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EVALUATION OF 100-CHANNEL DISTANCE MEASURING EQUIPMENT

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SUMMARY

This report describes a series of tests, engineering and operational, performed on early model 100-channel distance measuring equipments (DME) These tests were performed for the purpose of evaluating the new techniques required for expansion of the earlier 50-channel system into a 100-channel system The specific purpose and the results of each test are evaluated in the light of 100-channel DME requirements As a result of these tests it is concluded that the proposed 100-channel DME system is based on sound engineering principles and is compatible with the most stringent operational requirements

INTRODUCTION

Equipment to be employed for the automatic measurement and display of distance in aircraft has been under development since late in 1945 Development of distance measuring equipment (DME) progressed rapidly and by the fall of 1948 was sufficiently advanced so that production contracts could be placed The equipments in existence at that time provided for the selection of any of 50 independent and noninterfering operating channels At that time there were two different methods in use for providing this channeling capacity, one designed around the technique of high-stability transmissions and narrow-band receivers, and the other designed upon the principle of pulse-multiplex [1] Extensive tests conducted under the auspices of Subcommittee SC-40 of the Radio Technical Commission for Aeronautics led to the conclusion that both of these techniques represented a practical means of DME channeling About this time, a re-examination of future air traffic control and navigation requirements resulted in a change of the number of DME channels required from 50 to 100 By combining both the pulse-multiplex and high-stability techniques into the same equipment, it is possible to obtain 100 channels and actually reduce the total frequency spectrum previously occupied by either of the 50-channel systems [2] A total band of 225 Mc was employed by both types of 50-channel systems, whereas the total spectrum required by the 100-channel system amounts to only 55 Mc

On theoretical grounds, implementation of the 100-channel system, using only tested techniques (techniques employed in either or both of the 50-channel systems) presents no problems Past experience, however, has indicated that until equipment meeting specific requirements has actually been built and operationally tested, it is sometimes difficult to predict performance with accuracy For this reason, the placement of contracts for 100-channel equipment on a production basis was delayed until several developmental models became available It was believed that satisfactory performance of such models under conditions which are to be encountered by future production equipment would be an excellent criterion of the soundness of 100-channel principles Equipment manufacturers were urged to expedite delivery of 100-channel developmental models (both transpondors and interrogators) and simultaneously the Civil Aeronautics Administration initiated a project for combining two of the 50-channel interrogators (one pulse-multiplex and one high-stability type) in such a manner as to check various 100-channel characteristics In addition to laboratory tests of 100-channel equipment, it was deemed essential to perform flight tests of the equipment under conditions of traffic density equivalent to that predicted for the foreseeable future

Since the distance measuring equipment, being an integral part of the Common Air Navigation and Traffic Control System defined by SC-31 of the RTCA and now being developed under the direction of the Air Navi-

[1] SC-40 report, RTCA Paper 121-48/DO-24, December 15, 1948

[2] R C Borden, C C Trout, and E C Williams, "UHF Distance Measuring Equipment for Air Navigation," Technical Development Report No 114, dated June 1950

gation Development Board, is a facility to be used by military as well as civil aircraft, a committee embracing both civil and military members was set up to direct the 100-channel DME evaluation program This committee met on September 15, 1949, at the Technical Development and Evaluation Center to discuss the various aspects of the test program

The test program was divided into four phases

Phase I Tests of the CAA combined pulse-multiplex high-stability 50-channel units

Phase II Laboratory tests of pre-production 100-channel units

Phase III Flight tests to determine the traffic handling capacity of 100-channel equipment

Phase IV Laboratory tests to determine the traffic handling capacity of 100-channel equipment

Phases I and II consisted of rechecking equipment characteristics which are common to both 50- and 100-channel systems, and particularly the testing of combinations of 50-channel techniques required for implementation of the 100-channel system

