Development of a Lightweight Distance-Measuring Interrogator

Part I

The Model DIB Interrogator

by

Carl C Trout

and

Warren E Haworth

Electronics Division

TECHNICAL DEVELOPMENT REPORT NO. 228

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT CENTER
INDIANAPOLIS, INDIANA

December 1956

U S DEPARTMENT OF COMMERCE
Sinclair Weeks, Secretary

CIVIL AERONAUTICS ADMINISTRATION
James T Pyle, Administrator
D M Stuart, Director, Technical Development Center

TABLE OF CONTENTS

DEVELOPMENT OF A LIGHTWEIGHT DISTANCE-MEASURING INTERROGATOR

PART I

THE MODEL DIB INTERROGATOR*

SUMMARY

This report describes the development of a lightweight distance-measuring interrogator, Type DIB, for use in private and smaller commercial aircraft This equipment contains only 23 vacuum tubes and has an installed weight of less than 25 pounds The specification is included, along with a detailed description of the theory of operation of the equipment Laboratory and flight tests are described, and the results in terms of performance and accuracy are included

INTRODUCTION

Distance-measuring equipment (DME) is the designation of the air-navigation aid which furnishes a continuous measurement of the distance to a selected ground facility and indicates this distance to the pilot The DME system utilizes equipment in the aircraft and at the ground facility, referred to as the interrogator and transponder, respectively The round-trip travel time of the radio-frequency (rf) signals is measured by sending an interrogating signal from the aircraft which causes a reply signal to be transmitted from the ground facility Both the interrogating signal and the reply signal are identified by means of frequency channels and pulse-multiplex spacings A combination of pulse-multiplex spacings, one for interrogation and one for reply, is called a mode This system uses 10 interrogation frequencies, 10 reply frequencies, and 10 modes If only one of these parameters is shared in common by any two channels, 100 operating channels are possible The rf channels are spaced 2 1/2 megacycles (Mc) apart, the 10 interrogation channels are in the band 962 25 to 987 25 Mc, and the 10 reply frequencies are in the band 1182 25 to 1212 25 Mc The 10 modes use combinations of interrogation and reply spacings of 14 to 77 microseconds

Each of the 100 DME operating channels is paired with the radio frequency of a VHF navigation (omnirange) or landing (localizer) facility in order to allow simplification of the channel-selection process and to eliminate excessive marking of charts In each case, the DME transponder and the paired facility are installed at the same site The 100 DME operating channels showing the frequencies, modes, and paired omnirange and localizer frequencies (channel-pairing plan), are given in Table I A more complete description of the DME system may be found in earlier reports [1,2,3]

---

*Report submitted for publication October 1956

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

[2] R C Borden, C C Trout, and E C Williams, "Evaluation of 100-Channel Distance Measuring Equipment," CAA Technical Development Report No 119, July 1950

[3] John R Hoffman and Robert E. Carlson, "Developments in DME Interrogators," CAA Technical Development Report No 212, June 1953

TABLE I*

DME-VOR-ILS
PAIRING AND CHANNELING PLAN

Paired with VOR (tenth megacycle)		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
DME Interrogation (megacycle)		963.5	966.0	968.5	971.0	973.5	976.0	978.5	981.0	983.5	986.0
Paired with VOR/Localizer (megacycle)	DME Reply (megacycle)										
108	1188.5	0A	1B	2C	3D	4E	5F	6G	7H	8I**	9J
109	1191.0	10D	11E	12F	13G	14H	15I	16J	17A	18B	19C
110	1193.5	20G	21H	22I	23J	24A	25B	26C	27D	28E	29F
111	1196.0	30J	31A	32B	33C	34D	35E	36F	37G	38H	39I
112	1198.5	40C	41D	42E	43F	44G	45H	46I	47J	48A	49B
113	1201.0	50F	51G	52H	53I	54J	55A	56B	57C	58D	59E
114	1203.5	60I	61J	62A	63B	64C	65D	66E	67F	68G	69H
115	1206.0	70B	71C	72D	73E	74F	75G	76H	77I	78J	79A
116	1208.5	80E	81F	82G	83H	84I	85J	86A	87B	88C	89D
117	1211.0	90H	91I	92J	93A	94B	95C	96D	97E	98F	99G

Mode	Interrogation (microseconds)	Reply	Mode	Interrogation (microseconds)	Reply
A	14	77	F	49	42
B	21	70	G	56	35
C	28	63	H	63	28
D	35	56	I	70	21
E	42	49	J	77	14

*Instructions for use of table. The DME operating-channel number is indicated for each VHF paired frequency. A VHF facility frequency is obtained for a given DME operating channel by adding the VHF megacycle units and decimals in the horizontal and vertical lines.

**VHF radio frequency 108.8 Mc not scheduled for assignment to localizer service. Corresponding DME Channel 1 to be assigned to emergency service.

Guard bands have been assigned between 960.0 and 962.25 Mc and between 1212.25 and 1215 Mc.

The problem of designing electronic equipment for smaller aircraft has required constant simplification and reduction in size and weight The equipment described in this report is not considered the ultimate in this respect, but it is the first airborne distance-measuring equipment to direct the trend toward smaller, lighter, and less complex equipments The first 1000-Mc DME interrogator to be developed in the United States, by the Combined Research Group of the Naval Research Laboratory, was 5 by 7 1/2 by 19 1/2 inches (1/2 air transport rack) in size, and it weighed 25 pounds [4] This equipment was comparable in size to the lightweight equipment described in this report, but it was capable of operation on only one channel It was not intended for operational use but was constructed to determine the feasibility of a system of distance measurement in the 1000-Mc frequency region Later developments produced equipments with sizes of approximately 3/4 and 1 ATR which were capable of operation on 52 channels [5] The requirement that the DME operate on 100 noninterfering channels necessitated another redesign of the interrogators As a result of the increased channel requirement, a 100-channel interrogator was developed, designated the Type DIA It occupies a space 24 1/16 by 9 5/16 by 11 1/8 inches and has a total installed weight in the aircraft of 57 pounds, including shockmount, remote-control box, distance indicator, connectors, and antenna [6,7] This equipment, although suitable for the larger transport aircraft, is not practical for use in the smaller commercial and executive aircraft

Since the evolution of the distance-measuring system, consideration has been given to methods and techniques which might be employed in the design of a lightweight and simple equipment suitable for use in smaller aircraft It was realized that the utility of the system would be maximum only if airborne equipment, suitable for use in all aircraft operating in instrument flight rules (IFR) weather, was available At various times proposals were made for the design of such an equipment, but the continual increase in the number of operating channels and operational requirements for the equipment prevented initiation of a development program

In 1951, the Air Navigation Development Board requested TDC to negotiate for the development of lightweight DME equipments The objective of this development, as stated at the outset, was " to develop a lightweight, low-cost DME interrogator suitable for use in private and smaller type commercial aircraft "

As a result of the establishment of this project, a specification for the development of an interrogator was prepared This specification was designated Specification No TD-125, and it appears as Appendix I to this report Specification TD-125 was prepared to allow the utmost latitude in the design of the equipment and to eliminate the maximum possible number of performance requirements in order to obtain an equipment of simple design and light weight As background for preparation of this specification, a number of preliminary tests were made, and the requirements were discussed with all interested agencies as well as with manufacturers of previous interrogators and prospective development contractors It is believed that this specification represents the minimum requirements for an interrogator operating in a fully implemented distance-measuring system

Bids were solicited and development contracts were awarded to Hazeltine Electronics Corporation and to the National Aeronautical Corporation (NARCO) Two separate contracts were awarded in order to assess the merits of two widely divergent techniques of transmitter stabilization and decoding methods The equipment developed by Hazeltine was designated the Type DIB, and that developed by NARCO was designated the Type DIC The Type DIB interrogator is described in this report, and the Type DIC equipment will be covered in a subsequent report

PRELIMINARY TESTS

A number of preliminary tests were conducted before and during the preparation of Specification TD-125 to determine the minimum performance and functions which would be

---

[4] Borden, Trout, and Williams, CAA Technical Development Report No. 114, op cit

[5] Ibid

[6] Borden, Trout, and Williams, CAA Technical Development Report No 119, op cit.

[7] Hoffman and Carlson, op cit

acceptable in a lightweight DME interrogator These tests were concerned primarily with methods of indicating distance to the pilot, antenna tests, and minimum interrogator transmitter outputs and receiver sensitivity

A number of designers and users of DME interrogators had suggested the use of a cathode-ray-tube distance indicator to eliminate the interrogator-tracking circuitry An oscilloscope indicator also would permit the use of a low-stability, manually tuned receiver because the oscilloscope display could be used as a tuning indicator for proper tuning of the receiver frequency To lengthen the effective scale length of the oscilloscope display, it was proposed to utilize a circular sweep on the cathode-ray tube

Accordingly, a circular sweep cathode-ray-tube indicator was constructed, and video signals were applied to it in the laboratory to simulate its operation in an airborne interrogator The results of these tests were as anticipated from earlier experience with similar indicators used with the Signal Corps Radio 718 high-altitude altimeter Sufficient brilliance could not be obtained from this indicator for proper viewing in the ambient light conditions to be expected in the cockpit of smaller aircraft In addition, the cathode-ray-type indicator required considerable space for the cathode-ray-tube circuits to produce the synchronous quadrature sweep signals and blanking circuits

As a result of these tests, the cathode-ray indicator using existing techniques was considered unsuitable for use in an interrogator of this type Specification TD-125 was not altered, however, to delete this alternate type of indicator, thus allowing maximum flexibility of design and permitting the use of a cathode-ray indicator, in the event the designer was able to show that he could overcome the difficulties

Tests were made on several types of airborne antennas for use with DME to determine those most suitable for use with lightweight interrogators These tests consisted of a measurement of voltage standing-wave ratios in the laboratory and relative radiation efficiency and pattern measurements in the vertical plane at an antenna range The data on these tests have been analyzed, and a description and the results of the tests are included

Two commercially available antennas, four experimental models, and one model of commercial design fabricated at TDC were tested The laboratory tests consisted of voltage standing-wave measurements at several points throughout the DME frequencies In the case of each of the experimental antenna models, it was necessary to make several series of measurements with changes in antenna length in order to adjust the antenna length for resonance at the proper frequency

Because antenna mismatch affects the transmitter of the interrogator more adversely than the receiver, it was decided to resonate the antennas at the center of the transmitter band (975 Mc) and hold the standing-wave ratio (SWR) to 3 decibels (db) (1 41 1) or less over the transmitter band A greater mismatch then could be tolerated at the receiver, and an SWR of 6 db (2 0 1) was considered satisfactory at these frequencies All manufacturers' models tested, as well as the TDC-fabricated model, met these requirements Three of the four experimental antennas failed to meet the SWR requirements, and no further tests on these antennas were made The antennas tested and the results are listed in Table II

TABLE II

ANTENNA TYPES TESTED

Antenna	Description	Results
Type DIA*	1/4 wavelength with matching section	Satisfactory
Hazeltine	1/2 wavelength with matching section	Satisfactory
TDC-Fabricated	1/4 wavelength with matching section	Satisfactory
Experimental	1/4-wavelength rod, 3/16-inch diameter	Unsatisfactory
Experimental	1/4-wavelength rod, 3/8-inch diameter	Satisfactory
Experimental	3/4-wavelength rod, 3/16-inch diameter	Unsatisfactory
Experimental	3/4-wavelength rod, 1 1/4-inch diameter	Unsatisfactory

*Manufactured by Federal Telecommunication Laboratories

Antenna Range Measurements

Further tests were conducted at the TDC antenna range on the four satisfactory antennas The range consists of a transmitter house, a turntable, and receiver house located approximately at the apexes of a right triangle, with the distances between the houses and the turntable approximately 150 feet The antenna on the turntable was fed from the transmitter by means of an underground coaxial cable and rotating joint at the table The receiver pickup was made by means of a horn just outside the receiver house

