distance or motion. Drift rates equivalent to from 100 to 1000 knots (20.38 to 203.8  $\mu\text{sec}/\text{min}$ ) either toward or away from the trigger pulse are obtainable. The equipment has a maximum range of 200 nautical miles and has adjustable output pulse length and amplitude.

The pulse counter is a high-rate device which can count as many as 1 million pulses per second and has a pulse-resolving power of 0.5  $\mu\text{sec}$  between leading edges. This device, which is invaluable in measuring high pulse density, counts for a crystal-controlled, one-second period and then gives a direct decade reading.

The nature of the other equipments (Figure 2) is self-evident.

The effect of R-559 potentiometer voltage setting on the ability of the DME to terminate a search under some conditions actually encountered in operation was studied by using the equipment (Figure 2) described in the previous paragraph.

As a test set-up the equipment (Figure 2) was designed to operate as follows. The keying pulse from the DME was used to trigger the moving interrogator simulator and the delayed pulse there obtained was mixed with the output of the multiple pulse generator which was used here to simulate other interrogators simultaneously interrogating the beacon. This mixed output was in turn fed to the artificial transponder whose dead time was set as shown in Figure 3 (the standard amount for the mode) to give the proper transponder efficiency. The transponder output was in turn amplified and fed back to the DME, thus completing the loop. The problem of the DME was then to search and lock on to the responses to its own interrogations (triggering pulses) in the presence of the interference caused by the multiple pulse generator. The pulse counter was used as a check to see that the prescribed number of pulses was fed into the artificial transponder and that this latter equipment was giving the proper output.

The pertinent constants of the test are as follows:

DME prf = 32 pps

Pulses into artificial transponder = 2400/sec

Recovery time

Mode A,  $t_r = 164 \mu\text{sec}$

Mode J,  $t_r = 227 \mu\text{sec}$

## Resultant transponder efficiency

Mode A, B = 0.718

Mode J, B = 0.648

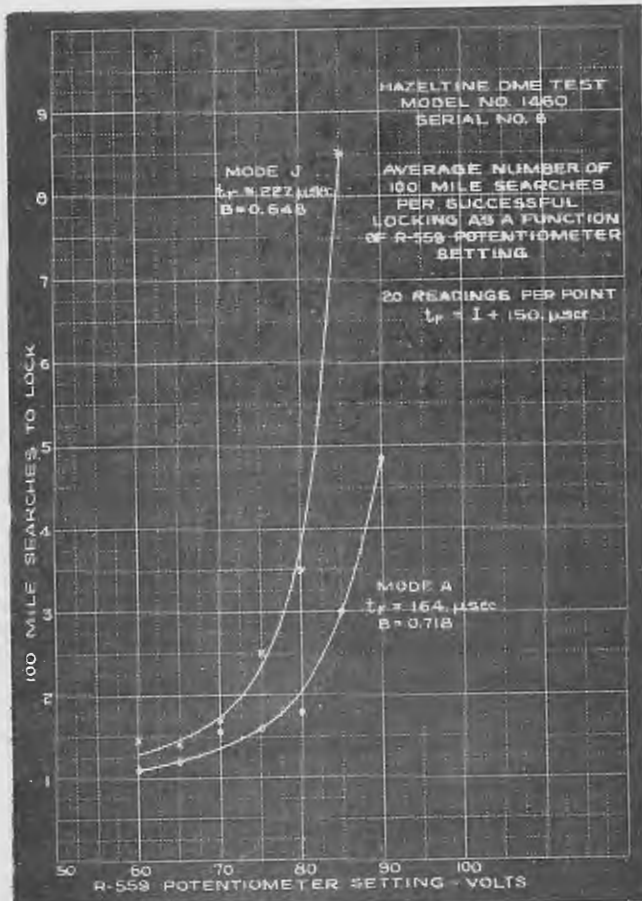
Artificial transponder pulse length = 2.5  $\mu$ sec

Figure 3

It is observed from the curves giving the results of this test (Figure 3) that in the neighborhood of the 69-volt setting of R-559, about 1.25 searches-to-lock are required for Mode A and 1.60 for Mode J. The reason for the difference is obviously the greater beacon efficiency of Mode A over Mode J. Mode A and Mode J represent the extreme conditions. The number of searches-to-lock for the other eight modes (B through J) can be expected to lie between 1.25 to 1.60. For the higher settings of R-559 the searches-to-lock figure becomes prohibitively high.

Prior to the running of this test it was necessary to make a very minor circuit change. Resistor R-528 was increased from 1.8 megohms to 2.2 megohms, because the retrace relay K-403 delayed in operating, causing search time to increase excessively. The V-423 cathode (range follower) sweeps to +120 volts, maximum. When it reached this point, before R-528 was changed, the V-424 relay tube did not operate immediately but waited several seconds before operating. This is improper because the relay should operate before the maximum of 120 volts is reached. Changing R-528 corrected this trouble.

Effect of R-559 Potentiometer Setting on Memory Time

The set-up used for this test (Figure 4) is somewhat similar to the set-up for the search-to-lock test (Figure 2) except that more artificial transponders were used in order to include the effect of fruit on memory time. Artificial transponder No. 1 represents the transponder receptive to the code sent by the DME interrogator. The other four artificial transponders represent the other nine transponders of the ten transponders normally found on each frequency channel.

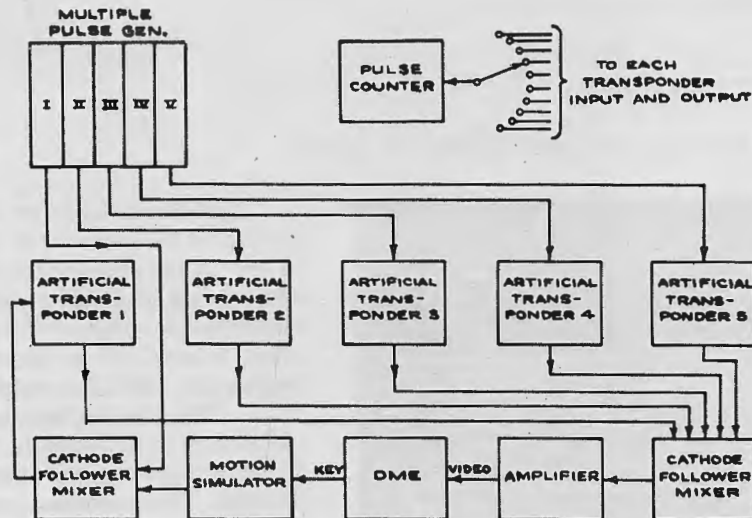


Figure 4 - Test set-up for finding effect of R-559 potentiometer setting on memory time

Because only four other transponders were available, it was necessary to represent the normal number of nine by these four. In order to compensate for the fewer number of transponders these were interrogated at a proportionally higher rate so that the double pulse output from four would correspond closely to that which would normally be expected from the full nine.

In this test the memory time was adjusted to its minimum value by reducing R-1114, the memory time control, to zero ohms.

The constants of this test are as follows:

DME prf = 32 rps

R-1114 = 0.0 ohms

Sources per artificial transponder = 60

Source prf = 30 cps for transponder No. 1, 67.5 cps for transponder Nos. 2, 3, 4, 5

Transponder pulse length = 2.5  $\mu$ sec

Interrogation rate artificial transponder No. 1 = 1800/sec

No 1 transponder efficiency B = 0.737

Total number of pulse pairs from other transponders approximately 11,600

DME Mode = F

Memory time was measured by allowing the DME to lock on the replies to its own interrogations. After it had locked, the DME interrogations were stopped but all the others were allowed to continue and the time for the DME required to resume search was measured.

The results of this test are summarized in Figure 5. The searches-to-lock curve shows the same characteristics as those in Figure 3. As was expected, the memory time decreased with increasing R-559 potentiometer voltage because of the increasingly higher density of pulses through the decoder required to hold C-559 at a constant voltage.

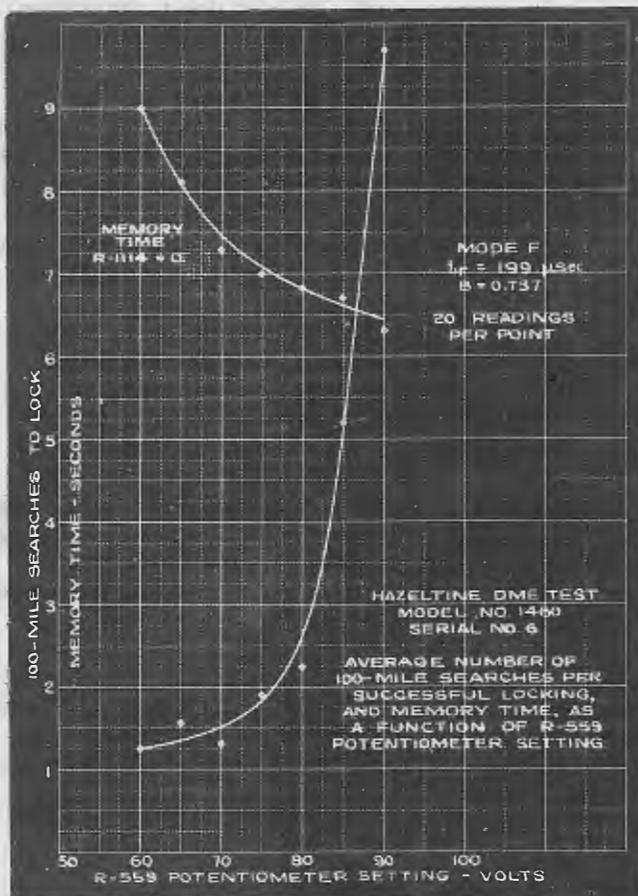


Figure 5

Pulse code spacing is considered acceptable by the DME so long as the wide-gate multi-vibrator, V-427, operated.