Phases III and IV are considered of major significance inasmuch as they were set up for the purpose of providing more realistic justification that the 100-channel system, as designed, is capable of operating under the high traffic densities which ultimately are anticipated Prior to the initiation of this test program, there was no suitable laboratory test equipment for determining traffic handling capacities of such systems accurately, nor were there a sufficient number of ground stations geographically located so that an operational test could be arranged Data of the type desired previously were limited to statistical analyses and to laboratory tests conducted with equipment not completely capable of simulating actual operating conditions Although the data from these two sources were in reasonable accord, it was believed highly desirable to perform tests under more realistic conditions If 100 transpondors were used in a 500-mile square, then there would be a total of ten transpondors transmitting on a common frequency, i e, each transpondor frequency would have to be repeated ten times It is conceivable that each of these transpondors may, at a given time, be supplying service to as many as 50 aircraft In such cases, all of the transmitted replies will be eligible for reception by all of the 500 aircraft involved, subject to line-of-sight propagation restrictions Any given aircraft will receive only one of the ten transpondors with a proper reply spacing, but all ten will be received at the correct frequency Interlacing of the replies from the nine improperly moded transpondors will result in an appreciable number of artificial replies having the correct mode being produced In this case, the ability of the aircraft decoding circuits to sort out the replies of proper spacing and reject all others is extremely important Furthermore, the ability of the searching and tracking circuits of a particular interrogator to recognize and respond to only those properly moded replies initiated by its own transmitter is imperative Inserting the line-of-sight limitations and a more realistic picture of traffic distribution, SC-40 concluded that the ability of the system to operate properly in the face of a loading of 20 aircraft for each of the nine improperly moded transpondors, and 50 aircraft for the properly moded transpondor, would guarantee satisfactory system operation for many years to come The purpose of Phases III and IV of this program was to determine whether or not this ability was inherent in equipment which can be built now

TESTS

Phase I

In order to obtain 100-channel data at the earliest possible date, the Technical Development and Evaluation Center immediately commenced work on an experimental 100-channel interrogator This unit consisted of the combination of a 50-channel interrogator of pulse-multiplex design with a similar interrogator of high-stability design Although both double-pulse transmissions of unstabilized character and single-pulse transmissions of high-stability character had been separately tested and found satisfactory, the combination of the high-stability feature with the double-pulse transmission had not yet been accomplished In order to assure that such a combination would not unduly complicate the aircraft transmitter, modulator, or automatic frequency control system, the double-pulse modulator was used to operate the high-stability transmitter The circuitry employed is shown as Fig 1 Operation under this condition

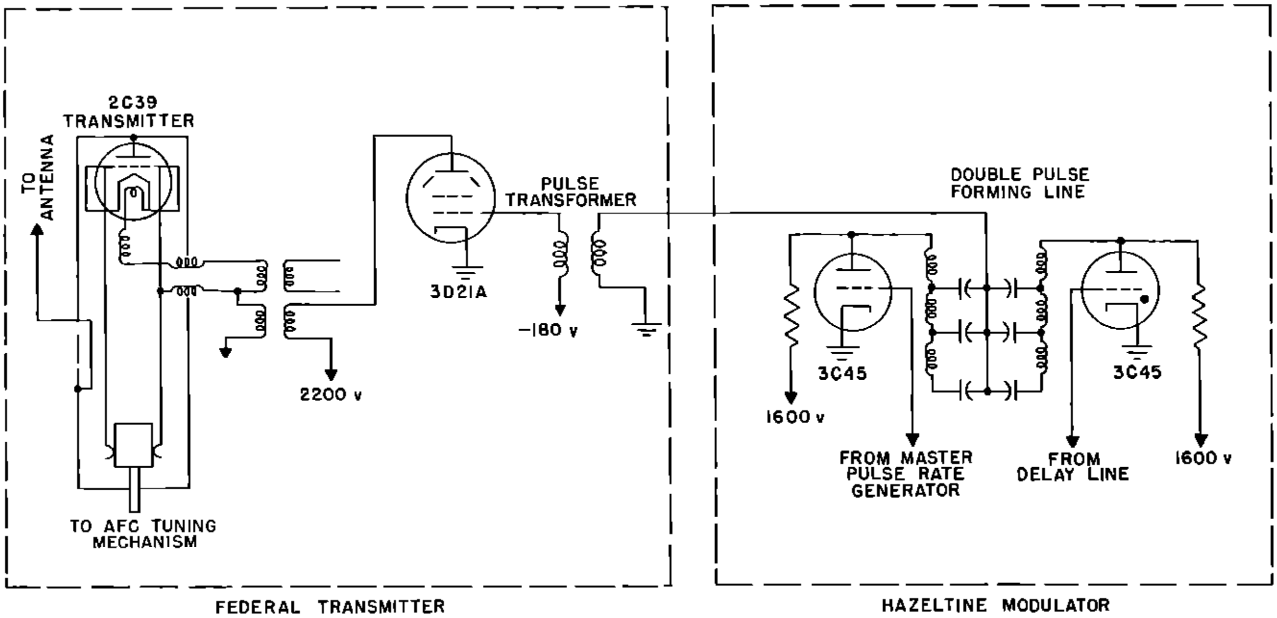

Fig 1 Circuit Employed for Modulating High Stability Transmitter with Double-Pulse Modulator

