Development of a Lightweight Distance-Measuring Interrogator

Part II

The Model DIC Interrogator

by

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THE MODEL DIC INTERROGATOR*

SUMMARY

This report describes the results of tests conducted at the Technical Development Center of the Civil Aeronautics Administration with the model DIC distance-measuring interrogators developed by the National Aeronautical Corporation. The Model DIC interrogator provides continuous indication of distance from a selected ground station. It is composed of a receiver, distance indicator, transmitter, and associated distance-searching and -tracking circuits. Typical performance data for equipments developed under the contract are presented, along with the results of tests made to determine compliance with the development specifications.

INTRODUCTION

The distance-measuring equipment (DME) described in this report is intended as a component part of the civil-military common system for air navigation and traffic control. Its development was sponsored by the Air Navigation Development Board as a part of its program for improvement of the component parts of the common system.

The Model DIC interrogator provides 100 operating channels through the use of 10 transmitting frequencies, 10 receiving frequencies, and 10 pulse-multiplex modes. The channeling system used has been employed in all 100-channel DME interrogators, and it has been described in several earlier reports.[1,2,3] Table I shows the DME-VOR-ILS frequency pairing and channeling plan.

The Model DIC interrogator was developed to meet the requirements of Specification TD-125 which has been included in this report as Appendix I. The contractor for this development was the National Aeronautical Corporation, Ambler, Pennsylvania. The contractor chose to pursue a different approach to the equipment design for compliance with the specification in the Model DIC interrogator from that which was used in the Model DIB interrogator which was described in a previous report.[4] As a result, the Model DIC interrogator incorporates a number of design features not required by the specification and not incorporated in the Model DIB equipment. The more significant of these are: (1) remote channel selection, (2) crystal control of both transmitter and receiver, (3) dual-scale distance indication, (4) increased accuracy, (5) automatic transmitter- and receiver-sensitivity reduction on short-range operation, and (6) coder and decoder using magnetostrictive delay lines.

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*Manuscript submitted for publication August 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.

[4]Carl C. Trout and Warren E. Haworth, "Development of a Lightweight Distance-Measuring Interrogator, Part I, The Model DIB Interrogator," CAA Technical Development Report No. 228, December 1956.

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.

EQUIPMENT DESCRIPTION

Subsequent to and resulting from the development of the Model DIC interrogator, the contractor made available for civil aviation an interrogator incorporating the design features of the Model DIC equipment and designated as his Model UDI-1A. This interrogator has been tested, and it has been found to show a marked improvement over the Model DIC equipment in several important characteristics. The major improvements are better reliability of operation, increased transmitter-power output to about one kilowatt peak, and improved receiver sensitivity and signal-to-noise ratio. These improvements were made by minor circuit and component changes as the components became available, and more important, by better manufacturing and testing techniques as production personnel acquired skill. The original Model DIC units delivered under the development contract included many unique design characteristics which enhanced the operational reliability of the equipment. The later commercial Model UDI-1A interrogators have been granted a Civil Aeronautics Administration type certification for air navigation.

The complete Model DIC interrogator has an installed weight of 32.8 pounds, less interconnecting cables. It is shown in Fig. 1. The weight and size of its components are listed in Table II.