Equipment was set up to test the action of the decoding circuit (Figure 6). Table 1 summarizes the results of the test.

#### Significance of First Three Tests

The three tests, which have just been described, were designed to check the effect of the R-559 potentiometer voltage to indicate the proper setting. The data obtained on search-to-lock and memory time is rather fragmentary and incomplete, but subsequent tests deal with these quantities much more extensively. As a result of these first three tests it was decided to hold R-559 between 68 and 69 volts and to maintain this setting for the remainder of the tests.

#### Decoder Characteristics

The DME under test is designed to accept pulse pairs having some specific pulse separation depending upon the "mode" setting. There are ten modes and hence ten potentially acceptable pulse separations or codes. The DME can recognize the proper pulse spacing by delaying the first pulse of a pulse pair by an amount dependent upon the mode setting and detecting coincidence of the delayed pulse with the second pulse of the pulse pair.

TABLE 1  
Acceptable Tolerances in Code Spacing

Mode	Nominal R ( $\mu\text{sec}$ )	$\Delta R$ ( $\mu\text{sec}$ )
A	77	2.2
B	70	2.0
C	63	1.8
D	56	2.0
E	49	2.1
F	42	2.1
G	35	2.1
H	28	2.3
I	21	2.1
J	14	2.0

The effect of variation of input pulse length was also investigated. For pulse lengths less than  $2.0 \mu\text{sec}$  the equipment would not operate satisfactorily. For a pulse length of  $2.5 \mu\text{sec}$ , which is the length for which the equipment was designed, the results are those given in Table 1. For lengths greater than  $2.5 \mu\text{sec}$ , one would expect an increase in  $\Delta R$  but no substantial increase was observed no matter how long the input pulses were made. This is due to intentional differentiation of the input pulses in the grid circuit of V-418B.

Differentiation of the input pulse, while it was found to decrease fruit interference, as will be shown later, results in the equivalent of reduced transponder efficiency. This phenomenon will be taken up in more detail in the section dealing with searching and locking.

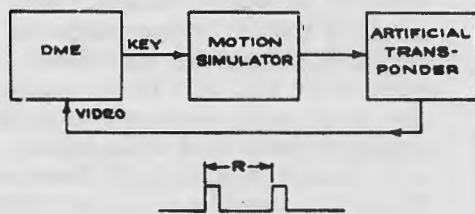


Figure 6 - Set-up to test action of decoding circuit

$\Delta R$  as given in Table 1 is for a single source, i.e., 32 pulse pairs per sec input. Under high pulse density conditions, the decoder delay line driver circuit does not operate properly. There is as high as 65 percent loss in amplitude in the decoder output (pin 6 V-425). This effectively decreases  $\Delta R$  and also introduces the equivalent of reduced transponder efficiency (more count-down) under very high input pulse density. This phe-

nomemon, too, will be taken up in more detail in the section dealing with searching and locking.

The average  $\Delta R$  is  $2.07 \mu\text{sec}$  making the effective pulse length =  $2.07/2$  or  $1.03 \mu\text{sec}$ . The action of the differentiation circuit is not entirely responsible for this short, effective pulse length. The spike suppressor circuit V-416 shortens the input pulse more than  $0.5 \mu\text{sec}$ .

## Searching and Locking Characteristics

### Search Time with Pulse Input

The minimum time required for a complete scan of 100 nautical miles range is determined by the range-voltage generating circuit. This is essentially a very slow sweep circuit which has a period on the order of 13 seconds in the equipment under test. Thus, the basic scan rate is 100 miles in 13 seconds.

During the scanning process, replies received during the first half of the range gate, i.e., narrow gate, tend to retard the building up of range voltage and hence to increase the search time even though the search process is never really terminated more than momentarily through the operation of K-402, the search-to-track relay. Replies which

fall in the last half of the range gate, on the other hand, tend to speed up the searching process, so that there is a counter-balancing action.

For the equipment under test, the variation of search time with signal input was practically nil. The maximum deviation observed from the basic rate was only 2 percent. Actually, minor variations in line voltage seemed to have more effect on search time than did a substantial increase in input signal density, at least up to the point where search was terminated and the equipment switched over to "track."

It was expected that a high pulse density input would substantially increase search time due to the fact that the narrow gate was measured to have a greater retarding effect than the last half of the range gate had an accelerating effect. The fact that this was not the case is apparently due to the limiting action of the decoder circuit. The average level of video signal amplitude out of the decoder falls with increasing input pulse density. This fall in level has a marked effect on the retarding action of the narrow gate since this action is proportional to the video level. The action of the acceleration circuit is also dependent upon the video level out of the decoder but not in the same way. So long as the video level is sufficient to key the wide-gate multivibrator, V-427, the action is normal. There is evidence to show that for very high input pulse density the video level out of the decoder is below the keying level of the wide-gate multivibrator a high percentage of the time. This fact will be proved in the search-to-lock tests.

To summarize, search time in the equipment under test, is substantially independent of input pulse density despite theoretical expectations to the contrary. The failure of the search time to increase with increasing input pulse density is due to the fall in video level out of the decoder.

#### Search-to-Lock

One of the most important characteristics of a DME is its ability to find the responses to its interrogations quickly and to "lock" on them and then to track. Ideally it should find the responses instantaneously. This is not possible practically, a certain time being required to scan out to the range where the responses are located. The problem of finding the responses is further complicated by the fact that these responses must be received with sufficient regularity to distinguish them from spurious or unsolicited responses which are continually received when the DME system is operating under high pulse density conditions. It is possible to derive the theoretical probability of finding responses to interrogations with sufficient regularity to successfully terminate the search. This probability, of course, depends on such constants as the number of interrogators interrogating each transponder, the number of these transponders as well as their individual recovery times, the characteristics of the searching and locking circuits and the pulse lengths and repetition rates involved. Some of these probabilities are given in Hazeltine reports (4, 5).

It is convenient to express the performance of the searching and locking circuits in terms of searches-to-lock. This number is the average number of scans before the search is successfully terminated and the tracking circuits take over. The theoretical probability of a successful completion of search may likewise be expressed in terms of searches-to-lock and an operating efficiency of the searching and locking circuits may be obtained by comparing the theoretical and actual figures.

To find the average number of searches to lock, the equipment was assembled as in Figure 4. To speed up the taking of data, a portion of the 100-mile range was scanned



de-energizes  $K_A$  and search begins immediately from the 25-mile point. This process, taking about 1.2 sec, repeats so long as the gate fails to lock.

The quotient of the total number of searches and the successful locks figure gives the average number of searches-to-lock.

The constants of the searches-to-lock test are as follows:

Number of properly coded transponders - 1

Transponder Mode - F

Recovery time  $t_r = 199 \mu\text{sec}$

Output pulse length =  $2.5 \mu\text{sec}$

Keying rate - variable (Figure 8)

Number of improperly coded transponders - 4

Keying rate - variable (Figure 8)

Output pulse length =  $2.5 \mu\text{sec}$

R-1114 setting - 68.5 v

Each point on the curves giving the results of this test (Figure 8) represents the average of about 500 readings. The curves (Figure 8) which give the average number of searches started before locking and tracking take place, are plotted against two abscissas—keying rate on the properly coded transponder, and transponder efficiency. Since the transponder recovery time,  $t_r$ , is given, transponder efficiency is dependent only on the keying rate.

The lower curve (single transponder properly coded) gives the searches-to-lock when only pulses from the properly coded transponders are received by the DME. The other curves give the searches-to-lock number when additional input from improperly coded transponders is mixed with that from the properly coded transponder. The improperly coded input is specified in terms of individual pulses. On a double-pulse basis this number should be divided by two.

The output of the incorrectly coded transponders is specified in terms of pulses rather than in terms of equivalent number of interrogators because this is regarded as more precise. The equivalence in number of interrogations per transponder depends on transponder efficiency (a function of dead time) as well as the increase in interrogation rate due to bunching (a function of pulse length and number of pulses per code group). However, on the basis of constants used in a Hazeltine report (5), the 36-kc curve represents about 40 interrogators on each of the 9 other modes on each frequency channel. An effective keying rate of approximately 2500 interrogators per second is obtained by 40 interrogators on the properly coded transponder.