for a period of time revealed no deleterious effects to either the modulator, the transmitter, or the automatic frequency control The peak output power of the transmitter was reduced by less than one db with respect to the peak power obtainable when operated as a single-pulse transmitter There was no appreciable difference in the radio frequencies of the two transmitted pulses This initial test effectively duplicated the airborne transmitter prescribed for 100-channel equipment By using this transmitter to interrogate a ground transpondor, and by employing a high-stability narrow-band receiver for reception of the transpondor reply, a two-way DME transmission was completed on one of the radio frequency channels to be employed by the 100-channel system The ranging circuits of the pulse-multiplex interrogator were used to complete the 100-channel airborne unit, the transpondor reply was locked in the gates, and the indicator displayed the correct distance to the ground station This earliest and somewhat crude implementation of 100-channel equipment differed in technical characteristics from ultimate equipment in only two major respects

(1) Pulses of 1 1/2 μ sec duration were employed rather than the 2 1/2 μ sec pulses prescribed for 100-channel equipment

(2) The longer pulse spacings required for ten modes were not provided

No attempt was made to modify the laboratory equipment to meet these requirements inasmuch as the first 100-channel developmental models were received from the manufacturers at this time

Phase II

Upon delivery of the initial prototype equipment (both interrogators and transpondors) the system was installed and operated in aircraft Hazeltine Electronics Corporation and Federal Telecommunication Laboratories were suppliers of the equipment, which is shown as Figs 2 and 3 All equipment was thoroughly checked No evidence of failure to meet system characteristics was observed One new technique which previously had not been tested was the use of the spike-suppressor circuit to obtain very narrow receiver bandwidths The earlier 50-channel pulse-multiplex equipment employed a spike-suppressor to provide steep skirts on the receiver response curve, but some question was raised as to whether this circuit could be used successfully to provide a proper response curve at the narrower bandwidths required in the 100-channel system Upon arrival of the first narrow-band receivers in-

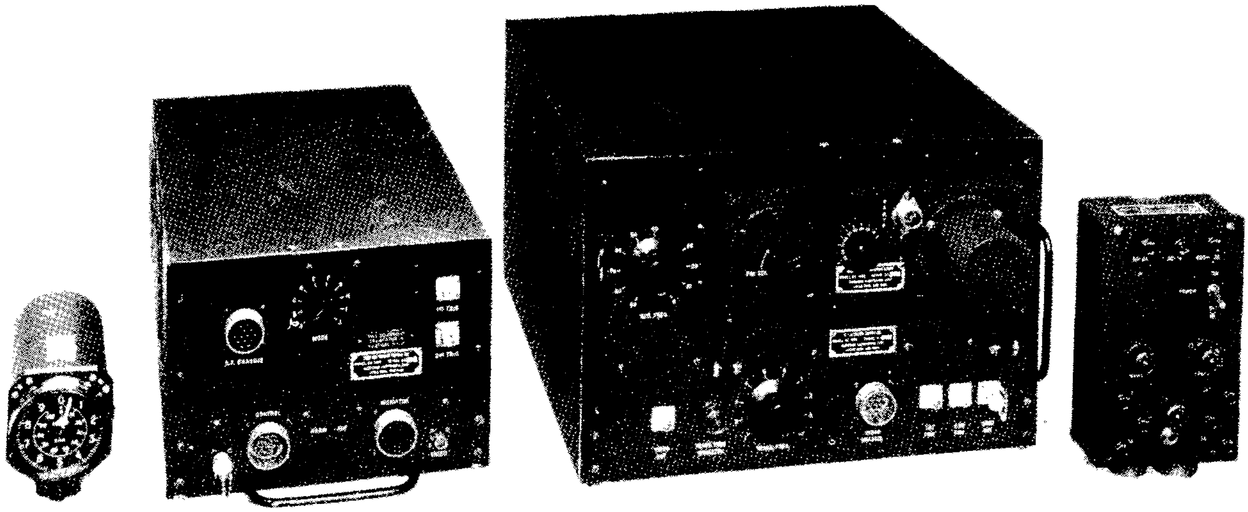

Fig. 2 Hazeltine 100-Channel DME Interrogator

Fig. 3 Federal 100-Channel DME Interrogator

corporating this design, response curves were plotted and compared with the response requirements of the specification. The bandwidth measured is shown as Fig. 4. This indicates performance within the figures prescribed by SC-40. The lengthening of the radio frequency pulse width from 1.5 to 2.5 μ sec. results in no deleterious effects. Use of longer spacings for obtaining the ten modes led to a requirement for greater care in the initial adjustment of delay lines; but, once the delay coils were properly adjusted, no difficulty was experienced with moding. Operation of the decoding circuits at the longer 2.5 μ sec. pulse width is indicated as Fig. 5.