Relative radiation efficiency measurements were made by plotting vertical radiation patterns of the antennas in succession, with no changes of transmitter or receiver controls The only variable involved was the time consumed in testing and changing antennas It was believed from experience with repeating several tests over a period of several hours, however, that some drift of readings did occur, as a result, the readings taken were not accurate to closer than ±10 per cent The tests were continued, however, because it was believed that tests to this accuracy would reveal significant differences between antennas The results of these tests are given in Table III

TABLE III

ANTENNA PATTERN TESTS*

Antenna	Angle of Maximum Radiation (degrees)	Relative Merit at Angle**	Relative Merit at 0°**	Ratio of Radiation at Maximum Angle to Degrees Radiation
DIA***	30	0 91	0 94	3 37
1/2 wavelength (Hazeltine)	27	0 79	0 88	2 97
1/4 wavelength with matching stub	30	1 0	1 0	2 90
1/4-wavelength rod (experimental)	30	0 93	0 91	3 60

*All of these tests were at 1087 0 Mc

**The values shown are a ratio of radiated output of each antenna to the output of the most efficient antenna, which was assigned a value of 1 0 in each case The figures indicate the amount of losses in the antenna itself as well as the relative gain of the antenna at 0°

***Manufactured by Federal Telecommunication Laboratories

Following these tests, a vertical pattern was plotted for each antenna at six frequencies, 963 5, 975 0, 986 0, 1188 5, 1201 0, and 1211 0 Mc. The data collected from these tests are not included because no significant differences were observed between the vertical patterns of the several antennas at a given frequency

An important consideration in the choice of airborne antennas is the gain or efficiency of the antenna at small angles from the horizontal plane of the aircraft position It can be shown that the angle of arrival of the signal at this horizontal plane does not exceed 5° at altitudes up to 12,160 feet (two nautical miles) and at slant distances from the station greater than 25 nautical miles Experience has shown that at lesser distances, deterioration of signal up to 20 db can be tolerated without loss of service The most critical aircraft position for DME performance is at the maximum range and at minimum altitude for line-of-sight conditions At 100 nautical miles and minimum line-of-sight altitude, the vertical angle of signal arrival is approximately 1 5°, neglecting refraction and ground-antenna height, both of which tend to reduce this angle

It is believed that the radiation from the antennas at vertical angles greater than 45° is a minor consideration because a cone of silence or signal loss never has been observed close to or over a DME ground station with belly-mounted airborne antennas in use These antennas show as little as 5 per cent efficiency of that at 0° at or near 90° from the horizontal The same antennas, when mounted on top of the fuselage have exhibited a small signal loss within a few miles of the station, but DME service was not interrupted owing to the memory action of the interrogator Under such conditions, the small amount of antenna radiation, coupled with the shielding effect of the aircraft itself, caused only a marginal performance rather than a complete signal interruption

On the basis of these tests, it was concluded that among the DME airborne-antenna designs available for the tests, no choice could be made on the basis of performance, and that the prime considerations of economy and availability should govern the choice of antenna This conclusion would not preclude later acceptance of an antenna design providing maximum or near maximum radiation at angles of not more than 1° or 2° from the horizontal plane

Specific tests to determine the minimum receiver sensitivity and transmitter-power output which could be tolerated at line-of-sight altitudes out to 100 nautical miles slant distance from the station were limited to a small number of flights to verify data taken in flight testing on earlier types of interrogators In this instance, allowance also was made for an increase in both receiver sensitivity and power output of the ground facility with the advent of the DME ground station, Type DTB, which was scheduled to go into use in numbers shortly after Specification TD-125 was prepared

EQUIPMENT DESCRIPTION

The complete Model DIB interrogator consists of an interrogator unit, a power-supply unit, antenna, and the necessary cables The complete interrogator, less cables, is shown in Fig 1 The type numbers and weights of the component parts are shown in Table IV

TABLE IV

SIZE AND WEIGHT OF
COMPONENT PARTS OF MODEL DIB INTERROGATOR

Description	CAA Type No	Over-all Size (inches)	Weight (pounds)	Weight (ounces)
Interrogator Unit	DIB/1	6 5/8 by 6 3/8 by 12 5/32	13	2
Power-Supply Unit	DIB/2	7 3/32 by 6 19/32 by 8 25/32	9	2
Antenna	DIB/3			5 1/2
Interconnecting Cable (as supplied)			2	
Total			24	9 1/2

The table does not include the necessary coaxial transmission line for connection of the interrogator unit to the antenna Solid dielectric coaxial cable of 51 5 ohms nominal surge impedance such as RG-8/U or RG-58/U is used for this purpose The coaxial fittings on both the interrogator unit and the antenna are Type C for use with UG-573/U cable or similar connectors

Electrically, the Model DIB interrogator differs from previous designs in DME interrogators in several respects The receiver and decoder circuits are the main points of difference, although several other features of this interrogator appear in distance-measuring equipment for the first time

The receiver of this interrogator achieves simplicity and compactness by use of a crystal mixer followed by a super-regenerative detector tuned to an intermediate frequency This arrangement produces a receiver somewhat less sensitive than earlier models but occupying a minimum of space and requiring only four vacuum-tube stages (local oscillator, intermediate-frequency preamplifier, super-regenerative detector, and quench oscillator) These circuits are comprised in two vacuum-tube envelopes The local oscillator is tuned to approximately 350 Mc, and it provides the mixer with a third harmonic output sufficient for conversion to the 140-Mc intermediate frequency

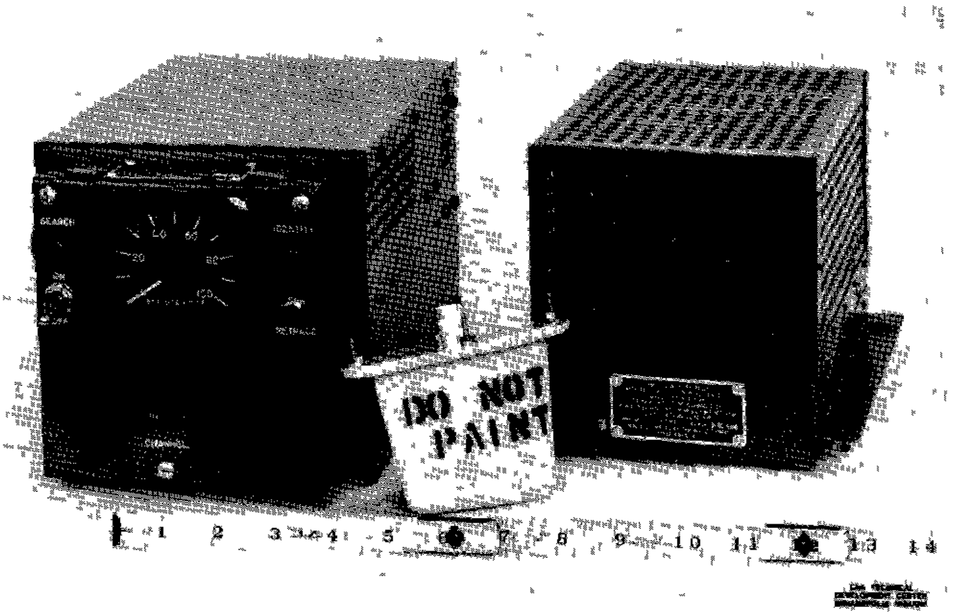


Fig 1 Complete Model DIB Interrogator

The decoder circuits for determining the proper received spacing are unique in that they do not employ delay lines or other passive devices for sampling the received pulses for correct spacing The decoding is accomplished by the generation of one or two gates, as required, at the proper delay time after the interrogation The first gate controls the presence of the second gate, depending upon the receipt of a pulse within it, and the presence of pulses within the second gate produces the tracking function

The transmitter and receiver local-oscillator portions of the interrogator are temperature-controlled by thermostats, heaters, and a blower for frequency stabilization This arrangement allows the use of self-excited oscillators for both functions, yet produces signals of the required stability In Fig 2, the transmitter cavity with its blanket heater and controlling thermostat button is shown in the lower left-hand corner of the main interrogator unit The exhaust fan is in the center of the bottom cover The method of channel selection also can be seen in Fig 2 The cams shown in the photograph are positioned by detents They control the travel of the cavity-tuning slug The wafer switches on the cam shafts are used to set the proper mode voltages automatically upon selection of the proper transmitter and receiver frequencies The distance-indicator meter is contained in the main interrogator unit, as delivered, although wiring provisions have been made for its remote operation if desired The channel selection must be accomplished from the front panel of the unit, no provision having been made for remote operation of the channel-selection mechanism

The equipment, when operated in an aircraft, requires the operation of a retrace pushbutton on its front panel This pushbutton is used to re-initiate searching action in the interrogator after a complete search of the distance from zero to full distance has been completed without reception of a proper or usable signal from a ground station After the proper reply has been received by the interrogator and the distance reading is "locked on," the proper distance reading then is indicated continuously, as the tracking action of the interrogator is automatic

A block diagram of the Model DIB interrogator circuits is shown in Fig 3 Although the DME system employs pulsed pairs for both interrogation and reply, the timing of the entire distance-measuring function begins with formation of the first transmitted pulse in the interrogator Circuits producing the second transmitted pulse, decoding the reply pulses, and the actual measurement of the distance are initiated by the first transmitted pulse In the DIB equipment, this first pulse is formed by the first modulator which uses a gas tube as a relaxation oscillator Firing this tube discharges a pulse-forming network through the primary of the modulation transformer The stepped-up voltage developed in the secondary of the transformer is applied to the transmitter oscillator to form an rf pulse This rf pulse then is fed to the antenna coupler and on to the antenna

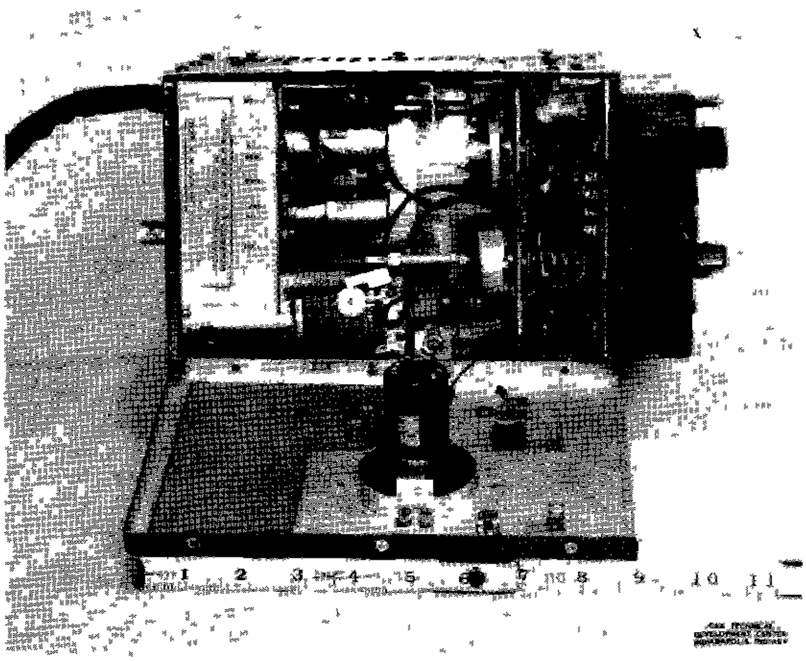


Fig 2 Main Interrogator Unit, Bottom Cover Removed

To form the second interrogation pulse, a trigger from the first modulator is used to start the code-delay phantastron The plate voltage of this phantastron then starts decreasing from a reference voltage In the block diagram this voltage is labeled "interrogation code reference voltage " The plate voltage on the phantastron decreases until it is stopped by the coder clamp The reference voltage for the coder clamp is the mode-reference voltage. Thus, depending upon the mode selected (distance between pulse pairs), the coder clamp will clamp the code-delay phantastron at the correct delay from the code-reference voltage By differentiating the screen-grid waveform of the code-delay phantastron and amplifying in the second modulator trigger, the second modulator is fired This then discharges the second pulse-forming network through the modulation transformer as in the first pulse formation, and the second pulse of the pair is transmitted The frequency of transmission of these pulses, of course, is determined by the channel selected This then completes the formation and transmission of the interrogation pulses