Figure 8 shows that the searches-to-lock number is not excessive when the input to the DME is limited to properly coded pulses from a single transponder (lower curve, Figure 8). However, when a high level of improperly coded pulse input is added, the search-to-lock number increases markedly, contrary to theory. According to theory, the addition of improperly coded input should not increase the searches-to-lock number but may actually decrease it somewhat (page 16 of Reference (5)).

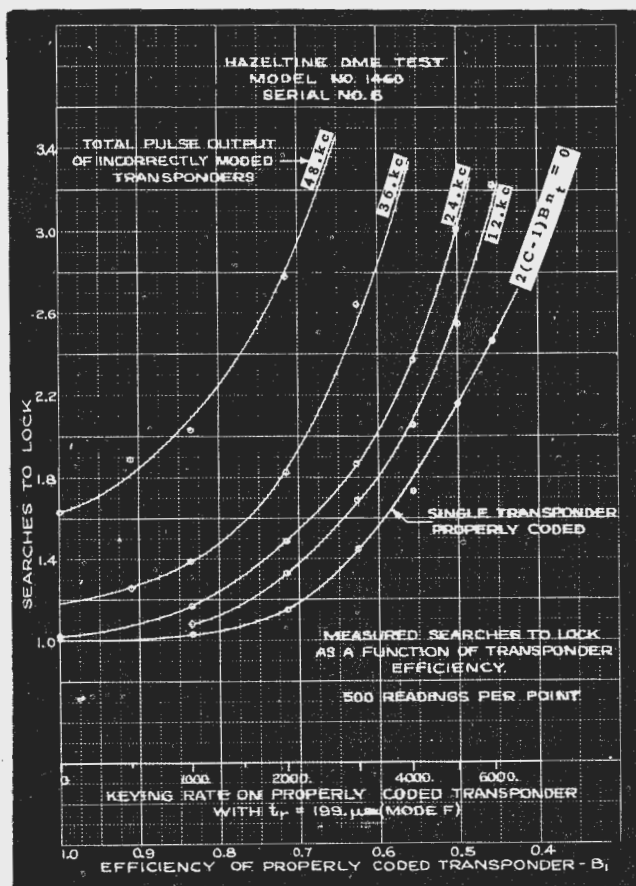


Figure 8

the more accurate upper curve. For reasonable values of pulse outputs this approximation is quite accurate.

When this differentiation correction (Figure 9) is applied to the lower curve of Figure 8 for various improperly coded input densities, the curves of Figure 10 result. This correction does not include the effect of bunching. Comparison of these two sets of curves shows that input differentiation is responsible for only a relatively small part of the increase in searches-to-lock.

## Tracking And Memory Characteristics

### Tracking Circuit Characteristics

After search is terminated the range-gate movement is controlled by the tracking circuit. The range gate consists of two parts, a wide gate of about 20  $\mu$ sec duration, which is identical with the range gate, and a narrow gate, which is simply the first 10  $\mu$ sec of the range gate. If a pulse falls in the wide gate, the range gate is caused to move out in range and if it falls in the narrow gate, the range gate moves in, in range. Obviously, if a response falls in the narrow gate it is also in the wide gate. But, since the effect of the narrow-gate circuits predominates, the range-gate movement is toward decreasing

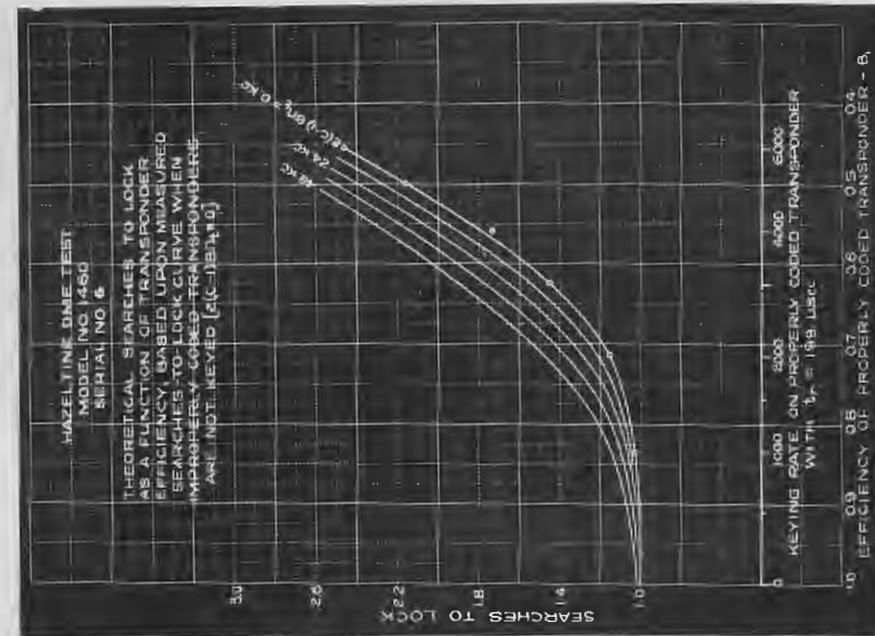


Figure 10

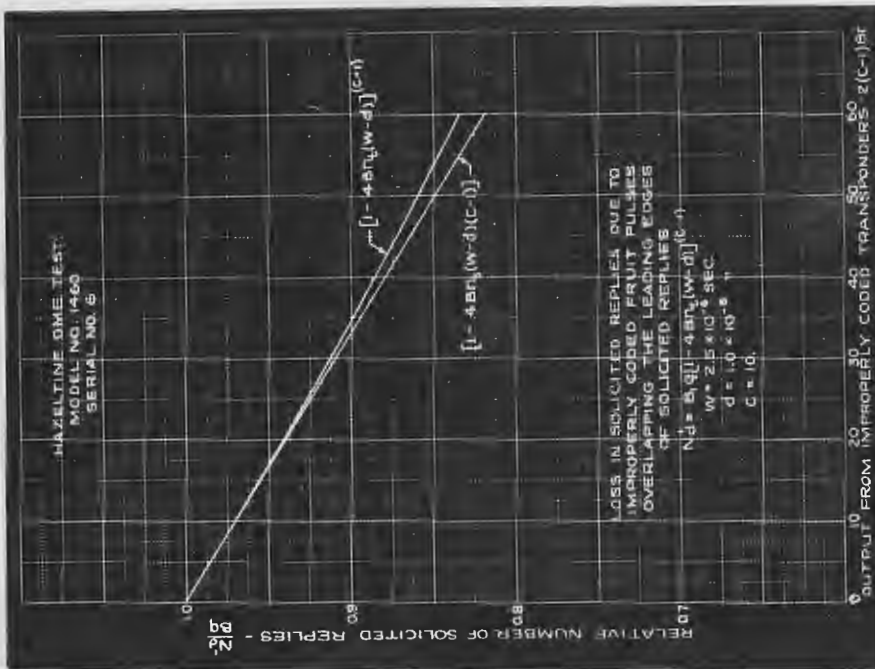


Figure 9

range. The purpose of this test is to measure the range-gate movement when a response is in the wide gate and when it is in the narrow gate.

The test was conducted as follows. The DME was placed in "track" condition by removing V-430, the search and memory tube, causing the relay, K-402, to go to the track position. In order to eliminate the effect of narrow-gate coincidences V-419, the narrow-gate coincidence detector, was also removed. The wide-gate multivibrator, V-427, was then keyed at the normal interrogation frequency of 32 pps and the movement of the range gate was observed. The lower curve of Figure 11 summarizes the results of this test.

To find the effect of a signal in the narrow gate, V-419 was replaced and V-415 was removed, killing both the wide and narrow gate generators. However, the narrow-gate coincidence detector, V-419, was placed in a gated-on condition by raising its screen voltage to the normal gated-on value, using an external voltage supply. Properly coded replies were then fed into J-402, the video input jack, at the interrogation frequency rate and the movement of the range gate was observed. The upper curve of Figure 11 summarizes this test.

Examination of Figure 11 shows that a signal in the narrow gate has from 2.5 to 3 times as much effect as one in the wide gate. This is not unexpected. It should be borne in mind that the upper curve of Figure 11 represents the motion of the range gate due to the narrow-gate coincidences alone. In operation, of course, there is wide-gate coincidence whenever there is narrow-gate coincidence so that the net motion due to a signal in the narrow gate is found by taking the difference of these two curves. It should also be borne in mind that the curves of Figure 11 are for complete coincidence; for partial coincidence in the narrow gate, movement would be less.

Ordinarily, one would expect that the range change would be independent of the range of the reply, but this did not prove to be the case (Figure 11). As the range increases there is a greater tendency toward decreasing range. A further test was made in an effort to determine the cause of this phenomenon. With no signal in, the range gate of its own accord was found to drift invariably toward decreasing range and at a rate which increases with range (Figure 12).

The drift is undoubtedly caused by charge leaking off C-512. The voltage of this condenser determines the location of the range gate. The drift is higher at maximum range because the condenser voltage is at its greatest value here and hence the leakage current would be the greatest.