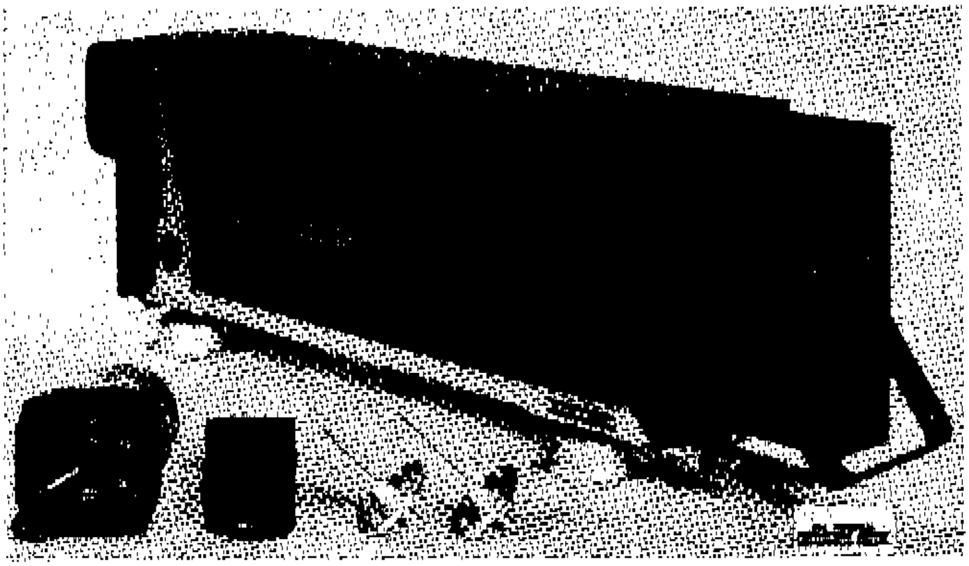

Fig. 1 Model DIC Interrogator Complete with Accessories

The total weight shown in Table II does not include the weight of the necessary interconnecting cables which vary in length, depending on the installation. Because separate transmitting and receiving antennas are used, two antenna cables are required. These cables are solid, dielectric, coaxial cables of approximately 50 ohms surge impedance, usually RG-58/U cable; however, in installations requiring longer antenna cables, RG-8/U has been used and is recommended. The antenna connectors at the interrogator proper and at the antennas are Type BNC, and Type UG-88/U or similar fittings are used with RG-58/U cable. Adapters or special fittings are required when larger cables such as RG-8/U are used. Interconnecting wiring or cable is required between the main unit and the channel selector, indicator, and OFF-ON switch. Minimum size of this wiring should be No. 20 AWG, and it should be larger for lengths in excess of 20 feet or for 13.5-volt installations.

The primary power source of the interrogator is 27 volts dc or 13.5 volts dc, depending upon connections made within the unit. The change from one voltage to the other is made by changing soldered-wire straps on terminal boards in the control unit, power-supply unit, and shockmount. Power consumption is 6.5 amperes at 27 volts and 13 amperes at 13.5 volts.

Reliable or "airline" type tubes have been utilized in the circuit design wherever possible to improve reliability and stability of equipment performance. This interrogator employs a total of 35 tubes, 30 of which are ruggedized reliable types. Of the remaining 5 tubes, 2 are thyratrons and 3 are transmitting types.

TABLE II

SIZE AND WEIGHT OF COMPONENTS OF MODEL DIC INTERROGATOR

Component	CAA Type No.	Length (inches)	Width (inches)	Height (inches)	Weight (pounds)
Interrogator (main unit)	DIC	23 1/4	4 15/16	7 3/4	25.5
Channel Selector	DIC/1	2 5/8	2	2 1/2	0.4
Distance Indicator	DIC/2	4 1/2	3 1/4	3 1/4	1.8
Transmitting Antenna	DIC/3	1 1/4	1 1/4	3 3/4	0.1
Receiving Antenna	DIC/4	1 1/4	1 1/4	3 1/4	0.1
Shockmount Assembly	DIC/5	25 3/4	5 7/8	9 3/16	4.6
Antenna Plugs (4 required)	--	--	--	--	0.1
Indicator Plug (1 required)	--	--	--	--	0.2
Total					32.8

Circuits are included in the Model DIC interrogator for reducing the transmitter peak power output and receiver sensitivity to eliminate or reduce multipath or echo effects when flying within a few miles of a ground station. Both transmitter power and receiver-sensitivity reduction are adjustable. Zero to 10 decibel (db) reduction is available for the transmitter power, and zero to 20 db attenuation for receiver sensitivity. These reductions are automatic in that they are accomplished by the range relay when the range switch is set to the short (20-mile) range.

The major characteristics of the Model DIC interrogator are given in Table III.

The mechanical construction of the interrogator is such that the several component parts of the unit are fastened to a metal structure or "backbone." All mechanical and electrical connections are made simultaneously with fastening, allowing the component parts to be interchanged or serviced separately for convenience. A view of the interrogator unit, partially disassembled, is shown in Fig. 2. The backbone with the channel-selector unit, range unit, and receiver in place, is shown at the left. The power-supply unit is shown in the center, with the transmitter unit at the right. Each of these units is discussed in the following section.

Transmitter.