When the ground station transponder replies to the interrogation pulses, the following sequence occurs The reply pulses received at the antenna and through the antenna coupler are coupled through two preselectors to the mixer Here the signal is mixed with the third harmonic signal from the local oscillator, the third harmonic signal being produced by the tripler crystal The intermediate frequency produced in the mixer is amplified in the intermediate-frequency preamplifier The intermediate-frequency signal is fed to a super-regenerative intermediate-frequency amplifier, the operation of which is controlled by the quench oscillator Detection of the rf signal is accomplished in this stage and is passed through two video amplifiers it then is in the form necessary for use in the tracking circuits. This signal consists of two reply pulses at the output of the second video amplifier which are delayed in an amount proportional to the distance of the ground station from the aircraft

In order to measure this time delay, the interrogator first must search out in time until the reply signal is found This is accomplished by taking a trigger from the second modulator and applying it to the range-delay phantastron Once triggered, the range-delay phantastron starts to decay By differentiating the trailing edge of the screen-grid waveform, a gate is produced which moves out in time with respect to the interrogation This gate is shaped and amplified by the track gate-generator stage

When this track gate has moved out in time to the same point as the first reply pulse, a check must be made at the time of the second reply pulse to see if a properly spaced reply has been received. To accomplish this, the track gate is applied to one grid of the first pulse-coincidence detector and the output of the second video amplifier to the other An output

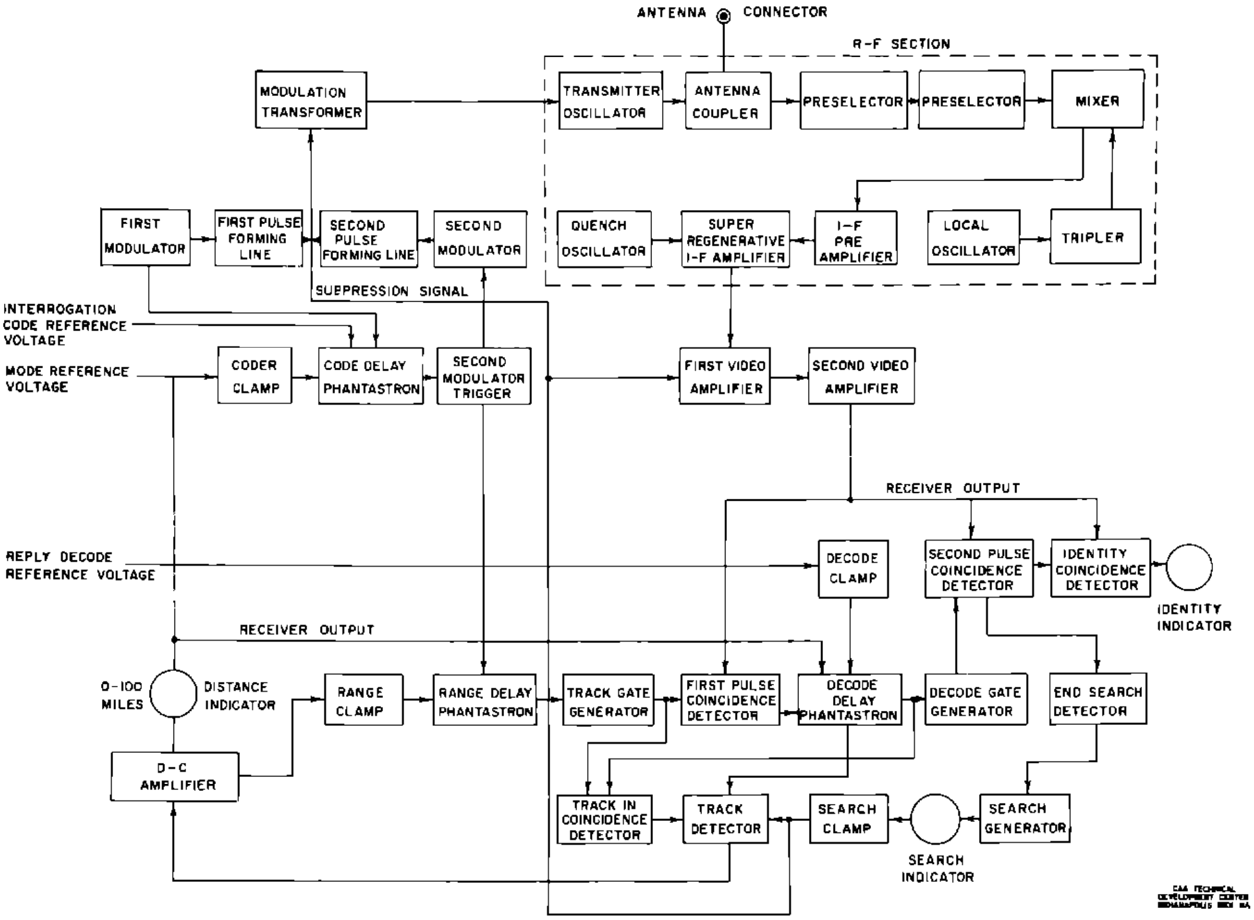


Fig 3 Block Diagram of Model DIB Interrogator

trigger is produced from this stage when the track gate and first reply pulse coincide in time This trigger is used to start the decode-delay phantastron decaying from the mode-reference voltage The reply decode-reference voltage provides a reference voltage for the decode clamp which clamps the decode phantastron The reply decode-reference voltage is determined by the mode in use on the selected channel By differentiating the screen-grid waveform of the decode phantastron, shaping and amplifying in the decode-gate generator, a gate is produced to check the second reply pulse This check is made in the second pulse-coincidence detector By applying the generated gate on one grid and the reply pulses on another in the coincidence tube, an output occurs when the gate and second reply pulse are coincident This indicates that the reply pulses are of the correct spacing, therefore, the reply pulses are produced by interrogation of the proper ground station

The presence of a correct reply having been established, the interrogator must end search and lock on the signal Because an output from the second pulse-coincidence detector indicates a signal of the correct frequency and spacing, this output is used to end search The end-search stage is a diode biased so that it conducts only when the large negative output from the second pulse-coincidence tube is present at its cathode The conduction of the end-search detector is used to bias the search generator to cutoff The search indicator remains lighted during search because of voltage present at the cathode of the search generator When the search generator is cut off at the end of search, this voltage is removed and the indicator is extinguished During the searching action, the search clamp keeps the voltage to the track detector constant

The track detector is used to relay information to the dc amplifier which in turn furnishes a reference voltage to the range clamp This range clamp stops the range-delay phantastron and the interrogator has completed locking on the signal

The indicator, a 0-1 milliammeter, is connected between the dc amplifier plate and the mode-reference voltage This meter is calibrated in miles, therefore, it indicates the distance from the interrogator to the ground station

After properly searching out and locking on a reply, the interrogator then must track or follow the reply signal to provide continuous distance indication This process is initiated when the track detector receives information which is applied to the dc amplifier to move its plate voltage up or down, causing the gates to move in or out in range (time) The information to the track detector comes from the track-in coincidence detector and the decode-delay phantastron From the decode-delay phantastron there is a positive pulse of constant amplitude and duration, and from the track-in coincidence detector there is a negative pulse of constant amplitude and varying duration When these two pulses are balanced in the track detector in the locked-on condition, any change in distance will upset this balance and the track detector will send information to the dc amplifier and cause the indicator to move in or out in range, as required to maintain balance

To provide a static condition in the interrogator during a short loss of signal, there is a memory circuit in the output of the end-search detector This is a resistor-condenser combination in the plate of the detector If, due to noise or "fruit" (random, nonsynchronous interference), the first and second pulse-coincidence detectors simultaneously produce a single output, the end-search detector will stop the searching action A small charge limited by a series resistor will be put on the memory condenser If no further output occurs from the coincidence detector, this memory voltage decays very rapidly and the interrogator again will start search If the proper signal is being received, however, the coincidence detectors, by their continued output, will fully charge the memory condenser Then if the signal is lost, the charge on the memory condenser will keep the search generator cut off for about 15 seconds If a signal again is received before expiration of this 15-second period, the interrogator will continue its tracking condition Should the memory condenser discharge before a signal again is received, the Model DIB interrogator will go into search and continue search to maximum range

If the unit searches to its maximum range without locking on a signal, it is necessary to push the retrace button to initiate a new cycle of operation Pushing the retrace button not only starts a new cycle of operation, but it removes the charge on the memory condenser so that time is not lost in waiting for the memory to dissipate at its normal rate Subsequent to delivery of the original equipments, an automatic retrace circuit has been developed and added to most units This circuit eliminates the necessity for depressing the retrace button to initiate a new search For indicating transmission of a third pulse for identity purposes from the ground station along with its normal pair of reply pulses, an additional circuit is needed In the Model DIB equipment, this circuit is the identity-coincidence detector A ringing circuit is placed in the cathode of the second pulse-coincidence detector, and by proper selection of components, the maximum output of the ringing circuit is 10 5 microseconds after the second reply pulse Applying this pulse to one grid of the identity detector and the three video pulses on the other results in an output pulse if the ringing pulse and identity pulse coincide The output of this detector is used to energize a neon bulb for visual indication of identification

On the block diagram there is a line from the modulation transformer to several points in the Model DIB interrogator This is a suppression signal which is applied to the various circuits during the transmission of the interrogation pulses This suppression signal keeps these circuits from being activated by the transmitter during its "on" period

The power supply for the Model DIB interrogator is the synchronous vibrator type, furnishing dc outputs of 650, 250, 100, 19, 12 6, and -15 volts The 650-volt output is regulated by a reference voltage from the interrogator The 250-volt output is regulated by a conventional series regulator, using the 100 volts (regulated by a voltage-regulator tube) as a reference voltage The 12 6-volt output is regulated by a ballast tube in the power supply, and it is used for filaments The 19 volts and -15 volts are unregulated

The application of plate voltages is delayed one minute by a thermal-time delay The following fuse protection is provided

Main power line	15 amperes
Primary of power transformer	6 amperes
650-volt line	1/32 ampere
250-volt line	1/4 ampere

These data for the power supply refer to the 27-volt unit The output voltages of the 13 5-volt supply are the same except for the filaments In the 13 5-volt unit, the filament voltage is 6 3 volts instead of 19 volts and 12 6 volts No changes are necessary in the interrogator when using either supply All of the required wiring changes are handled in the power cable between the power supply and the interrogator

TESTS

The tests performed in connection with the acceptance and investigation of the merits of the design of the Model DIB distance-measuring interrogator were of three classes These have been designated as type tests, laboratory tests, and flight tests

Type Tests

Acceptance tests to determine whether the equipment met minimum performance characteristics as set forth in Specification TD-125 were performed before acceptance of delivery of the equipment from the contractor These tests were performed by the contractor with observation and participation of TDC engineers The equipment successfully passed the type tests and was accepted

The following characteristics of the equipment not completely covered in Specification TD-125 are

Minimum transmitter-power output 630 peak watts
Maximum transmitter-frequency shift 275 kc
Interrogation rate 14 to 17 per second (15 nominal)
Receiver bandwidth approximately 2 Mc
Maximum receiver-frequency shift 180 kc
Power consumption with heater in operation.
13 5 volts at 17 9 amperes
27 volts at 8 8 amperes

Laboratory Tests

After delivery of the interrogators, a number of laboratory tests were performed to investigate the operation of the equipment to provide data for future specifications and interrogator design. These tests were conducted concurrently with the flight tests.