Figure 11 may be used to estimate the maximum rate that the interrogator may move with respect to the transponder and yet remain locked on the response. If the signal moves faster than the gate, obviously the gate will not remain locked on the signal. The gate will follow a signal moving out at a maximum rate of approximately 4250 knots at a 100-nautical-mile range, and 5200 knots at a 0-nautical-mile range. Moving in, the gate will follow a signal at a maximum rate of 7200 knots at 0 range and 8850 knots at 100-nautical-mile range. These figures assume that no interrogations go unanswered. For a transponder efficiency of  $\frac{2}{3}$  the maximum velocity of follow will be approximately  $\frac{2}{3}$  of the velocities given. Of course, if the maximum rate of tracking is exceeded while moving away from the transponder, search will momentarily be resumed until the range gate once more catches up with the responses. The range step-back circuit may effectively do this for tracking in.

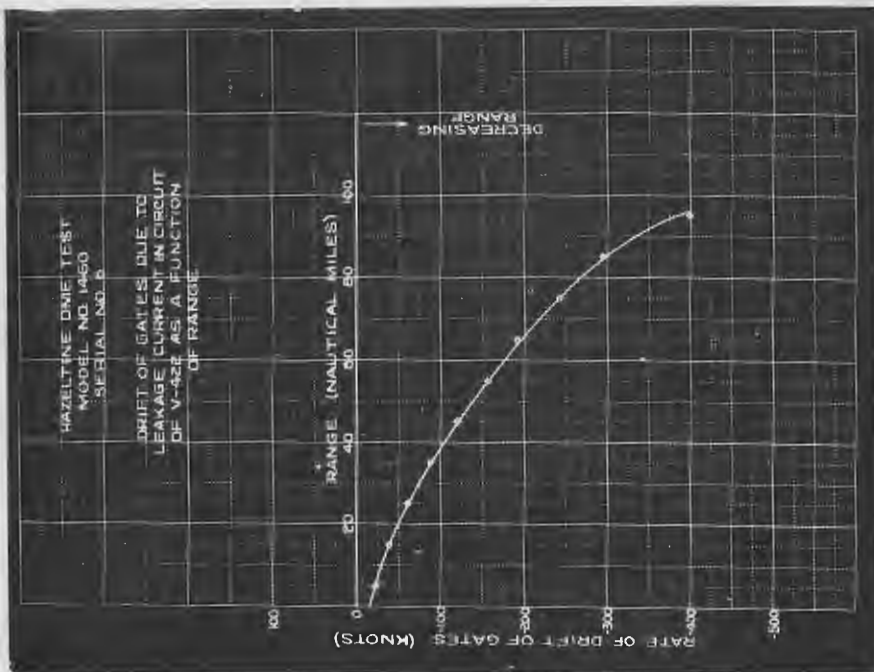


Figure 12

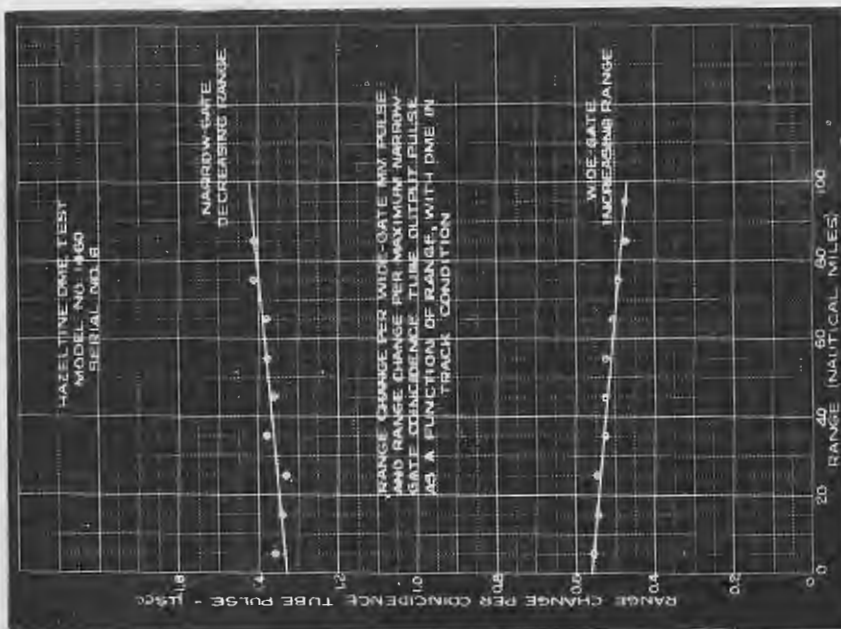


Figure 11

Using the artificial interrogator simulator (motion simulator) rates up to 1000 knots toward and away were simulated. The DME had no difficulty in tracking at this speed. This is consistent with the results given in Figure 11. In order for the tracking to fail at 1000 knots due to the responses moving faster than the gate, the transponder efficiency would probably have to be less than 25 percent, in which case tracking would undoubtedly cease anyway because of insufficiency of replies to hold the circuits in track position.

#### Range Accuracy

**Static Range Error.** Before the DME tests were started the range meter was calibrated in the manner prescribed by the instruction book accompanying the equipment (6). Zero-range and 100-nautical-mile-range indications were adjusted to be correct. Near the conclusion of the tests, range accuracy was checked to see how much the previously calibrated points were in error and what error, if any, there was in the intermediate range points.

Range was measured using a delayed-pulse generator, the delay being accurately calibrated against a crystal-controlled calibrator. The delayed pulse was used to key a properly coded artificial transponder and the DME tracking circuit locked on to its output.

The resulting calibration curve (Figure 13), shows that the 100-mile setting had drifted about 0.6 nautical mile, which turned out to be the maximum range error. Under 20 miles the range error was found to be practically zero. Percentagewise the range error is less than 1 percent over the entire range. This appears to be quite good.

Evidence was found which indicates that the range calibration changes somewhat with time and is dependent on line voltage. However, the variation does not appear to be excessive.

**Dynamic Range Error.** The error in range when the DME is tracking a moving signal was also investigated. Using the motion simulator generator rates up to 1000 knots were fed into the tracking circuit and the dynamic range error was compared with the static range error.

For high tracking rates the range-indicator needle hunts, oscillating as much as 0.2 mile about the true static range. (See section on Tracking and Memory.) The average of the extremes of the oscillations was taken as the indicated range and this indicated range was found to be practically the same as the static range even for transponder efficiency as low as  $2/3$ . The average dynamic range indication is essentially the same as the static indication and the static and dynamic range errors are not measurably different.

#### Average Memory Time as a Function of Input Pulse Density

When the interrogator receives a certain percentage of replies to its interrogation it will stop searching, lock on and track these replies. If this percentage is maintained during track for a sufficient length of time (about 2 seconds) a memory circuit becomes operative which will hold the interrogator in the track condition for a certain period of time

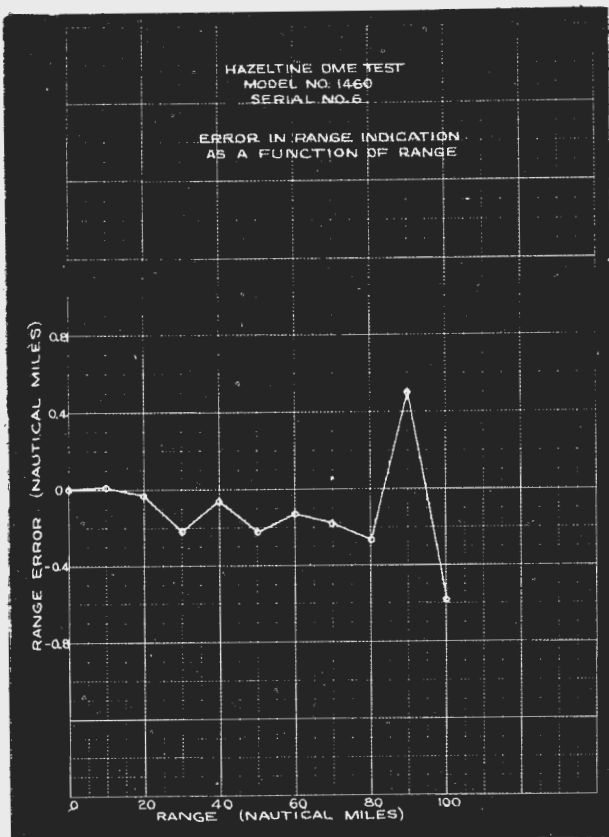


Figure 13

even if the interrogations go unanswered. This memory circuit is designed to prevent the resumption of search due to the temporary failure to get responses to interrogations.

In the equipment under test the memory time is dependent upon two things, the nominal memory setting which is a potentiometer adjustment, R-1114, and the density of nonsolicited responses and fruit pulses which are received during the period of unanswered interrogations. The nominal memory setting changes the memory time from a minimum of about 7.5 seconds to a maximum of about 33 seconds (Figure 14). The minimum memory time also depends to a certain extent on the R-559 setting (Figure 5). This is the memory time which is observed when the interrogator has tracked for several seconds and then all input is stopped. If all input is not stopped, merely the interrogation responses, a memory time differing from the nominal memory time is observed.

Theory says that the memory time with random pulse input should be greater than the nominal memory time

because fruit responses will be received occasionally at the proper time by pure chance, and act as a substitute for the absent solicited response. The memory circuit is so constructed that such chance reception prolongs memory time.