It is of interest to note that automatic

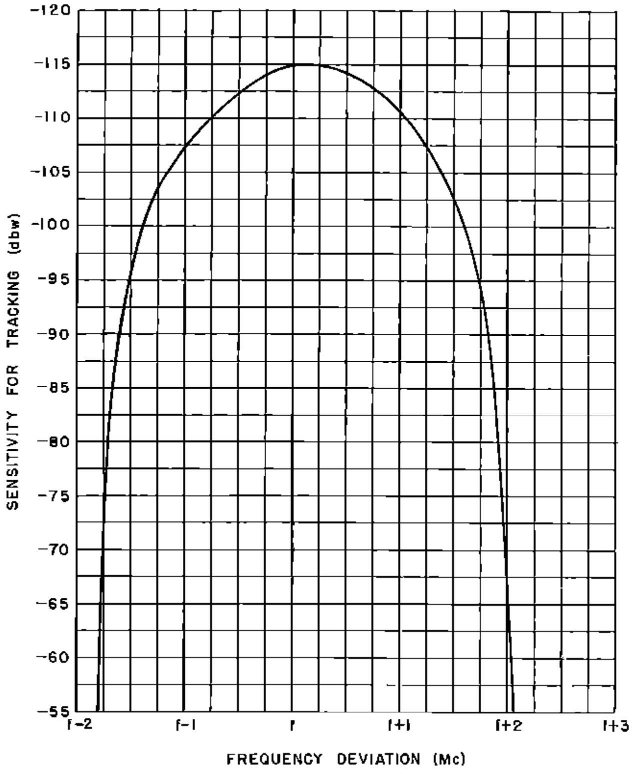

Fig 4 Receiver Bandwidth, HEC Interrogator (After Spike Suppression)

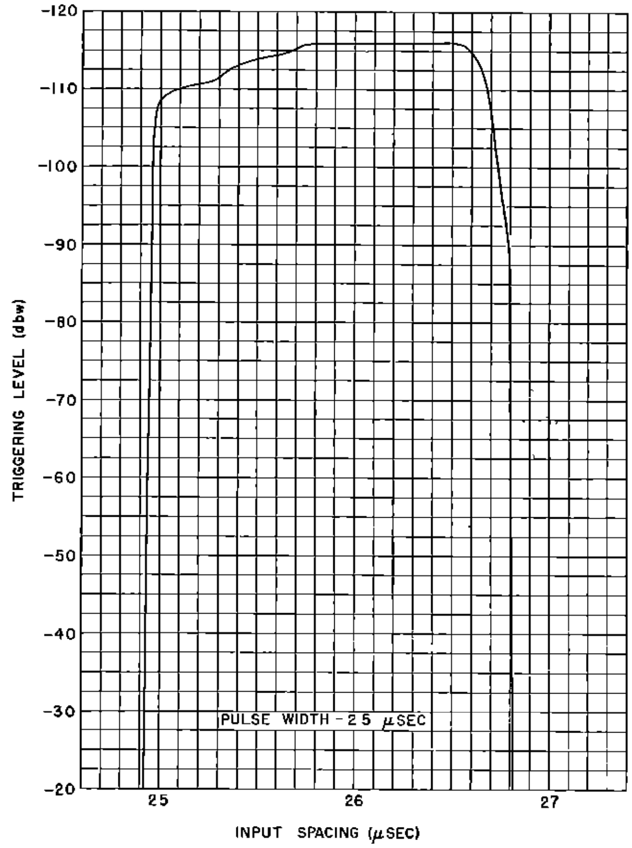

Fig 5 HEC Transpondor Decoder Response Curve

frequency control (afc) of the airborne transmitter was improved appreciably from a reliability point of view by Federal Telecommunication Laboratories, This circuitry, though properly designed to hold the airborne transmitter within the limits prescribed for 50-channel equipment, was probably the source of more equipment failures in the earlier (50-channel) models than any other component part The afc incorporated in the 100-channel interrogators proved to be comparable in reliability and accuracy of operation to any other circuitry involved in the airborne unit

Much criticism of the 100-channel system, as prescribed by SC-40, has been directed at the complexity of equipment necessary to adequately meet all requirements It is significant to note that one of the prototype models tested as a part of Phase II weighed a total of 55 pounds, including all accessories This is only a small increase over the weight of the earlier 50-channel equipment In view of the rapid progress made in the short period of a year, it is reasonable to believe that production equipment may be built lighter than the experimental 100-channel units It must be borne in mind that both manufacturers were urged to deliver equipment on accelerated schedules in order to provide units for use in the evaluation program, and were advised that weight and space requirements were not of major importance at this time