The transmitter of the Model DIC interrogator is the direct, crystal-controlled type; that is, the output of a crystal-controlled oscillator is multiplied and amplified to produce the required radio-frequency output. Because simultaneous amplification and frequency multiplication in a single vacuum-tube stage are difficult at UHF with present tubes and techniques, amplification of the signal to nearly the output-power level is accomplished in the earlier stages of the transmitter. Later stages multiply the frequency to the final transmitting frequency. A block diagram of the transmitter is shown in Fig. 3.

The crystal oscillator utilizes a Butler overtone oscillator circuit with fifth-harmonic mode crystals in the frequency band of 80.292 to 82.167 megacycles (Mc). Ten crystals are provided, and the crystal in use is switched by the channel-selector mechanism. The output of the oscillator stage is applied to the grid of the following stage which has its plate at zero dc potential; and 180-volt negative pulses, 2.5 microseconds in duration, are applied from the modulators to the cathode so that a pulsed rf output is generated. The following four stages of the transmitter are supplied with dc plate and screen voltages and are biased so that output pulses are produced only when grid driving power is present and no pulse modulation of these stages is necessary.

The 6AN5WA amplifier stage operates straight through, and the last three stages of the transmitter are frequency multipliers, doubling, tripling, and doubling in that order, to produce rf output pulses of 12 times the crystal-overtone frequency of from 500 to 1000 watts peak

TABLE III

CHARACTERISTICS OF THE MODEL DIC INTERROGATOR

Interrogator Pulse Length	2.5 microseconds
Interrogation Rate	20 to 30 per second (adjustable)
Maximum Distance Ranges	200 miles and 20 miles (nautical or statute)
Minimum Transmitter Power	500 watts peak on 200-mile range, 50 to 500 watts peak on 20-mile range (adjustable)
Minimum Receiver Sensitivity	-75 dbm on 200-mile range, -55 to -75 dbm on 20-mile range (adjustable)
Intermediate Frequency	25 megacycles
Memory	15 to 20 seconds
Plate Power Supply	Nonsynchronous vibrator type (integral with interrogator)
Receiver	Superheterodyne with crystal-controlled local oscillator source
Transmitter	Crystal oscillator, multiplier, amplifier type
Transmitter Crystals	Fifth mode operation, 80.292 to 82.167 megacycles (10 used)
Receiver Crystals	Fifth mode operation, 75.844 to 77.250 megacycles (10 used)
Receiver Mixer	Germanium diode, Type 1N73
Antennas	Transmitting, one-quarter wavelength, vertically polarized; receiving, one-quarter wavelength, vertically polarized
Encoding Delay	Nickel magnetostrictive line
Decoding Delay	Nickel magnetostrictive line
Distance Indicator	270° dc instrument, hand-calibrated
Distance Accuracy	±0.5 mile or ±2.5 per cent, whichever is greater
Number of Tubes	35

pulse power. The last three transmitter stages incorporate trimmer capacitors mechanically linked to the channel-selection mechanism to tune them accurately to the selected channel. Tracking adjustments also are included for each of these three stages. One-quarter-wavelength resonant cavities are used for tuning in the plate of the Type 4X150A tripler stage and in the grid and plate of the Type 4X150G output-doubler stage.

Reduction of the transmitter-output power is accomplished by adjustment of the transmitter bias supplied to the last four stages of the transmitter and is switched for long and short ranges by the range-switching relay in the range unit.

Receiver.

The receiver used in the Model DIC interrogator is the superheterodyne type with direct, crystal-controlled, local oscillator signal. A block diagram of the receiver is shown in Fig. 4. Ten fifth-harmonic mode crystals are provided in the frequency band 75.844 to 77.250 Mc, and the proper crystal is switched into the circuit by the channel-selector mechanism. The crystal-overtone frequencies are one-sixteenth of the required mixer-injection frequency for 25 Mc above the receiver band of 1188.5 to 1211.0 Mc. The output tank of the Butler oscillator circuit is tuned to twice the crystal-overtone frequency, which then is quadrupled by a