The purpose of this test was to observe the change in memory time under these conditions.

1. Solicited responses interrupted and a variable input from four equally loaded but improperly coded transponders, i. e., memory time with pure fruit input.
2. Solicited responses interrupted with a variable input from a properly coded transponder.
3. Solicited responses interrupted and the combination of a variable input from a properly coded transponder mixed with a high ambient of fruit pulses of 48,000 pulses per second from improperly coded transponders.

The variation in memory time for the three conditions just mentioned was made for the nominal memory set at the two extreme conditions, the maximum and the minimum.

Results of memory-time tests (Figures 15, 16) are surprising and at variance with theory. With the memory time set at a minimum practically no variation of memory time

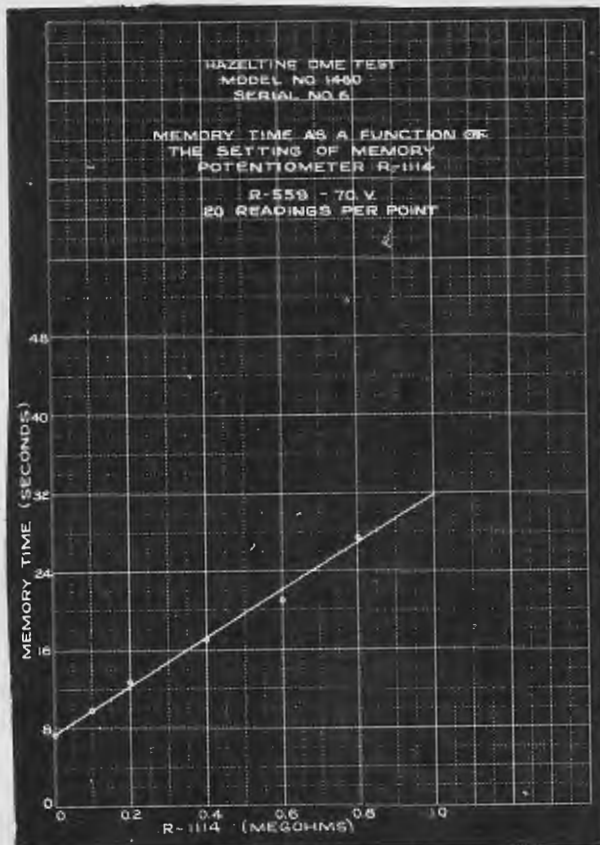


Figure 14

from the nominal value was observed (Figure 15). With an input of 60,000 pulses per second one should expect almost 4 wide-gate coincidences per second. While this is not enough to maintain the track condition it should increase memory time noticeably.

For the other extreme, nominal memory time set at a maximum, some increase in memory time was observed when the pulse input was high. With an input of 60,000 pulses 25 percent increase in memory time was measured. Apparently, the memory circuit is more affected by fruit pulses for the longer memory setting.

When the input consists of properly coded pulses the memory time shows a more-substantial increase, although the actual pulse input rate was held fairly low (Figure 16), the maximum input tested being about 2700 properly coded pulse pairs, which on a chance basis amounts to about 2 wide-gate coincidences per second. Although this number of coincidences is only about half of the output which should be expected when the input is 60,000 random pulses (Figure 15) the memory time increase for the former case was much greater. In fact, for the highest nominal

memory setting the point of infinite memory was almost reached. The reason for this difference seems to be that the high random-pulse input overloaded the video and the decoder circuits much more than the properly coded but much lower input pulse density. This overloading results in a much lower decoder output than should be expected from theoretical considerations.

The fact that a high pulse density of input actually overloads the video and decoder circuits is borne out by the second set of curves of Figure 16. When a random pulse input of 48,000 pulses is mixed with the properly coded pulses one should expect an even greater increase in memory time. But this was not found to be the case. Actually, the memory time is generally less for the combination of the two inputs than it is for the properly coded input alone. This is very evident for the case of the high nominal memory setting. Here again there is evidence that high input pulse density overloads the video and decoder circuits and actually reduces the number of pulses from the decoder and wide-gate coincidences.

It was indicated in the section of this report devoted to preliminary tests that the setting of potentiometer R-559 determines the sequence of responses necessary to cause the search function to be terminated and the track function to begin. In the course of these tests it was found that a potentiometer setting corresponding to a voltage of about

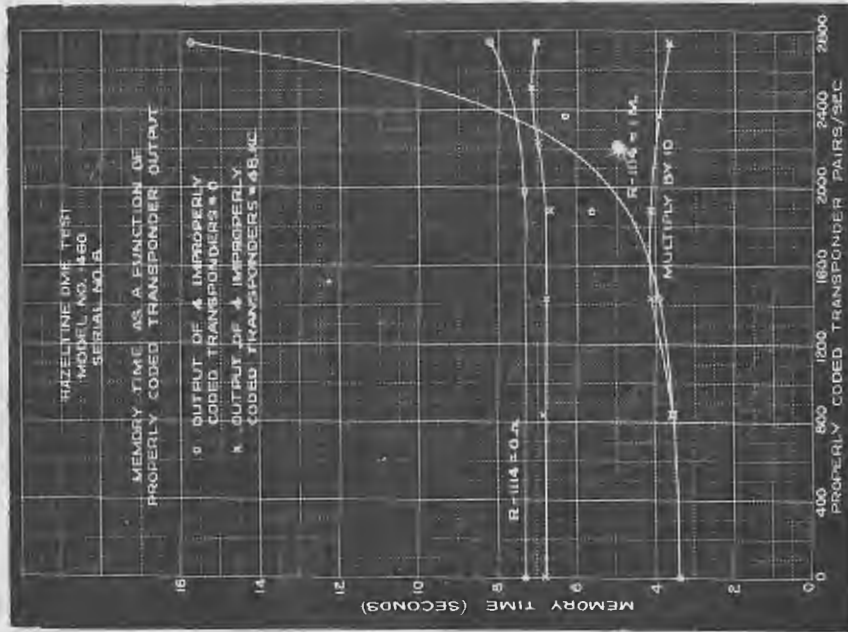


Figure 15

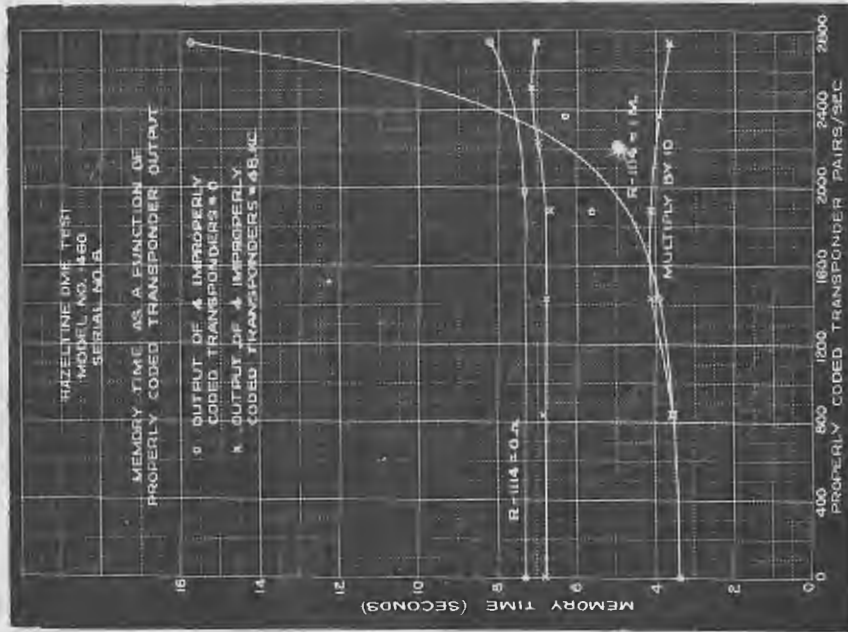


Figure 16

68.5 would cause the search-to-track relay to operate when two pulses out of three were received. At the time of those tests it was assumed that an average of 2/3 or more had to be maintained for some time in order for the track condition to be maintained. However, this is not the case. Further investigations brought out the following facts.

1. With potentiometer R-559 set at 68.5 volts any two responses to three successive interrogations cause the search-to-track relay to operate.
2. After the search-to-track relay operates a response efficiency of less than 40 percent is required to hold the relay in track until the memory circuit becomes operative.
3. After the memory circuit becomes operative an even lower response efficiency will maintain this relay in the track position. For the maximum memory setting the required response efficiency is on the order of 10 percent. For lower memory settings it is higher but never as high as 40 percent.

It has been indicated that under high pulse density conditions the operation of the video and decoder circuits deteriorates. However, when the video and decoder circuits are not overloaded with high pulse density input the behavior of these circuits is in close conformity with theory. This is borne out by the lower curve (Figure 8) which gives the average number of searches-to-lock when the input is limited to the output of a single properly coded transponder.