As required in Specification TD-125, the equipment originally was calibrated in nautical miles A subsequent decision to abandon nautical miles as a standard required that the interrogators be adjusted and recalibrated for statute-mile indication The change from nautical to statute miles in the interrogator resulted in an increase in the error, because the mode-correction voltage supplied to the meter in the equipment was adjusted for the nautical-mile calibration In an effort to eliminate or minimize this error, a number of tests were performed on the unit to determine the amount of error introduced by the mode-correction network A typical calibration curve plotted for three modes is shown in Fig 4 These curves reveal that sufficient additional errors were introduced by the change to statute miles so that the interrogator no longer met the minimum accuracy requirements of ±1 mile or 5 per cent, whichever is greater The investigation disclosed that when the calibration was changed from nautical to statute miles, a change was required in the mode-correction resistor network to compensate for the change in time delay per mile After proper changes in the resistance network, a typical calibration curve was plotted for three modes It is shown in Fig 5 It will be noted that this curve shows an improvement in excess of that to be expected for the nautical- to statute-mile correction This further improvement is assumed to be due to the fact that the original network could have been improved by closer selection of resistance values

In an effort to determine the sources of error in the interrogator, a number of tests were made The dc instrument was removed from the circuit and checked for linearity of current reading from 0 to 1 milliampere, using a Rubicon null-type potentiometer calibrated against an Epley standard cell which was calibrated by the National Bureau of Standards. The resulting error curve of the distance-indicator instrument, when compared to the over-all error curve of the interrogator with instrument reconnected in the circuit, is shown in Fig 6 It can be seen from these curves that most of the distance errors of the interrogator occurred in the indicating instrument The dc indicating instruments used in the Model DIB interrogator are basically of ±2 5 per cent accuracy, and they have been selected by the manufacturer for ±2 per cent This selection was necessary to meet the over-all accuracy requirement as

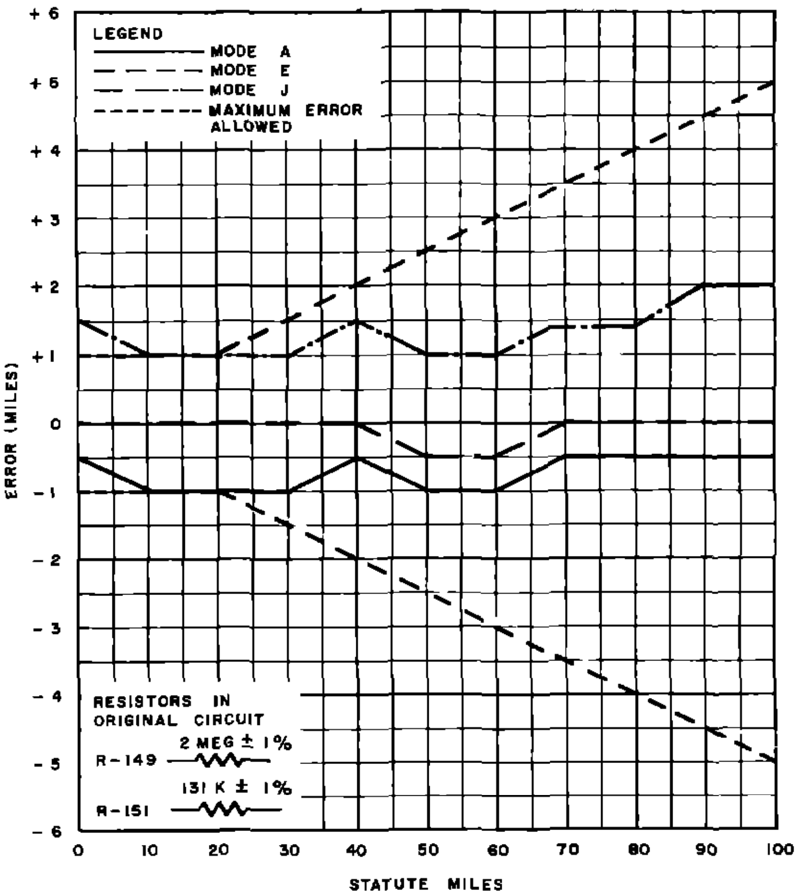


Fig 4 Calibration Errors Before Resistor Change
Model DIB Interrogator Serial No 4

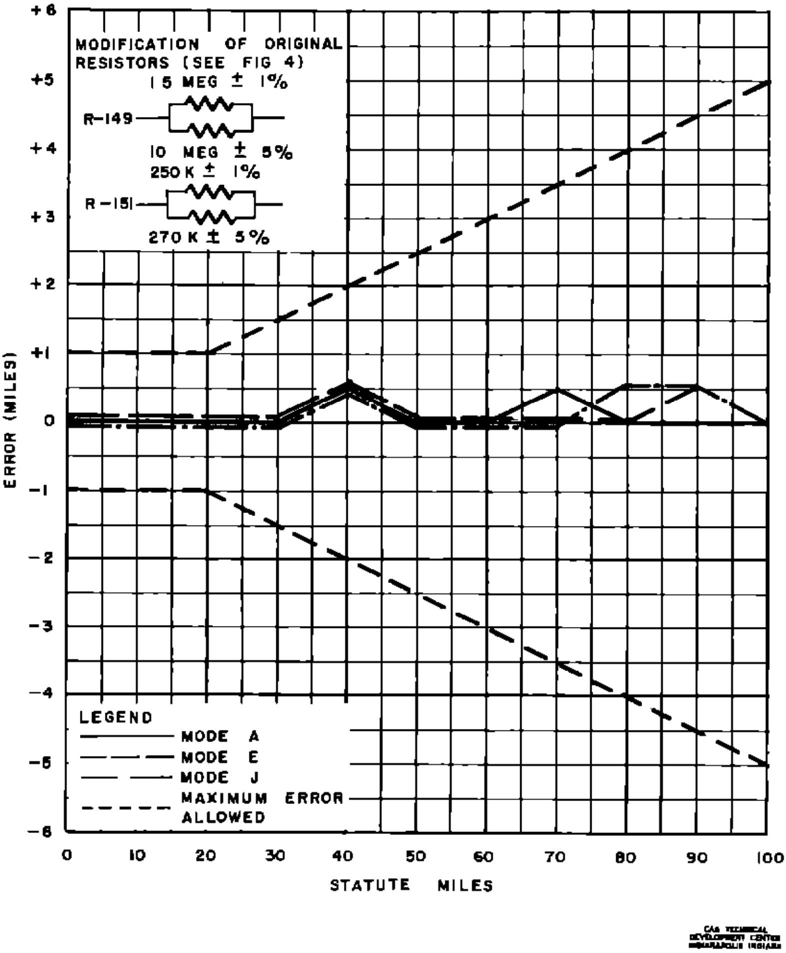


Fig 5 Calibration Errors After Resistor Change
Model DIB Interrogator Serial No 4

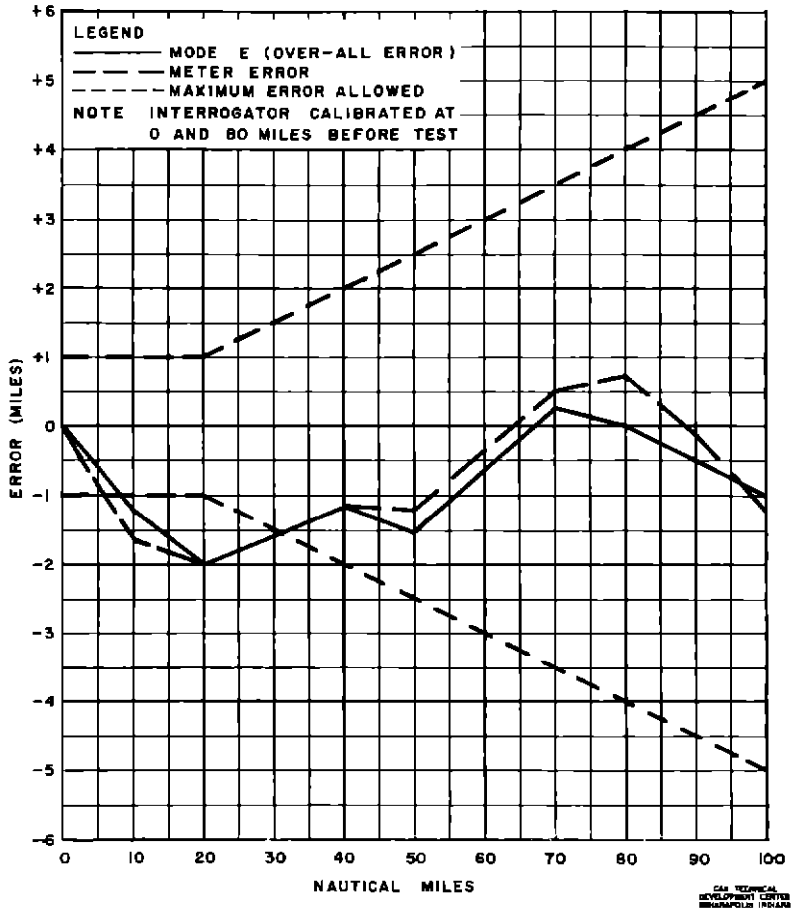


Fig 6 Meter Errors Compared with Over-all Interrogator Errors
Model DIB Interrogator Serial No 9

specified in Specification TD-125 In Fig 6 it will be noted that the error in the calibration curve in the area from approximately 7 to 32 miles exceeds that allowed in the specification This unit was calibrated at the 0- and 80-mile points without regard to the specification requirements for the purpose of illustrating the similarity of the meter-error curve to the over-all interrogator-error curve By tolerating an error near 0, the over-all calibration of the unit can be brought within specification limits

A further test of the linearity of the range voltage in the equipment was made by using a very accurate dc instrument having ±0 5 per cent accuracy and a scale length of approximately 4 inches No errors in distance were readable using this instrument, confirming the fact that the basic range-voltage accuracy of the interrogator is far more exact than that presented to the pilot when using the less accurate meter Increased accuracy in the dc instrument can be secured by substitution of a hand-calibrated dc instrument having an error of ±1 per cent or less, at a slight increase in cost

In an effort to reduce the total power drain of the equipment for use in aircraft having limited current-capability generators, a 13 5-volt equipment was modified to eliminate use of the heaters for stabilization of the transmitter- and receiver-cavity oscillators These heaters consume about 100 watts from either the 13 5- or 27-volt power source, and their elimination made the unit more practical for smaller aircraft This modification also included readjustment of the power-supply-regulated dc output voltage from 250 to 225 volts to provide regulation down to approximately 11 5-volt input, and a complete readjustment of transmitter, receiver, and pulse coding and decoding functions Further, this modification included reconnection of the blower fan in the unit to operate continuously instead of alternately with the heaters as previously connected, because it was believed that blower operation would improve temperature stabilization in the absence of heater operation.