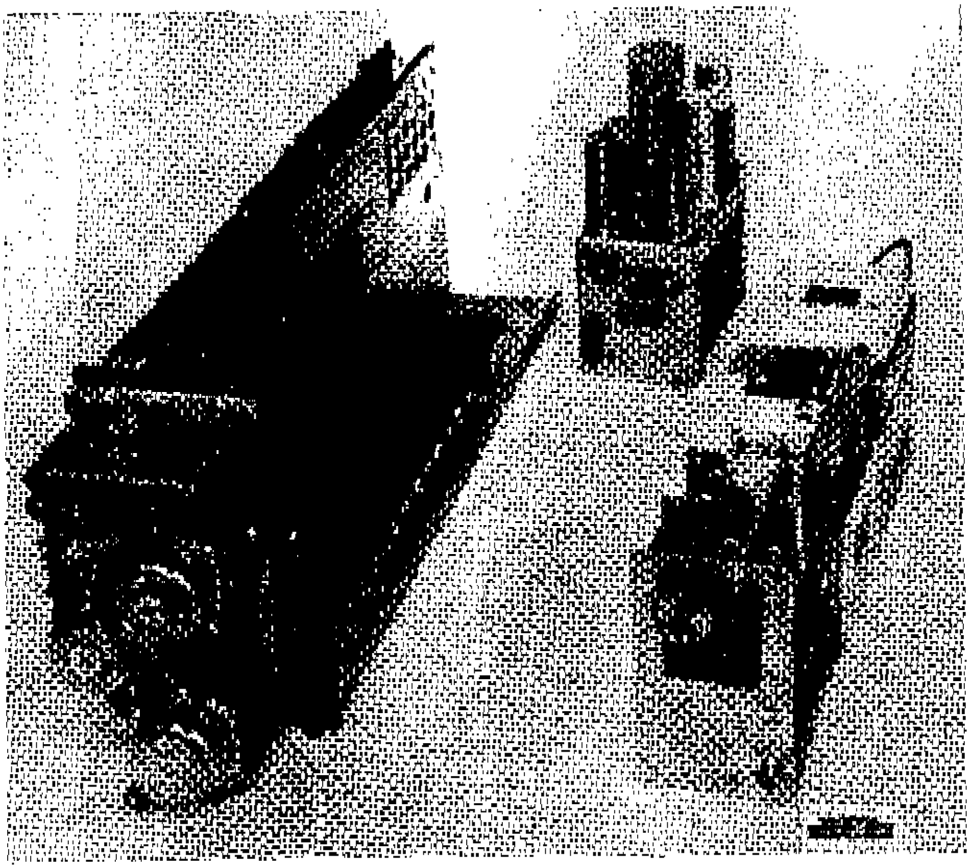

Fig. 2 Model DIC Interrogator Partially Disassembled

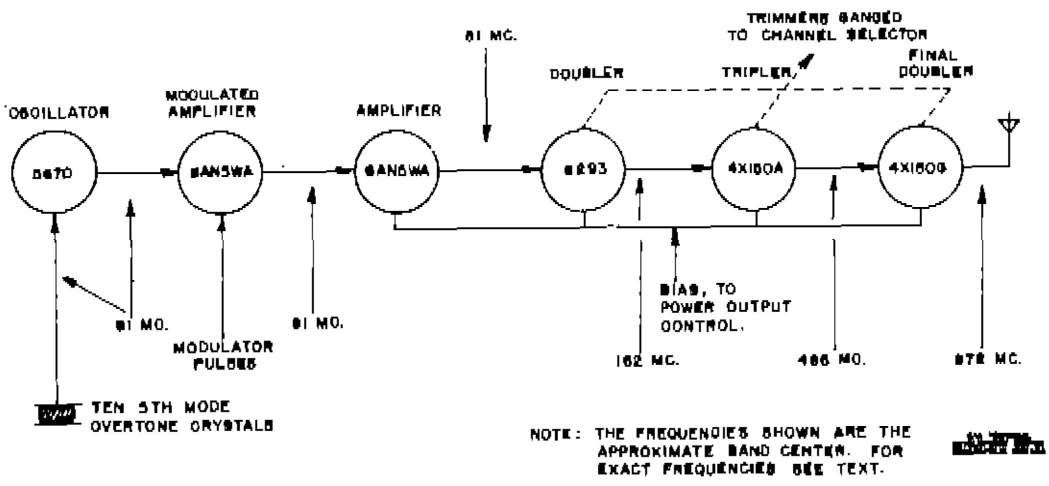

Fig. 3 Block Diagram of Transmitter

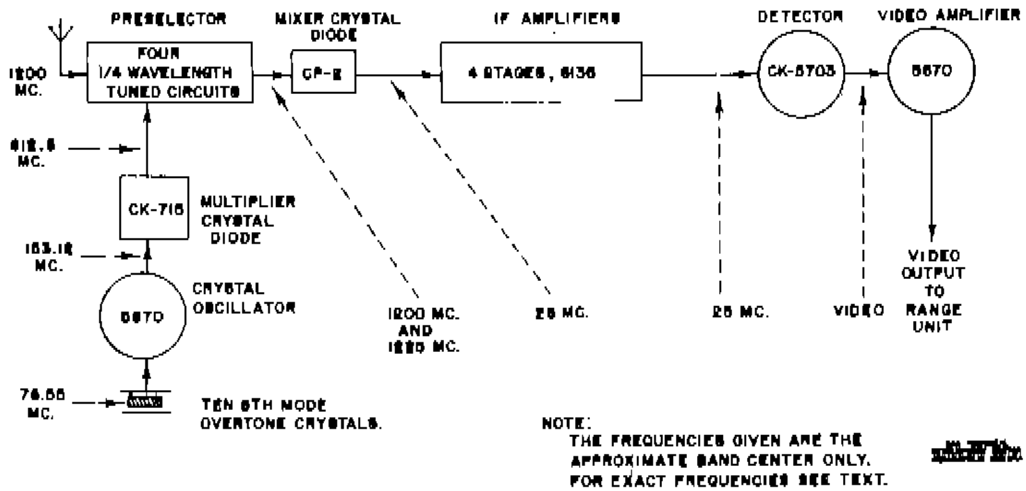

Fig. 4 Block Diagram of Receiver

germanium crystal-diode multiplier, Type CK-715. The local oscillator signal is further doubled in the germanium-diode mixer, and it is heterodyned with the receiver signal. Preselection of the signal from the antenna is provided by three one-quarter-wavelength resonant lines, with the third loop-coupled to the mixer crystal. A one-quarter-wavelength resonant line is provided for tuning the output of the quadrupler crystal, and it is coupled to the third preselector-tuned line and the mixer crystal.

The resultant 25-Mc intermediate-frequency signal is amplified by four double-tuned pentode stages, and it is demodulated by a simple diode detector. The grid bias for the intermediate-frequency stages is supplied from the range unit and gated so that the amplifiers are cut off except for about 3000 microseconds after transmission of an interrogation-pulse pair. The amplitude of the ON portion of this gate is controlled to adjust receiver gain and is switched for changing receiver sensitivity on long and short ranges, if desired.

A video amplifier and cathode follower are included on the receiver chassis for amplification and coupling of the detected reply pulses to the distance-measuring circuits in the range unit.

Range Unit.

As in previous models, the range unit is the heart of the Model DIC interrogator inasmuch as it generates all timing functions, decodes replies, and supplies a voltage output proportional to distance to the indicator, in addition to performing other secondary functions. In the description to follow, frequent reference to the block diagram in Fig. 5 and the timing relationships shown in Fig. 6 will be helpful in understanding the operation of the range unit. In Fig. 5, a number of vacuum-tube stages have been omitted or combined with others to simplify the diagram and to clarify the explanation of the circuit. In every case, the omitted stages are used for clamping, amplifying, or impedance changing.

Because the method of measuring distance is through measurement of time intervals with the velocity of propagation as a standard, the accuracy of distance indication is dependent upon the accuracy of the timing circuits within the range unit.

To begin the complete cycle of operation, a pair of negative pulses of about 180 volts amplitude and 2.5 microseconds in duration are produced by the modulators. Because they are the gaseous type, two modulator tubes are required, one for each pulse, with pulse-forming networks for establishing the 2.5-microsecond pulse length. The first modulator operates as a relaxation oscillator at about 25 pulses per second. A germanium diode CK-705 is used as a noise source to jitter the firing of this tube in order to produce a random firing rate. This prevents synchronizing of airborne interrogators operating with a common ground transponder.