Phase III

Performance of Phase III of the test program necessarily was delayed until ten transpondors had been modified to meet 100-channel requirements It was intended originally to employ this number of transpondors in the test, distributed as follows Indianapolis, Ind and vicinity, (4), Lafayette, Ind , (1), Terre Haute, Ind , (1), Dayton, Ohio, (1), and Wilmington, Ohio, (3) All of the transpondors were operated at the same reply frequency (1,201 Mc) but with different reply spacings

Due to transfer of the Air Force's All-Weather Flying Division activities from Wilmington, Ohio, to Wright-Patterson Air Force Base at Dayton, Ohio, it was not possible for

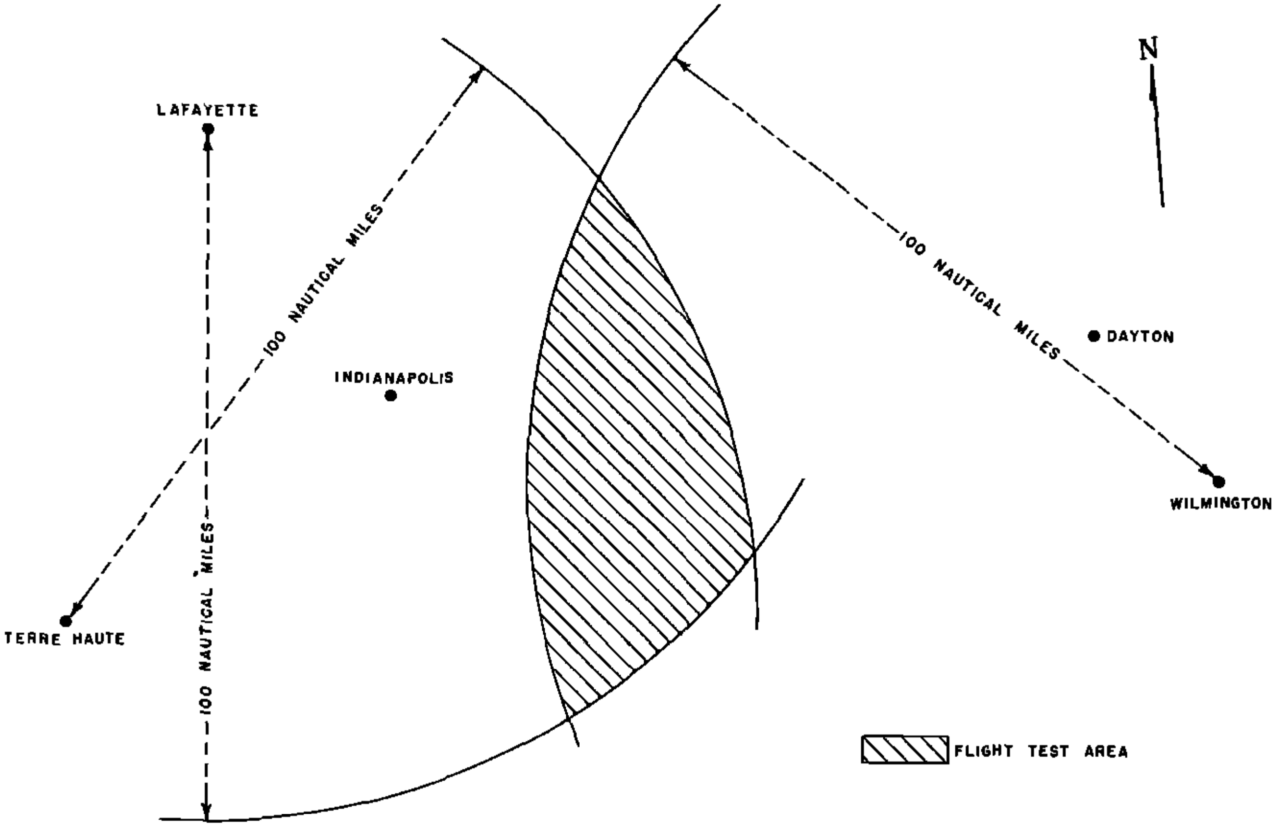

Fig 6 Map of Flight Area

that group to provide all of the transpondors assigned to them for the test, however, one of three was made available In order to avoid dependence upon air-to-ground communication to eight different sites during progress of the test flights, special schedules were set up based on time synchronization Flight tests were conducted on November 29, 1949, and repeated on the following day