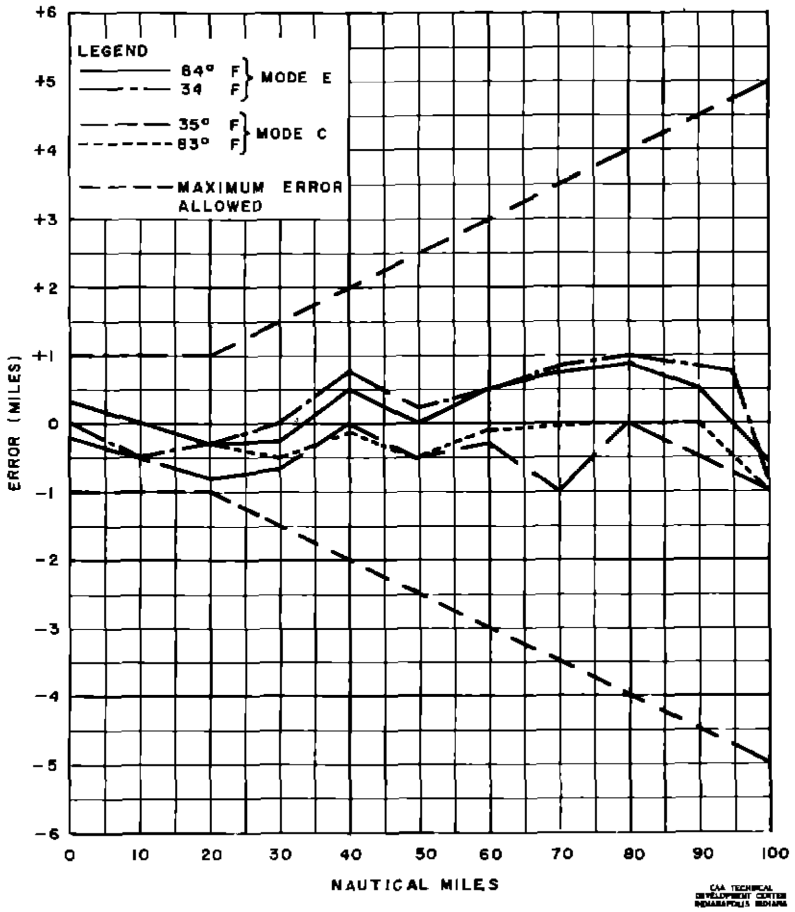


Fig 7 Calibration Curves of Modified 13 5-Volt Model DIB Interrogator Serial No 13

Bench tests on the unit were conducted to determine the amount of transmitter drift with changes in outside ambient temperature These tests indicated a transmitter frequency shift of about 6 kc per degree F (about 10 kc per degree C) over the outside ambient temperature range of 34° F to 83° F This temperature shift was judged to be tolerable for the climatic conditions expected

Calibration curves for the modified 13 5-volt interrogator are shown in Fig 7 It will be noted that no significant difference in accuracy appeared in the modified unit from that of an unmodified one

To determine the effect of continuous operation of the Model DIB interrogator, a set picked at random was operated continuously for more than 115 hours During this period there were no malfunctions due to the interrogator Because of poor regulation of the power source to which the Model DIB equipment was connected, the interrogator unlocked on several occasions, however, the interrogator did not in any case fail to lock on again when the retrace button was depressed Periods of continuous lock-on were as long as 36 hours

Flight Tests

Flight tests were performed on two Model DIB interrogators, the 27-volt unit and the 13 5-volt unit, modified for elimination of the cavity heaters

Unmodified 27-Volt Interrogators

A comprehensive series of flight tests was conducted on the 27-volt Model DIB interrogators in an attempt to uncover sources of unreliability in the equipment which had not appeared during laboratory testing These tests consisted of a series of flights of from 35 minutes to 4 hours and 55 minutes in duration, extending over a period of several months, with the equipment in operation in a Douglas DC-3 aircraft During this time the failures encountered were confined to the power-supply portion of the equipment These tests provided a total of approximately 100 hours of operation in the air Failures to measure distance to acceptable line-of-sight conditions during these series of flights totaled less than five, and at least one of these was traceable to improper adjustment of the equipment during bench-maintenance checks Two failures were due to tube failures, and one was due to vibrator failure

During the period, the equipment also was demonstrated without failure or malfunction in flight several times a day on a number of consecutive days to approximately 115 persons The equipment interrogated and indicated distance within the specification tolerances at all times during these flights

The flight tests included the proper interrogation and distance indication when operated with all ground stations in the area over which the flights were conducted The following stations were used Indianapolis VOR, Indianapolis ILS, Indianapolis TVOR (experimental), Dayton VOR, Chicago Heights VOR, Goshen VOR, and Chicago Midway ILS All observations of distances over ground checkpoints were found to be within specification tolerances after proper ground calibration of the equipment

Modified 13 5-Volt Interrogators

The 13 5-volt Model DIB interrogator, which was modified by disconnecting the cavity heater and readjusting the regulated power supply from 250 to 225 volts, was installed and flight tested in a Globe Swift airplane Two units were used successively during these tests, and 110 hours of flight were completed during which the units operated satisfactorily One trouble occurred which was traced to a defective tube socket

The ambient temperatures in which the unit operated during these tests varied from 32° F to 80° F No frequency shift sufficient to cause malfunction was experienced During most of the tests, the transmitter cavity was tuned to frequency in the laboratory at an ambient temperature of approximately 80° F , and it was not retuned after installation in the aircraft

The method of mounting the interrogator, indicator, power supply, and antenna in the Globe Swift airplane is shown in Figs 8, 9, and 10 The antenna used in these tests was not the Type DIB/3 antenna furnished for use with the Model DIB interrogator because the Type DIB/3 antenna was not available at the time of the first installation The antenna used has been found to have very similar characteristics to those of the Type DIB/3, both antennas being one-quarter-wavelength types

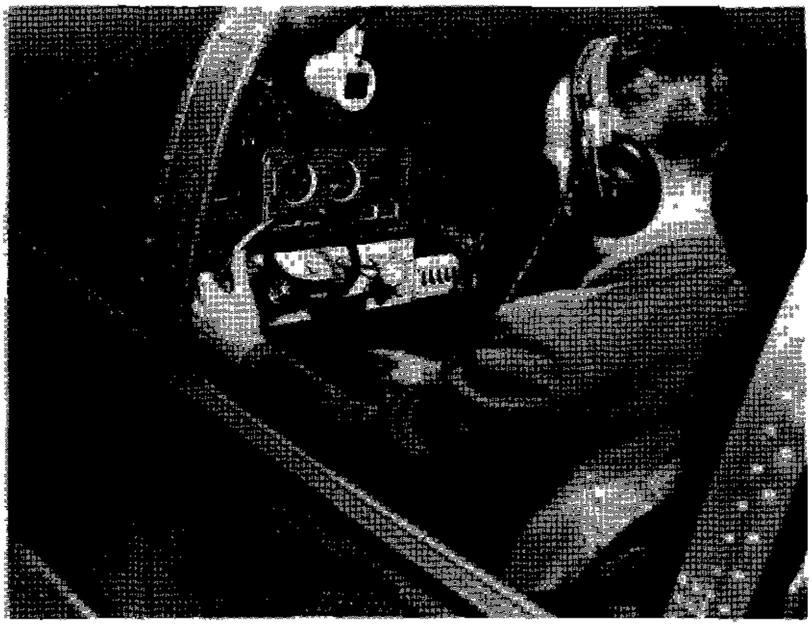


Fig 8 Instrument Panel of Globe Swift Aircraft With Distance Indicator Installed

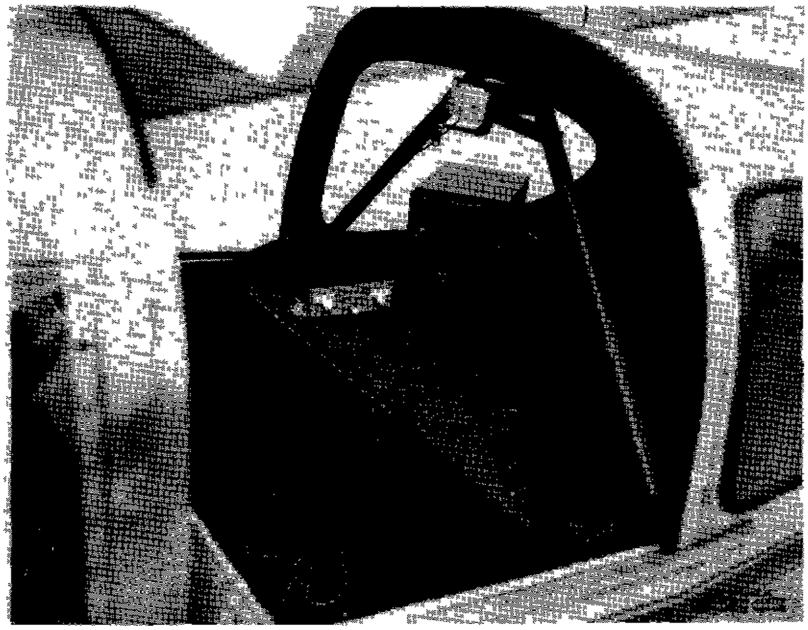


Fig 9 Cockpit of Globe Swift Aircraft With Model DIB Interrogator Installed

During these test flights, 234 observations of distance readings over ground checkpoints were made, and these checks were tabulated The average observed error was approximately 1 12 miles for all conditions, including several flights with improper calibration. During later test flights, the observed errors were reduced greatly by improved calibration procedures It was found that with proper calibration, under the limited environmental conditions encountered during the tests, the specification requirements of ±1 mile or 5 per cent, whichever is greater, could be bettered

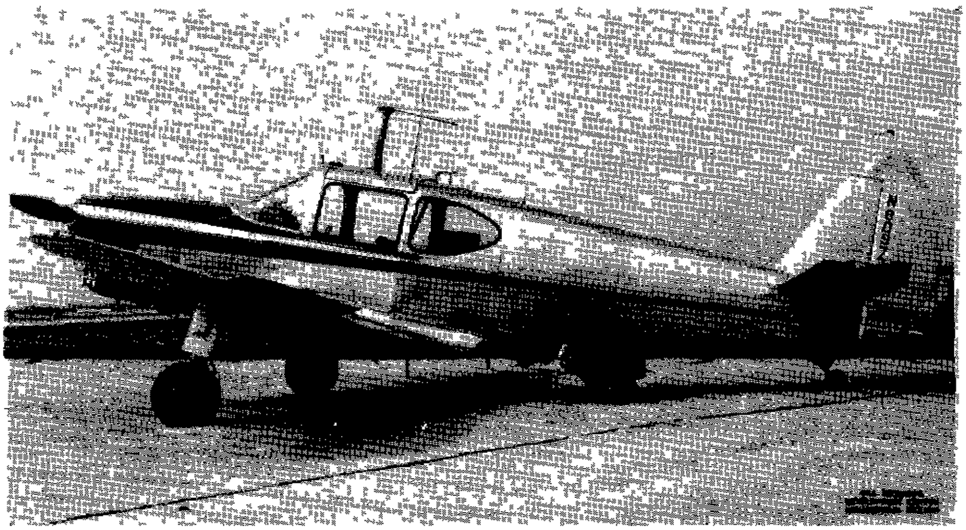


Fig 10 Globe Swift Aircraft With DME Antenna Installed

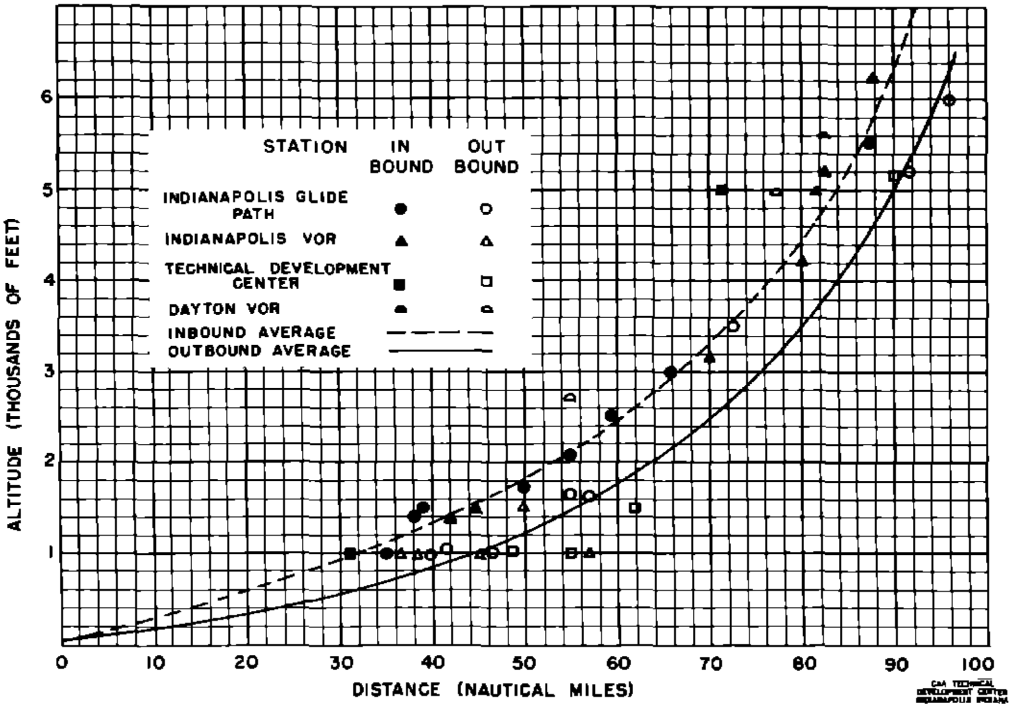


Fig 11 Maximum Ranges on Several DME Ground Stations in Indianapolis Area

The maximum range capabilities of the interrogator at specified altitudes also were investigated The maximum range capability of the equipment varied somewhat It was believed to be affected by the particular type of ground station (Model DTA or DTB), the ground-station site, condition of maintenance of both the ground station and the interrogator, propagation conditions, and other factors In general, the maximum ranges were near the radio line-of-sight approximation

$$D = \sqrt{2h} + \sqrt{2H} \qquad (1)$$

Where

D = maximum distance of operation, in statute miles
h = ground-antenna height, in feet
H = aircraft altitude above ground, in feet.