When changing channels, the delay between pulse pairs must vary from 14 to 77 microseconds in steps of 7 microseconds. This is accomplished by use of a magnetostrictive delay line. The magnetostrictive properties of a nickel tube are utilized to produce an acoustic wave which travels down the tube at a speed of about 5.28 microseconds per inch. A driving

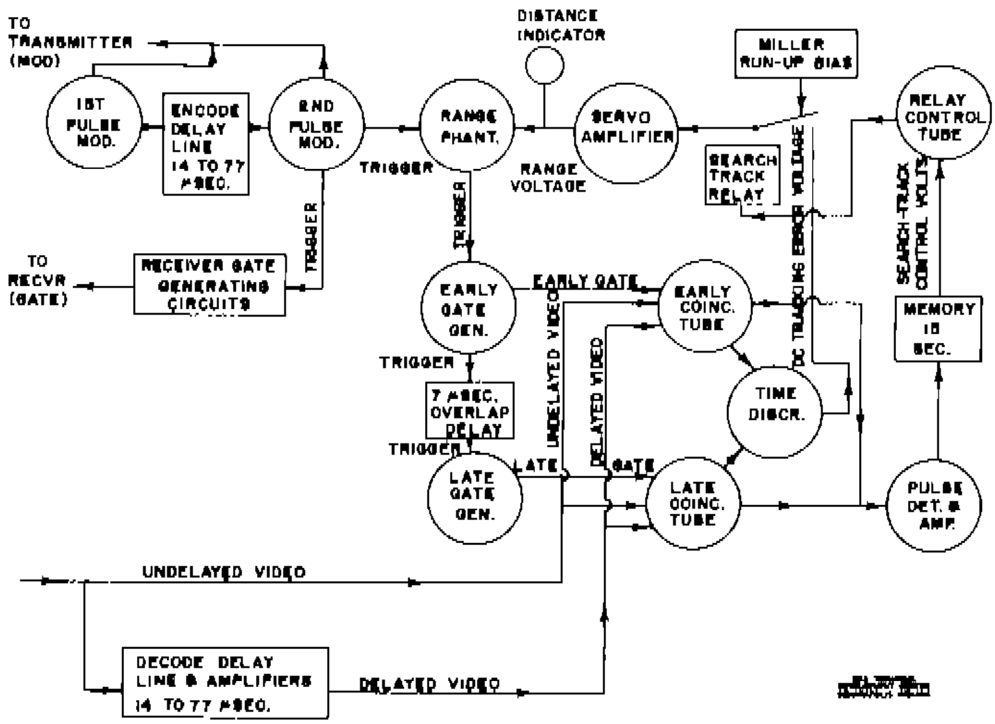

Fig. 5 Simplified Block Diagram of Range Unit

coil and 10 pickup coils are arranged on the tube to give the proper delay. The outputs of the 10 pickup coils are switched by the channel-selection mechanism to the mode for the channel in use.

In order to overcome the rather high insertion loss of the magnetostrictive delay line, the length of nickel tubing is inserted in the center of the first modulator pulse-forming network coil. This pulse-forming network then functions additionally as the driving coil for the encoding delay line. The output of the delay line then is amplified and used as a trigger for the second modulator. The outputs of the two modulator tubes are combined to produce the interrogation pulse pair.

The basic DME system is arranged so that the distance measurement is always made from the second interrogation pulse to the second reply pulse. This allows the decoders in both the ground station and the interrogator to receive and examine both pulses of a pair before notifying the associated circuits that a correct signal has been received and allowing that signal to pass on to the time-measuring circuits. For this reason, a small amount of the output of the second modulator is used to trigger the receiver-gate generating circuit and the range phantastron, thus energizing the receiver and beginning phantastron delay at the time of the second interrogation pulse.

The receiver gate is a signal beginning at the time of the second modulator pulse and extending for about 3000 microseconds thereafter. The time interval of 3000 microseconds corresponds to about 250 nautical miles. This gate is used as bias on the receiver intermediate-frequency strip to turn it on and leave it on for a sufficient time to receive all reply signals within the range capabilities of the interrogator. At the end of this time, the receiver is turned off. This allows an appreciable average power saving in plate supply to the receiver.