The schedule followed on November 29 was as follows

0900 - 0935 - All transpondors squitter at 300 pulse pairs per second

0935 - 0945 - Adjust transpondors to squitter at 600 pulse pairs per second

0945 - 1020 - All transpondors squitter at 600 pulse pairs per second

1020 - 1030 - Adjust transpondors to squitter at 900 pulse pairs per second

1030 - 1115 - All transpondors squitter at 900 pulse pairs per second

1115 - 1125 - Adjust transpondors to squitter at 1,200 pulse pairs per second

1125 - 1200 - All transpondors squitter at 1,200 pulse pairs per second

1200 - 1210 - Adjust transpondors to squitter at 1,500 pulse pairs per second

1210 - 1245 - All transpondors squitter at 1,500 pulse pairs per second

In order to assure that the test aircraft was within propagation range of all transpondor sites, a flight test area was selected which was within 100 miles of all sites This area is indicated on the map, Fig 6, and was roughly 40 miles east of the Center In order to assure further that strong signals would be received from all transpondors, all flights were made at altitudes above 8,000 feet indicated (mean elevation above sea level of all transpondors was approximately 800 feet) In tabulating the flight test data, unless a synchronized reply was received from a given transpondor, the "fruit" from that transpondor was not considered

Squittering of the transpondors was effected by turning up the automatic gain stabilization control while observing the transmitter current A curve showing the relation of