A graph showing the maximum distances obtainable at several altitudes on three ground stations in the Indianapolis area is shown in Fig 11

A variation in maximum usable range also was encountered when flying outbound on the three ground stations in the Indianapolis area on different radials from the station This variation was of the order of 7 or 8 miles at an altitude of 1000 feet above the ground station This variation was believed to be due to the topography around the ground-station site In the directions of maximum usable ranges from the ground station, the ground dropped off gradually in the first 7 miles from the station

Some characteristics of operation were apparent during flight testing which, although not entirely confined to this model, are significant to the operator of this equipment They are described here

The Model DIB interrogator in operation will track the same signal on an outbound flight a considerable distance further than it can search out and lock on this signal when inbound to the station. This differential averaged about 7 7 nautical miles (8 8 statute miles) This characteristic has been evident on all airborne DME interrogators tested at TDC, although to a lesser degree than with the Model DIB equipment The greater distances obtained on outbound flights were attributed to the memory action of the interrogator, coupled with the fact that the tracking gates are more sensitive to the presence of properly decoded signals when they are relatively stationary as during tracking than when they pass across the signal during search at the relatively high speed of several thousand miles per hour

The Model DIB interrogator was designed to accomplish retrace by hand The retrace button, when depressed, causes the gates and indicator to return to 0 miles and search out to beyond maximum distance again The retrace action in this interrogator has been slowed so that it is necessary to hold the button depressed for about one second in order to retrace the indicator from 100 miles to 0 on the indicator This action allows retracing only a portion of the range when the ground station is known to be within a certain portion of the distance range In the case of manual retrace action, this relatively slow retrace effectively decreases the search time when used with ground stations whose approximate distance from the aircraft position is known

Following development of the Model DIB interrogator, the contractor undertook development of an extension of the design to include several features found desirable during test and flight experience with the Model DIB interrogator This equipment was developed under contract by the CAA Office of Federal Airways It has been designated the Model DID interrogator

The Model DID interrogator has all of the functions and features of the Model DIB equipment with the following additions

1 Remote channel selection by use of common navigation-control heads
2 Remote dual-scale meter with 40- and 200-mile scales
3 Improved accuracy to ±3/4 mile or 3 per cent, whichever is greater
4 Automatic retrace action which provides automatic return of tracking gates and indicator to 0 after completion of a search
5 Flag alarm in indicator to indicate whether set is in the track or memory condition

The Model DID interrogator is housed in a standard one-half ATR case This equipment is designed for operation from a 115-volt, 400-cps ac source, using 27 volts dc input for heaters and motors in the equipment

CONCLUSIONS

The Model DIB equipment has demonstrated that DME interrogators can be designed and constructed which combine adequate performance characteristics with circuit simplicity, yet possess practical weight, size, and economy characteristics Specifically, the Model DIB interrogator has shown that satisfactory operation with the 100-channel DME system to minimum accuracy requirements can be achieved without the use of crystal-controlled rf oscillators, multistage intermediate-frequency amplifiers, magnetostrictive coders and decoders, mechanically driven ranging and indicating systems, and remote controls

The Model DIB interrogator, although not replacing more complex interrogators in accuracy of measurement, is available to users desiring a simpler, more compact and lightweight DME interrogator at a moderate sacrifice in accuracy

APPENDIX I

Specification TD-125
May 3, 1951

DISTANCE MEASURING EQUIPMENT
LIGHTWEIGHT INTERROGATOR

1 General

1 1 Purpose The purpose of this specification is to establish the requirements for an airborne distance measuring equipment interrogator for use in conjunction with present ground transponders by private and executive type aircraft The equipment transmits in the band 962 25 to 987 25 Mc and receives in the frequency range 1187 25 to 1212 25 Mc This equipment uses pulse multiplex coding techniques for both transmission and reception and indicates the distance from the ground station continuously to the pilot while in operation

1 2 Design Since this equipment is intended for use as an air navigation device, reliability, stability, and fail-safe operation are of prime importance in its design Every effort should be made in the design so that any failure of the equipment will be apparent to the pilot and no false indications of distance are presented under any foreseeable conditions of malfunction It is of prime importance, also, that the equipment should be capable of production at a moderate cost to the private pilot.

1 2 Service Conditions The equipment shall meet all requirements of this specification under any and all combinations of the following service conditions

a Temperature 0° C to +60° C
b Relative humidity 10 to 90 per cent
c Pressure simulating sea level to 20,000 feet. The upper limit of ambient temperature will be +25° C under this condition
d Voltage supply ±5 per cent from either 13 5 or 27 volts dc
e. Vibration to the extent normally encountered in private and executive type aircraft
f Continuous operation for 12 hours
g Primary voltage ripple of 5 per cent at 100 to 10,000 cycles

1 3 1 Low Temperature The equipment shall not be damaged when turned on and operated in ambient temperatures as low as -18° C

1 4 Material to be Furnished One complete equipment (DME), for purposes of this specification, shall consist of the following

a One interrogator or main unit housing the receiver, transmitter power supply, and associated video circuits, etc , including mounting base (shockmount) if required.
b Control unit
c Indicator
d Instruction book (five copies)
e One set of operating tubes, fuses, crystals, and any other plug-in assemblies required for operation of the equipment These may be installed in their proper sockets or packaged separately at the contractor's option
f One set of all plugs or connectors, both mechanical and electrical, required for operation of the interrogator
g One set of spares consisting of the following

(1) One set of all tubes
(2) One set of all fuses
(3) One set of frequency crystals for all frequencies used
(4) One set of rectifying or detector crystals required for operation of the unit
(5) One, each, spare electrical component other than those normally procurable as commercial stock items, if requested (See Paragraph 1 4)

1 4 1 List of Non-Standard Components The contractor shall furnish two copies of a list of all electrical components used in the design of the equipment, other than those normally

procurable as commercial stock items, within ten days after delivery of the first equipment One copy of this list will be returned to the contractor within ten days after receipt, indicating those components which are to be furnished as spares under Item g(5), Paragraph 1.4, for the first model This list shall then be used to satisfy Item g(5), Paragraph 1 4, on all subsequent deliveries under this specification

1 4 2 Combination of Units. No requirement of this specification shall prohibit the consolidation or separation of these units where possible or practicable in order to conserve space or weight The tabulation of units is included for purposes of clarity only

1 4 3 Additional Equipment The equipment, when delivered, shall include all accessories necessary for mounting and installing in an aircraft except for wiring and cabling between units

2 Requirements

2 1 General The equipment shall consist of a pulsed transmitter, a receiver, and associated indicator circuits coupled together in such a manner that the time required for the propagation of an interrogation pulse to the desired ground transponder and of the reply pulse back to the aircraft shall be measured and presented on the indicator which shall be calibrated in nautical miles (6080 feet or 1 1516 statute miles) The equipment shall also provide for identification of the ground transponder in use to the operator

Two alternate methods of distance indication are specified herein as examples The paragraphs marked "Alternate A" and "Alternate B" refer to these two alternates The method of distance indication to be used will be specified by the contracting officer at the time of final contract authorization

2 2 Design The design and construction of the equipment, including both material and workmanship, shall conform to the best commercial practice for aircraft instrument and electronic equipment

2 2 1 Life The equipment shall be designed so that it will have the maximum life with the minimum adjustment and repair that is consistent with low cost and other requirements of this specification

2 2 1.1 Motors Any motors used in this equipment shall have sealed bearings of a type that does not require lubrication or other attention for at least 1000 hours of operation

2 2 2 Components All electrical component parts, wherever practicable, used in the design of this equipment shall be of standard commercial manufacture such that they are readily procurable in the case of failure

2 2 2 1 Resistors Preference shall be given in the design of the equipment to use of one-half-watt, 10- or 20-per cent tolerance, insulated resistors

2 2 2 2 Capacitors Preference shall be given in the design of the equipment to the use of capacitors having a tolerance of ±10 per cent or greater

2 2.2 3 Motors No motors shall be used in the equipment without specific authorization from the contracting officer or his representative Exception will be allowed in this case for a dynamotor power supply, if required (See Paragraph 2 2 1 1)

2 2 2 4 Connectors All connectors shall be subject to the approval of the contracting officer or his representative

2 2 3 Primary Power Source The primary power source shall be nominally 13 5 or 27 volts dc.

2 3 Modes Ten modes shall be used Each mode consists of two pulse spacings, an interrogation pulse spacing and a reply pulse spacing The modes to be used are as follows (See also Table I)

Mode	Interrogation Spacing (microseconds)	Reply Spacing (microseconds)
A	14	77
B	21	70
C	28	63
D	35	56
E	42	49
F	49	42
G	56	35
H	63	28
I	70	21
J	77	14

2 3 1 Mode Selection The mode in use at any given time shall be determined by the operating channel in use in accordance with Table I herein The selection of the mode shall be accomplished at the time of channel selection either automatically from the receiver and transmitter settings or by use of a separate control In the case of a separate control, information shall be supplied by a table in the instruction book, or preferably by a nameplate on the control box, as to the correct mode for use with each channel

2 4 Channels

2 4 1 Number of Channels One hundred operating channels shall be provided by cross-banding ten receiver and ten transmitter frequencies Modes shall be added to alleviate the interference caused by common frequency interrogations and replies from and to other aircraft The arrangement of channels shall be in accordance with Table I

2 4 2 Channel Selection Selection of a channel shall consist of the following functions

a Transmitter frequency selection
b Receiver frequency selection
c Mode selection

In the interest of simplicity, the controls provided for channel selection shall be as few in number as is consistent with economical design However, it shall be allowed, expressly, to provide three separate controls, if necessary, to afford compactness and economy in the equipment

2 4 3 Channel Indication Indication shall be provided to indicate easily and quickly to the operator the operating channel to which the equipment has been set

2 4 4 Channel Pairing Each distance measuring channel will be paired with a VHF navigation facility frequency in installation of the ground equipment It would be desirable to indicate the proper VHF navigation facility frequency for pairing with each distance measuring channel on the selector control markings The proper VHF navigation frequency for each DME channel is indicated in Table I

2 5 Receiver

2 5 1 General The receiver shall receive paired pulse signals on any of ten frequencies (See Table I for frequencies) The receiver control shall provide positive channel selection unless other means for setting frequency accurately are provided

2 5 2 Radio-Frequency Input The antenna input circuit to the receiver shall be designed for connection to a 52-ohm coaxial line It is preferred that the receiver be designed so that the receiver and the transmitter are coupled to the antenna through a single input connection to the equipment The receiver shall not be damaged by the transmitter under any conditions of mismatch