As was stated, the search-to-track relay was adjusted to operate whenever two replies were received to any three interrogations, On this basis some of the points of this curve can be checked. If the transponder efficiency is 0.67, i. e., the probability of obtaining a response to an interrogation is 0.67, the probability of obtaining at least two responses to three successive interrogations is  $20/27$  or about 0.74. The average number of searches-to-lock should be  $27/20$  or 1.35. The measured value was found to be 1.28. For a transponder efficiency of 0.50, the probability of getting at least two responses from three interrogations is also 0.50, and the average number of searches-to-lock should be 2.00. It was measured to be 2.15.

It is evident from the investigations thus far recorded of the searching and locking characteristics of the DME that the decoder efficiency suffers markedly under high pulse density. To obtain more data on this condition, quantitative measurements of output versus input were made on the decoder (Figures 17, 18).

The curves of Figure 17 compare the measured output with the theoretical output when the input is derived from a single, properly coded transponder. For this case the decoder output, as measured by the rate of keying of the wide-gate multivibrator, is in close agreement with the theoretical output. The small and almost constant difference may be due to a small error in measuring the gate duration of the interrogation rate. Not much deviation of the output from the theoretical value should be expected here, because the pulse density of the input can never be made extremely high and after each pulse pair there is a transponder dead time which allows the video and decoder circuits to recover at least partially. Moreover, since these pulse pairs have almost exactly the correct code spacing, effective pulse length hardly enters in.

When the pulse input is a mixture of improperly coded pulse pairs from four independent transponders the situation is different. As Figure 18 shows, the decoder output is much lower than the value predicted by theory. The greatest deviation occurs when the input pulse density is the greatest. Also, strange as it may seem, the decoder output depends on whether the improperly coded transponders are set so that they produce

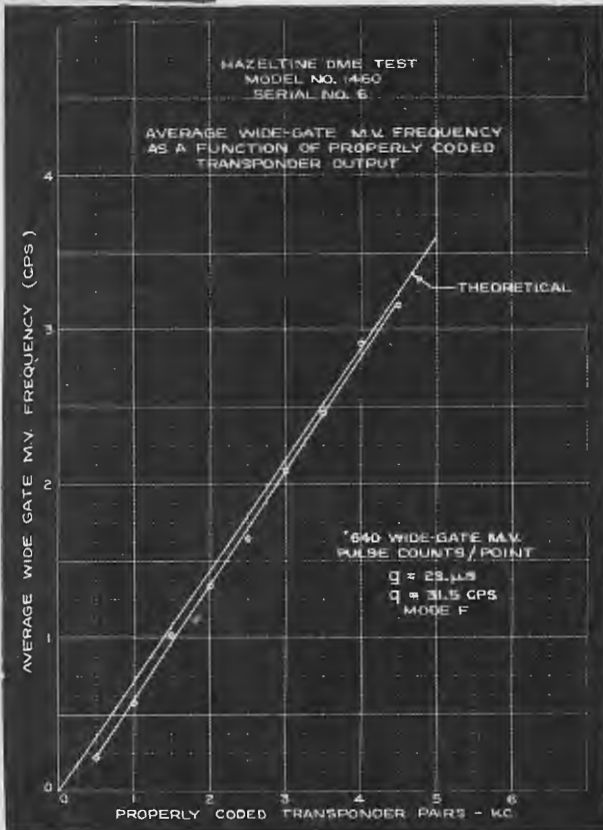


Figure 17

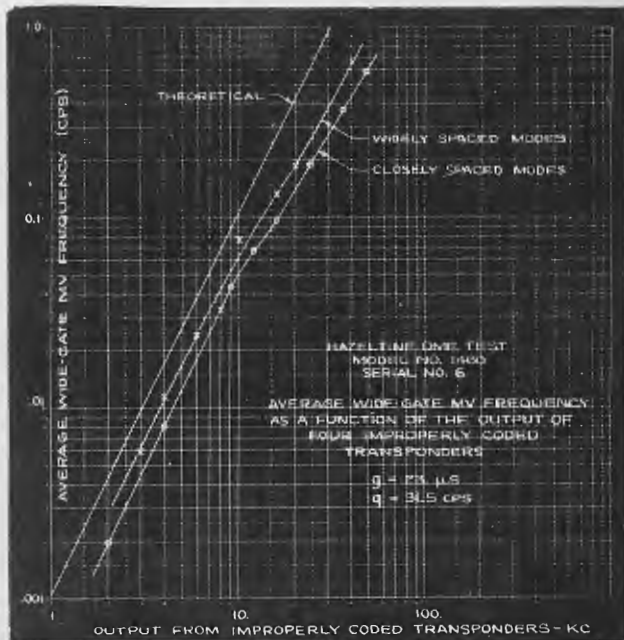


Figure 18

widely spaced pulse pairs or narrowly spaced pulse pairs. The output for the widely spaced pulse pairs is about 40 percent higher than that for the narrowly spaced pairs. The reason for this difference is undoubtedly due to the inability of the video and decoder circuits to recover quickly after passing a pulse. For the narrowly spaced pulse pairs the second pulse does not receive the same amount of amplification as the first pulse does. This effect is less pronounced for the wide spacing since more recovery time is available.

According to theory, the number of replies due to bunching of pulses from improperly coded transponders is given approximately by:

$$N_F = 8 n^2 (C-1)(C-2) d,$$

where  $N_F$  = the decoder output in pulses/sec

$n$  = the pulse pair output from each of  $C-1$  equally loaded, improperly coded transponders

$C$  = the number of properly coded transponders ( $(C-1)$ , improperly coded transponders)

$d$  = the effective pulse length

The rate of keying of the wide-gate multivibrator will be

$$N_E = N_F g q,$$

where  $N_E$  = number of wide-gate multivibrator keyings per second

$g$  = effective gate length

$q$  = interrogator interrogation rate

From these equations it can be seen that the effective number of replies due to bunching is directly proportional to  $d$ , the effective transponder pulse length. One way to interpret the relative falling off of output with increased density of pulse input is in terms of a reduction of effective transponder pulse length. On this basis the tests show that the effective pulse length for a very high density of pulse input is only from a third to a fourth of its value for very low density of pulse input (Figure 18).

The waveform of the decoder delay-line output varies markedly with the mode setting (amount of delay). Figure 19 shows this waveform for four of the ten modes. The input is a square pulse of  $2.5 \mu\text{sec}$  duration. In magnitude the output is greatest for Mode J (minimum delay) but it is not smallest for Mode A (maximum delay); Mode D gives the minimum output, only about 25 percent of that of Mode J. The output for Mode D is too low to give consistently satisfactory output.

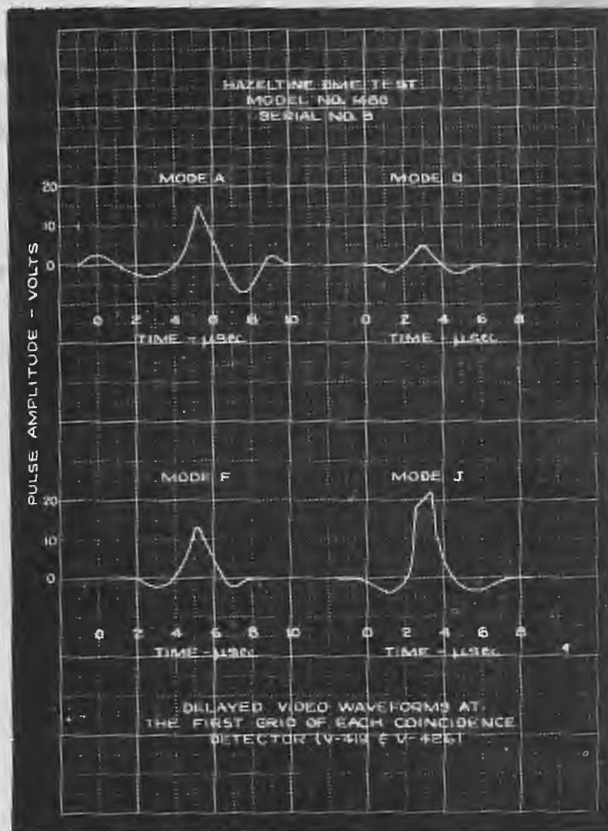


Figure 19

When a high density of pulse input is applied to the decoder circuit the magnitude of the output of the decoder delay line is not constant although approximately the same relative waveform is maintained. The amplitude frequently falls to a third of its normal value.

Obviously, the condition indicated by Figure 19 is far from ideal. The output waveform and magnitude should not vary with mode setting. Likewise, there should be no reduction in amplitude when the input pulse density is increased.

#### Miscellaneous Observations

The video and search unit also contain circuits designed to detect transponder identifying codes. A transponder identifying code consists of a third pulse sent after the second pulse of a normal transponder reply. This third pulse is delayed from the second pulse by either one of two fixed amounts. One delay corresponds to the "Mark" and the other to a "Space." When mark pulses are sent the mark light on the control box lights up and space pulses will cause the space light

to light. By sending a characteristic combination of mark and space pulse sequences, a transponder can identify itself to the interrogator.

No extensive tests were made on these identification circuits because information was received that this type of transponder identification is no longer being contemplated. However, investigation did show that these circuits would operate in the prescribed

manner although with low transponder efficiency a rather objectionable flashing of the mark and space lights was observed.