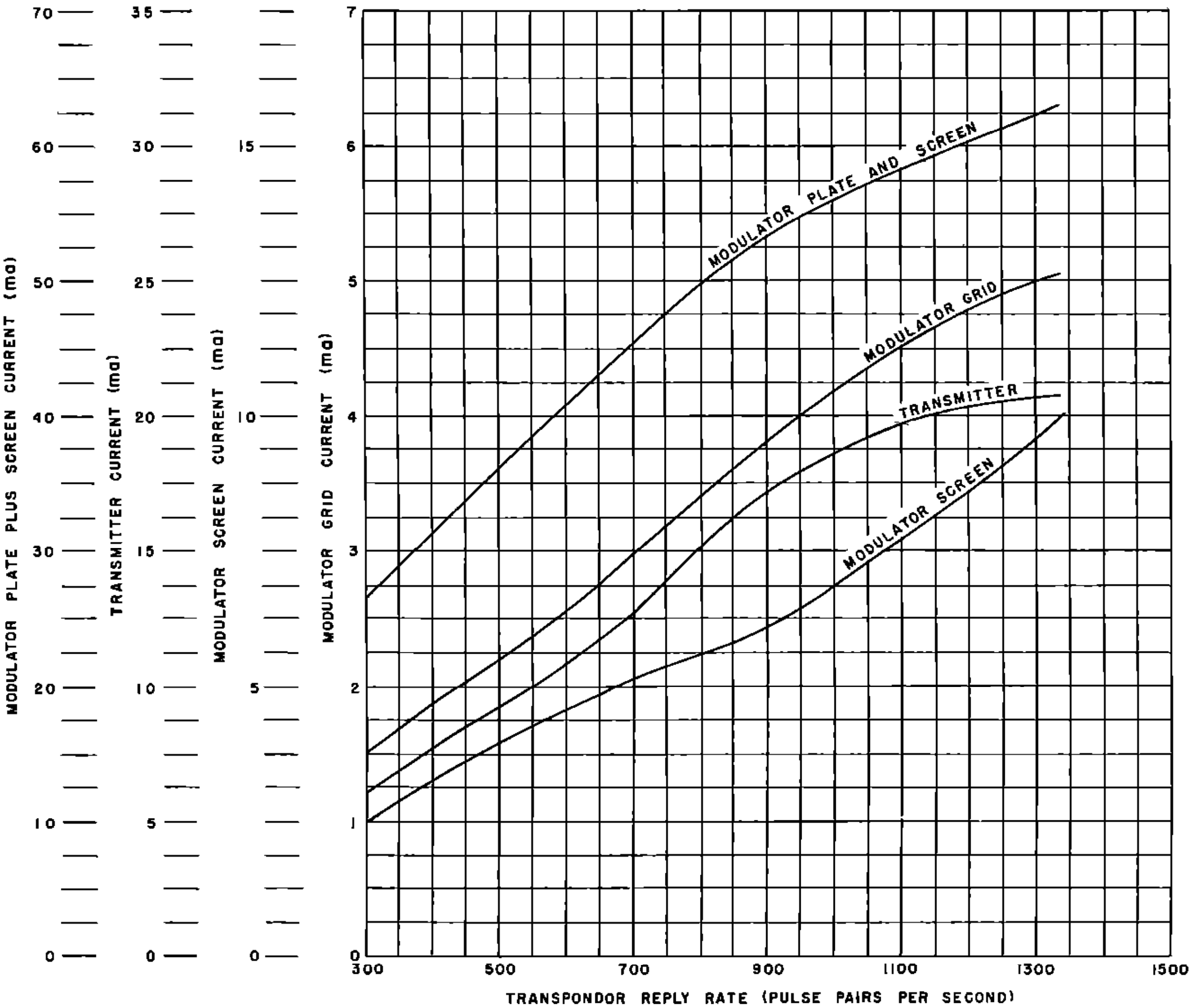

Fig 7 Variation of Transpondor Parameters with Reply Repetition Rate

transmitter current and other transpondor characteristics to squitter rate is shown in Fig 7 The squittering rates employed, ignoring the effect of count-down, are roughly equivalent to the interrogation of each transpondor by 10, 20, 30, 40, and 50 aircraft, taken chronologically

Two aircraft were employed during the first day's test, one from the Naval Air Test Center, Patuxent River, Maryland, and the other a CAA airplane N181, based at the Technical Development and Evaluation Center The test setup as installed on the Navy DC-4 airplane is shown in Fig 8 Both aircraft carried 100-channel airborne equipment manufactured by the Hazeltine Electronics Corporation On returning to the ground, the flight engineers of both aircraft reported failure to receive replies from the Wilmington transpondor at all times during the flight Replies were obtained from the remaining seven transpondors at all times

In the case of the Lafayette and Brownsburg, Ind (Indianapolis area) transpondors, although strong synchronized replies were observed at the 1,500 pulse pair "fruit" level, it was not possible to lock-on the station Examination of the oscilloscope carried in each airplane, indicated that this failure was due to erratic transmission of the second reply pulse at high transmitter duty cycles This is not a traffic handling capacity problem

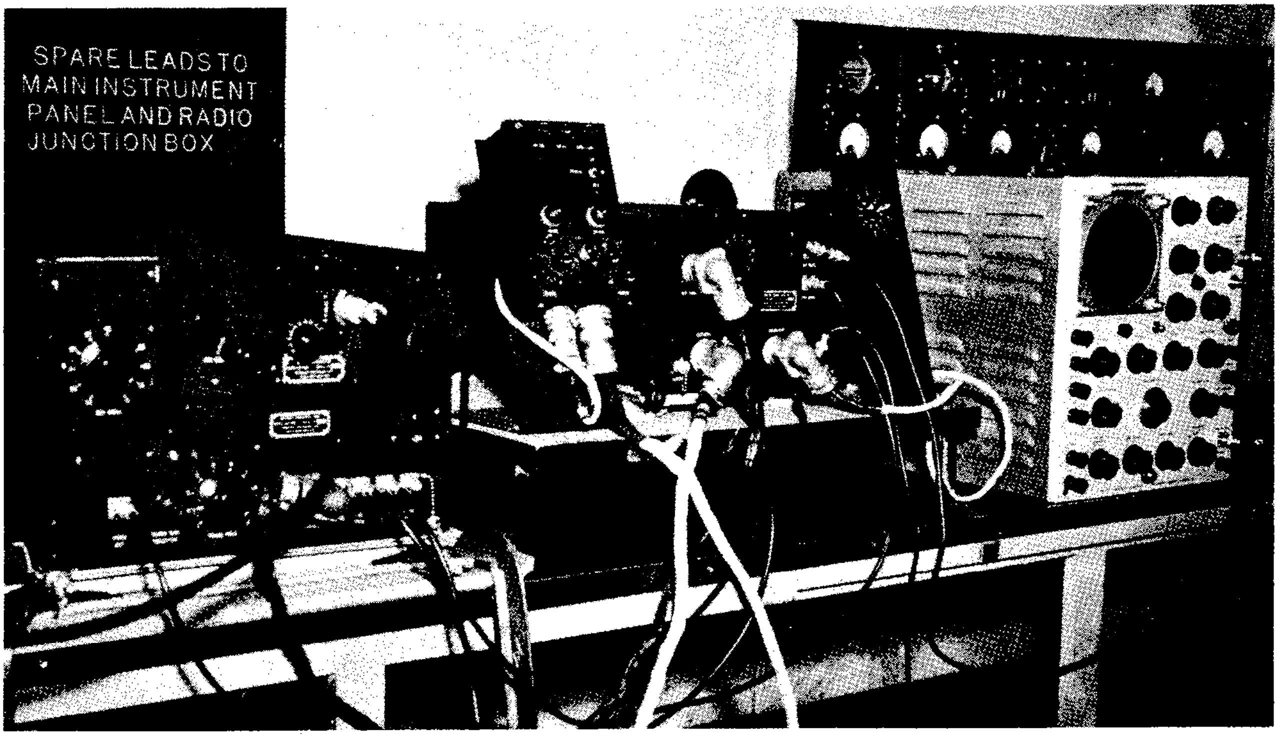

Fig. 8 DME Test Installation in Navy "Delta"