2 5 3 Sensitivity The sensitivity of the receiver shall be 108 db below one watt or better, on all channels This sensitivity shall be maintained under all conditions of fruit specified in Table II herein The signal level into the receiver input requred to maintain distance

information shall be the sensitivity figure in the case of automatic tracking The sensitivity for "locking on" shall be within 3 db of the sensitivity for tracking (Alternate A) In the case of the oscilloscope indicator (Alternate B), receiver sensitivity shall be defined as that signal level required to produce a peak signal plus noise-to-peak-noise ratio of 2 1 on the indicator

2 5 4 Receiver Frequency Stability Either a high or low stability receiver may be provided by the contractor in accordance with the definitions in Paragraphs 2 5 4 1 and 2 5 4 2

2 5 4 1 High Stability Each receiver center frequency shall be within 200 kilocycles of its specified value in Table I, under all service conditions as specified in Paragraph 1 3 In this case, the receiver bandwidth to pulses may be either wide, narrow, or intermediate in accordance with the definitions in Paragraphs 2 5 5 1, 2 5 5 2, and 2 5 5 3

2 5 4 2 Low Stability Each receiver center frequency shall be within ±1 5 Mc of its specified value in Table I, under all service conditions specified in Paragraph 1 3 In this case the receiver bandwidth must be in accordance with Paragraphs 2 5 5 1, 2 5 5 2, and 2 5.5 3

2 5 5 Receiver Bandwidth The receiver bandwidth may be wide, narrow, or intermediate, depending upon the receiver frequency stability (See Paragraph 2 5 4) The definitions of these bandwidths are as specified in Paragraphs 2 5 5 1, 2.5 5 2, and 2 5 5 3

2 5 5 1 Wide Bandwidth Reception band of the receiver shall be in 5 Mc, ±0 5 Mc at 3 db down, and no more than 10 Mc wide at 50 db down

2 5 5 2 Narrow Bandwidth Reception band of the receiver shall be no less than 1 25 Mc, ±0 25 Mc at 3 db down, and no more than 10 Mc wide at 50 db down

2 5 5 3 Intermediate Bandwidth Any bandwidth between the limits specified for wide and narrow bandwidth may be employed, provided the stability meets the requirements of Paragraph 2 5 4 1

2 6 Identity

2 6 1 Identity, Alternate A Identification of the transponder with which the interrogator is operating shall be accomplished by means of a third pulse of 2 5 microseconds in duration, having similar characteristics to that defined in Table III and Fig 1 This pulse will be spaced 10 5 microseconds after the second reply pulse and shall be periodically sent on a one-for-one basis with each reply from the transponder Suitable circuitry shall be provided to produce a visual or aural indication of its presence

2 6 6 1 Operating Time At least 8 but not more than 12 identity pulses shall be required to produce the indication mentioned in Paragraph 2 6 1

2 6 1 2 Identity Sensitivity The sensitivity for proper operation of the identification circuits shall be within 3 db of the sensitivity for tracking

2 6 2 Identity, Alternate B No identity circuits are required for oscilloscope indicators, the display being relied upon to provide indication of identity

2 7 Decoder

2 7 1 Decoding, Alternate A The decoder shall be capable of being set to decode any of ten different paired pulse spacings transmitted from the ground station, yielding an output if the spacing is proper and no output if the spacing is improper

2 7 2 Decoding, Alternate B In the case of the oscilloscope indicator, no automatic decoder is required, the oscilloscope presentation being relied upon to allow recognition of proper spacing if needed

2 7 3 Decoder Spacing The pulse spacings to be transmitted from the ground equipment are specified in Paragraph 2 3 and in Table I

2 7 4 Decoder Tolerance The decoder (Alternate A) shall accept paired pulses that are within 0 5 microsecond of the correct spacing, and it shall reject, by more than 50 db, pulses whose spacing is more than 3 microseconds from the correct value

2 8 Distance Measuring Circuits

2 8 1 Display Time After completion of the selection of a channel, it shall not require more than 20 seconds (search time) to display the proper distance on the indicator under normal fruit conditions (see Table II) It shall not require more than 40 seconds under maximum fruit conditions (see Table II) These requirements shall be considered satisfied if the display time is met in 9 out of 10 tries

2 8 2 Search All searching, whether manual or automatic, shall be outward (increasing distance) to prevent locking on multipath signals Provisions shall be made to prevent inward searching by disabling the circuits or other means

2 8 3 Aircraft Speed It shall be possible to measure distance properly in aircraft having speeds up to 300 knots under maximum fruit conditions (see Table II)

2 8 4 Distance Range It shall be possible to measure distances from 0 to at least 100 nautical miles

2 8 5 Calibration The calibration of the distance output shall be in nautical miles (6080 feet, 1 1516 statute miles) The output shall be designed to read 0 miles when the delay between the second interrogation (transmitted) pulse and the second reply (received) pulse is 115 microseconds For purposes of this measurement, time shall be measured from corresponding points on the rf pulses at the antenna connector, using a signal level of 50 db above minimum usable and pulses as specified in Table III and Fig 1

2 8 6 Memory

2 8 6 1 Memory, Alternate A The distance output shall have a simple range memory lasting from 8 to 15 seconds after the loss of a signal which has been present for at least 15 seconds The range indication at the output shall not drift more than ±1 mile during memory

2 8 6 2 Memory, Alternate B No memory is required for an oscilloscope indicator

2 8 7 Pulse Repetition Rate The distance measuring circuits shall not require the transmitter to transmit an average repetition rate greater than 30 pulse pairs per second when averaged over a period of 10 minutes In no case shall the pulse repetition rate exceed 35 pulse pairs per second

2 8 8 Interrogation Jitter There shall be a random variation of at least ±1 per cent in the time between transmission of successive pairs of interrogation pulses

2 8 9 Interrogation Rate Stability Design of the pulse repetition rate determining circuits shall be such that their short time stability is purposely degraded in order to insure further against accidental synchronous operation from two interrogators operating on one transponder

2 8 10 Interference Injection of any of the following types of signals into the antenna connection, in addition to proper transponder replies, shall not cause the proper distance reading to change outside the limits specified herein.

a Third pulse identity This consists of a third pulse, in addition to the normal two, transmitted from the ground transponder for purposes of identity (See Paragraph 2 6 1)

b Fruit as specified under maximum conditions in Table II (Note This condition differs from receiver bandwidth)

2 9 Transmitter

2 9 1 General The transmitter shall transmit a paired pulse signal on any of ten stabilized frequencies

2 9 2 Frequencies The transmitter shall be capable of being set to any of the ten frequencies, as specified in Table I, by a single detent control

2 9 3 Pulse Shape and Spectrum The detected pulse envelope and spectrum of each pulse transmitted by the transmitter shall be in accordance with the values specified in Table III and Fig 1 In addition, each pulse of a pulse pair shall be as nearly identical as possible

2 9 4 Frequency Stability The transmitter frequency shall be stabilized within ±400 kilocycles of its specified frequency on all ten channels, under all service conditions, and in addition, a mismatch corresponding to a voltage standing wave ratio of 2 1, or less

2 9 5 Power Output The peak power of each transmitted pulse shall be not less than 500 watts under all conditions of operation The peak power of each pulse of a pair shall not deviate by more than 1 db from the other These conditions shall be met with a mismatch corresponding to a voltage standing wave ratio of 2 1, or less, of any phase at the antenna connector of the equipment

2 9 6 Output Load The output of the transmitter shall be designed to operate into a load impedance of 52 ohms

2 9 7 Spurious Radiation During intervals between generation of individual pulses, transmission at any frequency shall be more than 50 db below the peak power of the main pulse transmission at the radio frequency of operation This provision refers to all transmissions, including modulator and generator interference

2 10 Coder

2 10 1 Coding The coder shall be capable of being set to produce any of ten paired pulse spacings as specified in Table I

2 10 2 Coder Tolerance The spacing between constituent pulses of a pulse pair shall be maintained within 1 microsecond of the proper value under all conditions

2 11 Indicator It is the purpose of this specification to permit alternates for the method of distance indication Two alternate methods are specified as examples The sections marked "Alternate A" throughout this specification apply to an equipment using a meter indicator with automatic tracking circuits The sections marked "Alternate B" apply to equipment using an oscilloscope distance indicator without automatic tracking circuits

2 11 1 Design, Alternate A The indicator shall be designed as a meter movement with a scale covering 240° or greater, and calibrated in nautical miles from 0 to at least 100 with a linear scale

2 11 2 Size, Alternate A The instrument, including connector, shall not project more than 10 5 inches behind the instrument panel when mounted in its normal position (See Paragraph 2 14 2)

2 11 3 Accuracy, Alternate A The indicator, when connected to the equipment, shall indicate the correct distance to a ground transponder within ±5 per cent or ±1 nautical mile, whichever is greater

2 11 4 Indicator Dial, Alternate A The indicator must be so designed that the distance is clearly legible at a distance of three feet The contractor shall furnish with his proposal a sketch of the contemplated indicating instrument The contractor shall further furnish a final drawing of the indicator face for approval before construction of the indicator

2 11 5 Design, Alternate B The indicator shall be designed as an oscilloscope with a circular trace, with a scale covering as great a portion of the circular trace as possible, and calibrated in nautical miles from 0 to at least 100

2 11 6 Size, Alternate B The indicator shall not project more than 10 5 inches behind the instrument panel when mounted in its normal position

2 11 7 Accuracy, Alternate B The indicator, when connected to the equipment, shall indicate the correct distance to a ground transponder within ±5 per cent or 1 nautical mile, whichever is greater

2 11 8 Indicator Dial, Alternate B The oscilloscope face itself or a suitable overlay shall be calibrated and lettered so as to be easily legible from a distance of at least three feet from the instrument The words "nautical miles" shall also be prominently marked on the instrument The contractor shall furnish a sketch of the proposed indicator face with the proposal, and he shall further furnish a final drawing for approval before construction or lettering of the indicator

2 11 9 Case The instrument shall be fitted with a suitable case or dust cover to protect it

2 12 Computer Output

2 12 1 Proposed Computer Output The contractor shall carefully consider all possible methods of providing an output from the interrogator, which is proportional to the indicated distance, for use by course line or pictorial computers As a result of this consideration he shall furnish the following information to the contracting officer or his representative

a Possibility of computer output
b Type of output (see Paragraph 2 12 2) or outputs
c Estimated distance accuracy
d Estimated additional cost

2 12 2 Types of Output Desired The following are types of output desired for computers in order of preference

a Direct current or alternating current volts proportional to distance with 15 to 30 volts at 0 to 150 to 250 volts at 100 nautical miles
b Same except 0 volts to some lower value
c Alternating current volts with phase shift proportional to distance
d Others

2 13 Service Adjustment

2 13 1 Calibration Means shall be provided to allow calibration of the distance accuracy by qualified service personnel as a shop adjustment This shall include a 0 adjustment in addition to any others required

2 13 2 Locking All service adjustment controls shall be provided with shaft locks or locking arrangements to prohibit their rotation when subjected to vibration

2 13 3 Adjustment Stability After adjustment, all equipment parameters shall remain within their tolerances herein specified without further adjustment when the equipment is installed in an aircraft and the aircraft is flown under normal flight conditions

2 13 4 Adjustment Accessibility All controls and components necessary for the proper adjustment and maintenance of the equipment shall be easily accessible upon removal of the dust cover or dust covers

2 14 Size

2 14 1 Main Equipment The equipment, exclusive of indicator, control box, shockmount, and antenna, shall be housed in a case not occupying more volume than a standard one-half ATR (The packaging need not take this form factor)

2 14 2 Indicator The indicator should be designed to mount conveniently on the instrument panel of typical light aircraft

2 14 3 Control Box The control box should be combined with the indicator, if practicable, without sacrificing weight, space, cost, or convenience of operation In the event this

combination is used, a drawing showing the arrangement and panel mounting space required, and giving the estimated weight of the combined unit, shall be submitted for approval to the contracting officer before construction

2 15 Weight

2 15 1 Total Weight The total equipment, including the main unit, control box, indicator, mounting base, and all connectors necessary for installation, shall not exceed 30 pounds This weight shall be exclusive of all cables and wires between the units comprising the equipment