In the course of the tests it was necessary to add more filtering to the power supply since an objectionably high 400-cps component was present in the B+ voltage. There was also some trouble caused by a sticking relay, K-402. The signal applied to wide- and narrow-gate generators seemed to have an excessive amount of noise in the form of short, low-amplitude pulses on them. Perhaps the biggest objection to the general behavior of the equipment was the relatively long warm-up period required before reliable repeatable data could be obtained on circuit performance. This period ran into hours. There was also considerable day-to-day variation in performance. The circuits seemed to be unduly sensitive to line voltage and temperature.

**THEORETICAL ANALYSIS**

**Additional Demand on Transponder Due to Bunching**

The formula derived in the Hazeltine report (5),  $N_E = 8N^2d$ , gives a slightly pessimistic figure for the increase in interrogation rate due to bunching, especially so at very high interrogation rates. In the derivation of this formula the effect of pulse overlapping is not considered.

If I (Figure 20a) is the proper code spacing, it is evident that either pulse 2 or pulse 3 along with pulse 1 would create an additional interrogation request on the transponder. According to the Hazeltine formula (5), this would be counted as two additional requests but actually due to overlapping it represents only one. At very high interrogation rates overlapping of this kind is not uncommon.

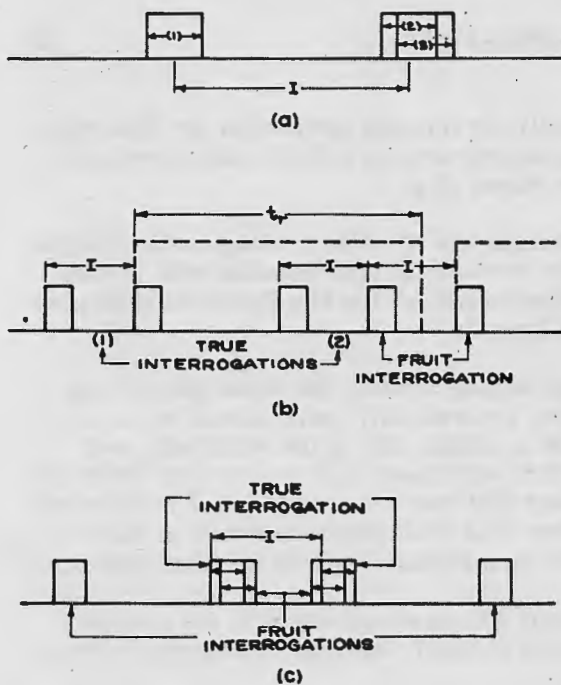


Figure 20 - Ways in which fruit interrogations may be formed

A more accurate evaluation of increase in interrogation rate may be made by considering the average number of overlapped groups such as are formed by pulses 2 and 3 and the average length of these groups.

In an NRL report (1) expressions applicable to the phenomenon of overlapping are derived. The average number of pulse groups per second including nonoverlapped pulses is

$$N_R = 2aq(1-2qd)^{a-1},$$

where  $N_R$  is the number of these groups per second

- a is the number of interrogators having the incorrect code
- q is the average interrogating rate per second (2q is the pulse output of each second)
- d is the length of the pulses

The average duty factor is given by

$$DF = [1 - (1 - 2qd)^a].$$

Hence, the average group duration (length) is

$$d' = \frac{DF}{N_R} = \frac{[1 - (1 - 2qd)^a]}{2aq(1 - 2qd)^{a-1}}.$$

These groups can form

$$\frac{[2aq(1 - 2qd)^{a-1}] [2aq(1 - 2qd)^{a-1} - 2q]}{2}$$

potentially correctly spaced pairs per second. The probability that the spacing of any particular pair is correct is  $4d$ . Hence, the net increase in interrogation rate due to bunching is

$$N_E = \frac{[2aq(1 - 2qd)^{a-1}] [2aq(1 - 2qd)^{a-1} - 2q]}{2} \times \frac{4[1 - (1 - 2qd)^a]}{2aq(1 - 2qd)^{a-1}} = 4q [a(1 - 2qd)^{a-1} - 1] [(1 - 2qd)^a]. \quad [1]$$

If this expression is expanded into a series, the first two terms are:

$$N_E = 8a(a-1)q^2d - (24a-8)a(a-1)q^3d^2. \quad [2]$$

The first term of this expansion is essentially the formula derived in the Hazeltine report, where  $a(a-1)q^2$  is replaced by  $N^2$ . The second term is a first-order correction which may be taken simply as  $24N^3d^2$  for large values of  $a$ .

On Figure 21, Equation [1] is plotted for various  $a$ 's and  $d$ 's,  $q$  being assumed equal to 30 per second. The Hazeltine equation for the increase in interrogation rate is also plotted on the same figure for comparison. A comparison of the two formulas show substantial agreement except for very high  $a$ 's and long  $d$ 's.

When a fruit pulse comes at the proper time before or after the pulse pair having the spacing to which the transponder is sensitive, theoretically there should be an additional call on the transponder. Practically this is slight, due to the relatively long dead times employed in the transponder. However, additional calls could come about in the manner illustrated in Figure 20b which shows that there is an additional call on the transponder due to the presence of the fruit pulse. The fruit pulse combines in such a way with the second interrogation pulses to form an additional call on the transponder.

The increase in interrogation rate due to fruit pulses combining with the properly coded interrogation pulses however, is very small at most, because it depends on three relatively improbable events.

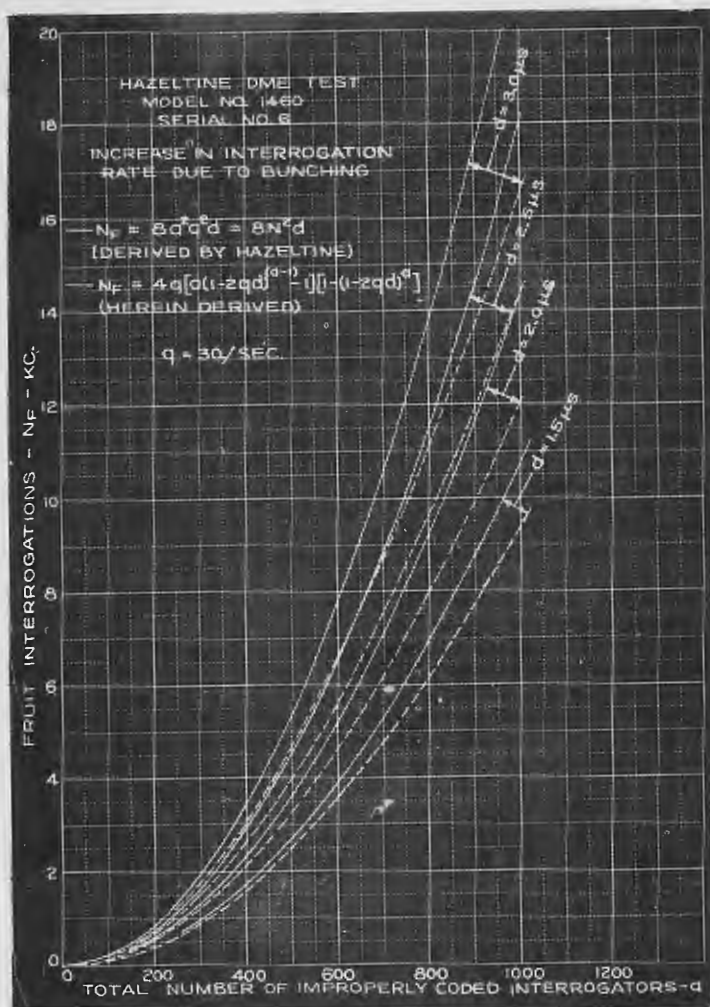


Figure 21

resultant error. Certainly this error would be below that encountered in the course of ordinary engineering approximations.

The bunching formulas which apply to the combined outputs of transponders on any one frequency as derived in the Hazeltine report (5) are subject to the same sort of corrections as was indicated for the combined outputs of interrogators. Since this correction is small at most, more accurate formulas are not worth the added complexity and hence they will not be included here.

It is perhaps appropriate to state here that no significant error was discovered in the deviations of the many formulas given in the Hazeltine reports (4, 5). Many of these formulas were derived independently and the results agree substantially. From these formulas and equations the manufacturer draws conclusions as to the probable behavior of his equipment under various conditions of operation. It is presumed that these assumed conditions of operation are as severe as will be encountered in operation and the calculated performance, if achieved in practice, is satisfactory.

1. That a normal interrogation will arrive during the transponder dead time. With a transponder efficiency of 2/3 of this, probability is only 1/3.
2. That the normal interrogation arrives during the later parts of the dead time.
3. That there will be a fruit pulse arriving at the proper time after the true interrogation. This is the least probable of the three.

Any increase in interrogation rate due to pulse combinations of this sort should therefore be very small. The increase is counterbalanced at least in part by total or partial correspondence of a fruit interrogation with a true interrogation (Figure 20c).