but was a temporary malperformance of the transpondor. The fact that proper locking-on to the remaining five beacons was accomplished is evidence that excessive "fruit" was not responsible for this malperformance. It is significant that the Terre Haute, Ind. transpondor, farthest from the operating area, was locked-on at all "fruit" levels without difficulty. Furthermore, the Terre Haute transpondor was transmitting three pulses (two for reply and one for identification) at all times, thus adding to the total "fruit" level.

At no time during either flight was the search time of the airborne units appreciably lengthened nor was the memory time of either unit extended. It is these two functions which generally fail first, under conditions of extremely high random pulse levels, i.e., "fruit". One of the interrogators was adjusted for a 15-second memory time throughout the test.

These findings support the statistical figures which had been previously presented. In view of the fact that the airborne equipments demonstrated the ability to operate through the highest levels of "fruit" reached during the tests, the upper limit cannot be stated. On the other hand, since the maximum "fruit" level produced during the period of the flight test was in excess of that demanded of the equipment by current specifications, there is no reason to believe that the equipment will prove other than completely satisfactory from a traffic handling point of view.

In order to ascertain that the results of November 29 were not representative of some intangible but favorable condition, the tests were repeated on the following day. On November 30, both aircraft repeated the flights of the preceding day with minor schedule changes. The results obtained were the same. One of the two interrogators employed on November 30 was the 100-channel interrogator developed by Federal Telecommunication Laboratories. The performance of this unit was identical to that of the Hazeltine equipment.

An important feature of the DME system is the means for identifying the transpondor. Although it is ultimately intended that aircraft pilots simultaneously select the omnirange and associated DME channel through manipulation of a single switch, it is believed desirable that an identification signal be provided to assure that the proper DME transpondor has been selected. Inasmuch as each omnirange is to be provided with a voice identification and/or a Morse code identification, the problem resolves itself into the design of a proper method of identifying the associated DME as the one actually operating at that particular omnirange site Present DME specifications require that the transpondor be capable of transmitting, as required, a third pulse, following the second reply pulse, at one of two specified intervals The third pulse may be modulated in any number of ways to provide identification information. The exact method of employing the third pulse must be governed by the anticipated traffic densities within the DME system One proposal has been to simply turn the third pulse off and on in accordance with characters of the Morse code In order to satisfactorily employ such a method of identification, the traffic density within the system must remain at a relatively low value In order to determine roughly what this value is operationally, in terms of actual aircraft, one of the eight transpondors employed in the Phase III tests was third pulse-coded In this particular case, a dot of one-sixth second duration and a dash of one-half second were employed Flight engineers reported that the code (ID in this case) could be read easily at squitter rates of 300 (10 aircraft per transpondor), was badly garbled at squitter rates of 600 (20 aircraft per transpondor), and was completely unreadable at squitter rates of 900 (30 aircraft per transpondor) and above In short, reliable operation of a Morse code identification system having the characteristics of that employed during the Phase III tests could not be expected in the case of traffic densities exceeding ten aircraft per transpondor An investigation of other methods of third pulse-coding is under way at the Center More recent tests in connection with this problem have indicated that even at traffic densities of the ten aircraft per transpondor level, this type of coding is far from satisfactory It is probable that identification of the code letters during the flight check was oversimplified due to prior knowledge by the observers of the specific code employed

Phase IV

This laboratory test program is being performed at the Naval Research Laboratory presently Effectively, these tests will establish an ultimate traffic handling capacity limit which should be considerably higher than that which it was possible to reach with the existing ground equipment employed in Phase III The data which evolve from the Phase IV test program will be of extreme value to design engineers concerned with planning future pulse type systems, particularly in cases where it will be necessary to resort to pulse-multiplexing It is virtually impossible to obtain quantitative data of this nature through operational testing

CONCLUSIONS

The following conclusions are drawn on the basis of the test program results

(1) The combination of 50-channel techniques to provide 100-channel equipment has been accomplished without detriment to the system

(2) The traffic-handling capacity of present 100-channel equipment exceeds that required by the specification

(3) It is apparent that development of 100-channel DME is sufficiently advanced to warrant the placement of contracts for production equipment

(4) Simple Morse coding as a means of transpondor identification is suitable only at very low traffic densities