2 16 Government Furnished Equipment

2 16 1 Antenna The Government will furnish the contractor with at least one sample of the antenna to be used within 90 days after award of the contract, to be used by the contractor in development and testing of the equipment This antenna shall be returned to the Government, at the time of final equipment delivery, in good condition

2 17 Instruction Book

2 17 1 Content The instruction book to be furnished by the contractor (Paragraph 1 4 d) shall contain the following material

a Index
b A description of the installation procedure and all necessary information for installing the interrogator in the airplane
c A description of the theory of operation of the equipment in sufficient detail required for an understanding of the principles used and the function of each tube and associated circuit in the interrogator, including a block diagram
d A photograph or drawing of each unit or assembly (control box, indicator, receiver-transmitter, etc) with as many replaceable parts as possible labeled by suitable overlay or marking according to the circuit schematic reference number
e An installation wiring diagram showing all wires and cables between units and the number, size, type, and connection point of each wire
f A circuit schematic, or schematics, of the complete interrogator showing nominal values for all replaceable parts
g Voltage and resistance charts showing voltages and resistances to ground (chassis) or other convenient point from each tube socket pin and any other points required for servicing the interrogator
h Parts list (including circuit schematic reference numbers, nominal values, tolerances, ratings, and unit or assembly in which they are used) for replaceable component parts in the interrogator
i Oscillographic waveforms throughout the equipment
j Any other material or information required for servicing the interrogator

2 17 2 Detail Required The descriptions and explanations in the instruction book shall be in sufficient detail to allow testing and repair of the interrogator by a technician skilled in the servicing of radio and electronic equipment

2 17 3 Submission of Manuscript The contractor shall submit a manuscript in any legible and orderly form of the proposed instruction book within 30 days after delivery of the first interrogator for approval by the contracting officer After approval the instruction book may be reproduced and bound for delivery in the quantities required in Paragraph 1 4

2 17 4 Preliminary Instruction Material The contractor shall furnish, with the first model and any subsequent deliveries of equipment before the final instruction book is available, at least one set of preliminary instruction materials This material shall consist of a block diagram showing waveforms, a schematic wiring diagram showing component values and ratings, and a wiring diagram showing all cables and wires between units or assemblies necessary for installation and operation of the equipment This condition will be satisfied by submission of additional copies of the instruction book manuscript

2 17 5 Binding and Reproduction The instruction book may be reproduced by mimeograph, on a good quality paper, or by offset printing processes Gloss or matte prints of photographs may be included, or half-tone cuts of photographs may be used if desired Ozalid or equivalent black line prints of drawings or schematics may be used The instruction book shall be bound in good quality, wet strength, limp paper cover

2 18 Tests and Acceptance

2 18 1 Preliminary Tests Preliminary tests for compliance with the following requirements of the specification will be conducted at the contractor's plant on the first model

a Receiver sensitivity (Paragraph 2 5 3)
b Receiver frequency (Paragraph 2 5 4)
c Receiver bandwidth (Paragraph 2 5 5)
d Decoder tolerance (Paragraph 2 7 4)
e Distance range (Paragraph 2 8 4)
f Memory (Paragraph 2 8 5)
g Pulse repetition rate (Paragraph 2 8 6)
h Transmitter frequencies (Paragraph 2 9 2)
i Pulse shape and spectrum (Paragraph 2 9 3)
j Power output (Paragraph 2 9 5)
k Coder tolerance (Paragraph 2 10 2)
l Distance accuracy (Paragraph 2 11 3 or Paragraph 2 11 7)
m Size (Paragraph 2 14)
n Weight (Paragraph 2 15)

2 18 1 1 Conditions of Tests The tests mentioned in Paragraph 2 18 1 shall be conducted under the following service conditions (See Paragraph 1 3)

a Temperature room temperature only
b Humidity normal room conditions at time of test
c Pressure normal room pressure prevailing at time of test
d Voltage supply ±5 per cent from either 13 5 or 27 volts dc
e Vibration none
f Continuous operation for at least four hours
g Primary ripple maximum available up to 5 per cent at any frequency available from 100 to 10,000 cycles

2 18 1 2 Facilities for Test The contractor shall furnish all facilities and test equipment for the preliminary tests and conduct the tests with the participation and/or observation of a cognizant engineer designated by the contracting officer

2 18 1 3 Notice of Tests The contractor shall notify the contracting officer at least ten days before he is ready to begin the preliminary tests in order to insure presence of the cognizant engineer without delaying the tests

2 18 2 Final Test and Acceptance Final tests and acceptance will be conducted at the Technical Development and Evaluation Center and complete tests on all subsequent deliveries

TABLE I*

DME-VOR-ILS
PAIRING AND CHANNELING PLAN

Paired with VOR/Localizer (megacycle)	DME Reply (megacycle)										
Paired with VOR (tenth megacycle)		0 0	0,1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9
DME Interrogation (megacycle)		963 5	966 0	968 5	971 0	973 5	976 0	978 5	981 0	983 5	986 0
108	1188 5	0A	1B	2C	3D	4E	5F	6G	7H	8I**	9J
109	1191 0	10D	11E	12F	13G	14H	15I	16J	17A	18B	19C
110	1193 5	20G	21H	22I	23J	24A	25B	26C	27D	28E	29F
111	1196 0	30J	31A	32B	33C	34D	35E	36F	37G	38H	39I
112	1198 5	40C	41D	42E	43F	44G	45H	46I	47J	48A	49B
113	1201 0	50F	51G	52H	53I	54J	55A	56B	57C	58D	59E
114	1203 5	60I	61J	62A	63B	64C	65D	66E	67F	68G	69H
115	1206 0	70B	71C	72D	73E	74F	75G	76H	77I	78J	79A
116	1208 5	80E	81F	82G	83H	84I	85J	86A	87B	88C	89D
117	1211 0	90H	91I	92J	93A	94B	95C	96D	97E	98F	99G

Mode	Interrogation (microseconds)	Reply	Mode	Interrogation (microseconds)	Reply
A	14	77	F	49	42
B	21	70	G	56	35
C	28	63	H	63	28
D	35	56	I	70	21
E	42	49	J	77	14

*Instructions for use of table The DME operating-channel number is indicated for each VHF paired frequency A VHF facility frequency is obtained for a given DME operating channel by adding the VHF megacycle units and decimals in the horizontal and vertical lines

**VHF radio frequency 108 8 Mc not scheduled for assignment to localizer service Corresponding DME Channel 1 to be assigned to emergency service

Guard bands have been assigned between 960 0 and 962 25 Mc and between 1212 25 and 1215 Mc

TABLE II

FRUIT CONDITIONS

Fruit signals may be of any amplitude from equality to 50 db above the desired reply signal, and of the same characteristics and shape (See Table III and Fig 1)

Condition 1-A
Normal Fruit
Narrow Band Receiver

This condition is caused by the injection of random pulses, in addition to the desired reply, into the antenna input of the interrogator under test The following types of fruit comprise this condition

(a) 750 pulse pairs per second at the proper spacing for the mode selected

(b) 3000 pulse pairs per second at improper spacing

Condition 1-B
Normal Fruit
Wide Band Receiver

This condition is identical to Condition 1-A, except

(a) 1500 pulse pairs per second at proper spacing

(b) 6000 pulse pairs per second at improper spacing

Condition 1-C
Normal Fruit
Intermediate Band Receiver

This condition shall be on a linear percentage relationship with the actual bandwidth between the two conditions, 1-A and 1-B

Condition II-A
Maximum Fruit
Narrow Band Receiver

Identical to Condition 1-B

Condition II-B
Maximum Fruit
Wide Band Receiver

Identical to Condition 1-A, except

(a) 3000 pulse pairs per second at proper spacing

(b) 12,000 pulse pairs per second at improper spacing

Condition II-C
Maximum Fruit
Intermediate Band Receiver

This condition shall be on a linear percentage relationship with the actual bandwidth between the two conditions, II-A and II-B

Note Transponder efficiency shall be considered to be no less than 70 per cent under all fruit conditions

TABLE III

PULSE CHARACTERISTICS

The following characteristics apply to the transmitted pulse and to standard pulses used for receiver tests (For definitions and standards, see Fig 1)

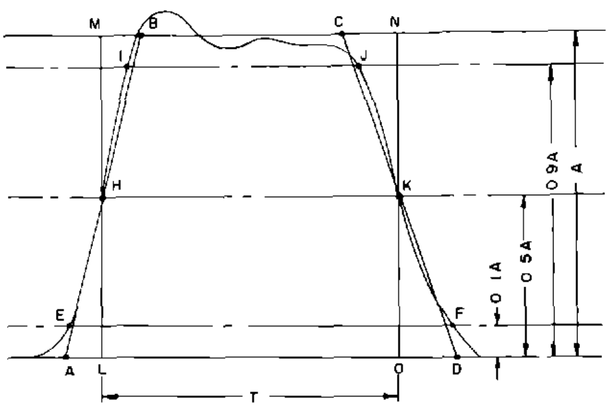
Rise Time 0 3 microsecond, or less

Decay Time 0 5 microsecond, or less

Flat Top ±10 per cent between 0 9A points

Duration 2 5 microseconds, ±0 2 microsecond

Spectrum 80 per cent of power in band, ±0 25 megacycle from center frequency on any channel



CONSTRUCTION OF EQUIVALENT RECTANGULAR AND TRAPEZOIDAL PULSE SHAPES

1 BY SUCCESSIVE APPROXIMATION OBTAIN RECTANGULAR PULSE (AMPLITUDE A) OF AREA EQUAL TO AREA UNDER ACTUAL PULSE AND PASSING THROUGH THE O 5A POINTS (H,K) ON THE ACTUAL PULSE ENVELOPE THIS IS RECTANGLE LMNO

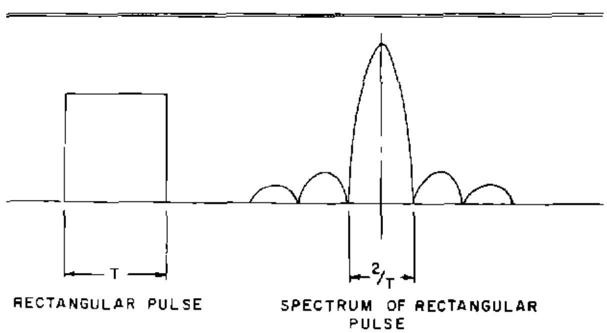
2 CHOOSE POINTS EF AND IJ ON THE ACTUAL PULSE AT O IA AND O 9A LEVELS RESPECTIVELY

3 THROUGH H DRAW AHB PARALLEL TO A STRAIGHT LINE CONNECTING E AND I

THROUGH K DRAW DKC PARALLEL TO A STRAIGHT LINE CONNECTING F AND J

THEN EQUIVALENT TRAPEZOIDAL PULSE IS ABCD

NOTE AREA ABCD AREA OF RECTANGLE AREA OF PULSE



DEFINITIONS

1 THE PULSE AMPLITUDE IS SPECIFIED AS A

2 THE PULSE LENGTH IS SPECIFIED AS T, i e THE TIME INTERVAL BETWEEN O 5A POINTS ON THE PULSE

3 RISE TIME, AS USED IN THIS SPECIFICATION, IS THAT PORTION OF THE TOTAL RISE TIME REQUIRED FOR THE PULSE TO CHANGE FROM O IA TO O9A

4 DECAY TIME, AS USED IN THIS SPECIFICATION IS THAT PORTION OF THE TOTAL DECAY TIME REQUIRED FOR THE PULSE TO CHANGE FROM O 9A TO O IA

5 THE FREQUENCY OF OPERATION IS THE MEAN FREQUENCY OF A BAND $\Delta F = \frac{2}{\text{PULSE LENGTH}}$ CHOSEN FROM THE SPECTRUM SO AS TO INCLUDE THE MAXIMUM POWER

CAA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS INDIANA

Fig 1 Definition of Pulse Shape and Radio-Frequency Spectrum