The fruit interrogation rate can therefore be added directly to the true interrogation rate to get the total interrogation rate on any transponder with very little

## Lowering of Reply Efficiency Due to Input Differentiation in the Interrogator

The pulse input to the video and search unit of the interrogator is differentiated. This differentiation prevents the transmission of long pulses to the decoder and thus prevents the lowering of the reply efficiency.

Consider the effect of the occurrence of a fruit pulse shortly before the occurrence of either of the pulses of a properly coded pulse pair. Due to differentiation one of the pulses of the properly coded pulse pair is effectively eliminated and there is no output from the decoder.

The resulting response efficiency due to differentiation will now be derived. In this derivation let:

$W$  = transponder pulse length

$d$  = effective pulse length after differentiation

$B_j$  = reply efficiency of transponder  $j$

$T = 1/q$  = DME interrogation period (about 1/30 of a second)

$n_{t_j}$  = effective number of challenges per second of transponder  $j$

$C$  = total number of transponders

$n_p$  = number of pulses in transponder code group, normally equal to two.

$N'_d$  = Output of interrogation decoder in pulses per second.  $N'_d T$  is the resultant reply efficiency as seen in the output of the interrogator decoder.

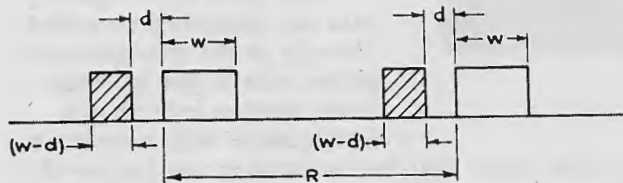


Figure 22 - Manner in which reply may be lost due to input differentiation

Consider an interval  $T$  where a properly coded solicited reply exists, as in Figure 22. If the leading edge of a fruit pulse falls in the space  $w-d$  in front of either pulse of the properly coded pulse pair there will be no output from the decoder due to differentiation. In the period  $T$  transponder  $j$  will have a total pulse output of

$$n_p B_j n_{t_j} T.$$

The probability that the leading edge of one of these pulses will fall in the intervals  $(W-d)$  so as to cause the loss of a reply is

$$\frac{n_p B_j n_{t_j} T}{1} \times \frac{2(W-d)}{T} = 2(n_p B_j n_{t_j})(W-d).$$

The probability that this will not occur is

$$\left[ 1 - 2(n_p B_j n_{t_j})(W-d) \right].$$

And the probability that no pulse from the C-1 improperly coded transponders will fall in these critical intervals is

$$\prod_{j=2}^{j=C} \left[ 1 - 2(n_p B_j n_t)_j (W-d) \right]$$

If the improperly coded transponders are equally loaded and are otherwise identical also this probability becomes

$$\left[ 1 - 2(n_p B n) (W-d) \right]^{C-1}$$

The normal output of the decoder is

$$N_d = B_1 q$$

Hence, the resultant effective number of replies will be

$$N'_d = B_1 q \left[ 1 - 2(n_p B n_t) (W-d) \right]^{C-1}$$

For most practical purposes only the first two terms of the expansion need be taken, i. e.,

$$N'_d = B_1 q \left[ 1 - 2(C-1)(n_p B n_t) (W-d) \right]$$

And the reply efficiency (Figure 9) is

$$\frac{N'_d}{B_1 q} = \left[ 1 - 2(C-1)(n_p B n_t) (W-d) \right]$$

#### Optimum Memory Time

In operation the airborne DME will inevitably fail to receive replies to its interrogations for certain periods of time. This failure may be due to a lowering of transponder efficiency as a result of high traffic conditions, or it may be a purely physical shielding of the signal during banking or some other plane maneuver. During these periods of no replies, it is the function of the memory circuit to hold the tracking circuit in operation pending the return of the transponder signal. Obviously, this memory time can not be made indefinitely long for then the DME might never indicate the correct range after once losing the transponder signal. On the other hand, if the memory time is made very short it is quite possible that the DME would search excessively. It will be shown that the average control time of the range gate ought to near optimum for memory time.

The choice of memory time is influenced by the probability of losses of signal, interrogation rate, airplane speed, range-gate duration, and, perhaps other considerations. However, a simple criterion for the memory time setting is available. As was stated, this setting should be the average control time of the range gate. If the memory time is longer than the control time of the gate and the signal returns after this control time is past, the signal will no longer fall in the range gate and the DME must eventually return into the search condition. Therefore, the part of the memory time in excess of the gate control time serves no useful purpose. It does not increase the probability of continuous tracking but merely postpones the inevitable return to search, and will increase average search time.

The control time of the range gate is determined primarily by two things—the length of the range gate and the speed of the airplane relative to the transponder. Assuming the transponder reply lies in the center of the range gate during track (which it does in the DME under test), the control time may be easily derived.

Let  $g$  = gate duration in  $\mu\text{sec}$ ,

$v$  = signal velocity in knots,

$t_c$  = control time in sec, and

1-nautical-mile radar range = 12.35  $\mu\text{sec}$ .

On the assumption that the signal normally lies at the center of the gate, the control time will be equal to the time for the signal to move the distance of the gate, i. e.,

$$t_c = \frac{\frac{g}{2} \mu\text{sec}}{\frac{v}{3600} \times \frac{\text{nautical miles}}{\text{sec}} \times \frac{12.35 \mu\text{sec}}{\text{nautical mile}}}$$

$$= \frac{14.59g}{v} \text{ sec.}$$

For an airplane speed (signal velocity) of 300 knots and a gate duration of 20  $\mu\text{sec}$  the control time,  $t_c$ , is slightly under 10 seconds. For the equipment under test the gate duration is actually about 20  $\mu\text{sec}$ . The normal airplane speed is of course variable depending on the type of airplane. In accordance with the aforementioned criterion the memory time of the DME installed in an airplane should be adjusted commensurate with the normal speed of the plane, the faster the plane the shorter the memory time. If 300 knots is taken as a good average, the memory time should be set at about 10 seconds.

#### CONCLUSIONS AND RECOMMENDATIONS

Undoubtedly, the greatest fault to be found with the equipment under test is in the behavior of the video and decoder circuits under high input pulse density, (simulated high traffic conditions). There is evidence that they become overloaded badly, resulting in an excessively high number of searches-to-lock when the pulse input is high. While the decoder delay line seems to give a stable delay for all modes, its output waveform varies considerably with mode setting (delay). The delay line driving circuit may be partly at fault here but, at any rate, circuits giving better performance should be incorporated in any subsequent equipment.

Improvement of the video and decoder circuit would undoubtedly result in an increase of search time and memory time but this should not be excessive. The reduction in the number of searches-to-lock should more than compensate for this increase.

Except for the oscillation (hunting) of the range indicator at high tracking rates, the tracking ability is good and the range error is small. Some effort should be made to reduce this oscillation of the range indicator during tracking. There is evidence to show that much of the oscillation is due to inertia in the range indicator servo-system.

The present airborne equipment is both heavy and large but this is not considered a legitimate objection to the equipment since it is only an experimental model.

It should be emphatically noted that no over-all conclusions of the complete DME system can be drawn from these tests. In actual operation, the performance of the system would be affected by the behavior of the ground equipment, and the r-f and i-f parts of the airborne equipment upon which no tests were made. However, it is reasonable to expect that the system performance will be no better than the performance of searching, tracking, and range indication circuits which have been the subject of the tests herein described.

If any single test should be made on the r-f and i-f units, it should be on the adjacent channel rejection capability of the receiver. Such a test would have been attempted by this Laboratory but for the pressure of time. In its present condition the equipment tested does not operate too well under simulated conditions of high traffic conditions, due to the relatively large number of searches required before tracking begins. This appears to be much more a circuit failure than a failure due to theoretical limitations.

The manufacturer, on the basis of theoretical studies, predicts the performance of his equipment under various assumed conditions of operation. Not much fault was found with these predictions. The inherent merit of the final equipment therefore seems to rest on three things.

1. That the assumed conditions of operation are actually as severe as will be encountered in practice.
2. That the theoretically predicted performance is satisfactory.
3. That the manufacturer is able to build equipment which will live up to theoretical expectations.

In passing it might be noted that the actual conditions of operation are still subject to a considerable amount of speculation. Estimates have been revised frequently.

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#### REFERENCES

1. Ohman, G. P., "Average Pulse Relationships in High Pulse Density Systems," Naval Research Laboratory Report R-3379, November 1948
2. Sheridan, J. P., "Multiple Pulse Generator," Naval Research Laboratory Report R-3372, October 1948
3. Watterson, C. C., "Video Pulse Counter," Naval Research Laboratory Report R-3679, May 1, 1950
4. Hirsch, C. J., "Traffic Handling Capacity of Distance Measuring Equipment Using Pulse-Pairs," Hazeltine Report No. 2059-W-R, Aug. 1947
5. "Traffic Handling Capacity of 100 Channel Distance-Measuring-Equipment (DME) Standardized by RTCA SC-40 and ICAO," Hazeltine Report No. 2081-W, Figure 6
6. "Modification of Airborne DME AN/APN-34(XA-7)," Hazeltine Report No. 9347

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