The range phantastron produces a continuously variable time delay from less than 115 to about 3000 microseconds, corresponding in distance from zero to more than 200 nautical miles. This delay is controlled by a dc voltage applied to the plate, and it is linear to a very precise degree with respect to the control voltage. The source and generation of this control voltage will be discussed later. The phantastron in the interrogator uses vacuum-tube diodes for clamping (both the start and stop action) and precision temperature-compensated components to provide an accurate and stable linear time base for distance measurement. A shift or change of this delay for a given control voltage appears as an error in range measurement after the unit has been calibrated.

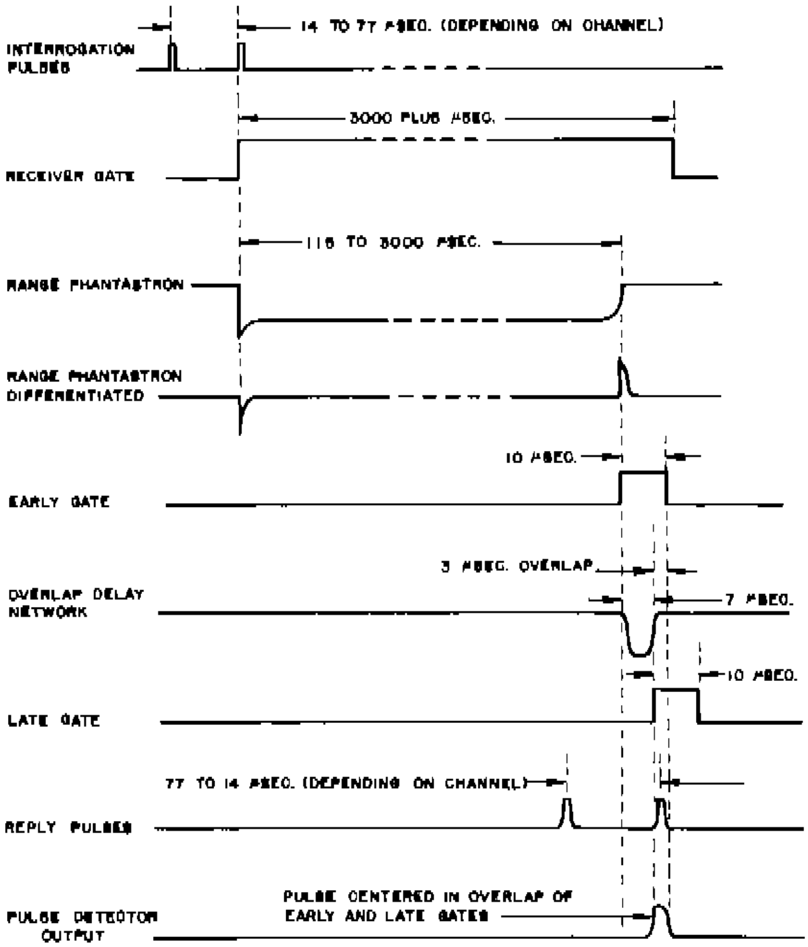

Fig. 6 Time Relationships of Range Unit

At the expiration of the delay generated by the phantastron, a trigger output is furnished to the early and late gate generators. Both of these gate generators are one-shot blocking oscillators, producing gates of approximately ten microseconds duration. An LC-delay network of about seven microseconds is inserted in the trigger to the late gate generator so that two gates are produced with an overlap of about three microseconds. The two gates thus produced then are fed to the early and late coincidence tubes. The occurrence of coincidental signals to the early or late coincidence tubes then is dependent upon a reply signal occurring during the ten microseconds during which these gates are present.

By use of these circuits, it can be seen that the delay of the early and late gates to the coincidence tubes with reference to the second interrogation pulse is controlled by the phantastron control voltage.

The operation of the range-unit distance-measuring circuits consists of three conditions. These have been called "search," "track," and "memory" conditions. During the search condition, a channel has been selected and a paired-pulse interrogation is being transmitted by the interrogator. The distance-measuring circuits then, in effect, are searching all distances from zero to 200 miles for a synchronous reply signal. Upon reception of a proper reply, the interrogator then is required to change to the track condition. During the track condition, the interrogator is indicating distance continuously by remeasuring the round-trip transit time of the pulse signals. During this condition, the gates are following the signal in time, and an integrated dc control voltage is derived in the range unit to control their delay position as the time interval increases or decreases. If the signal is lost during tracking, the interrogator is required to go into the memory condition for a short period and to resume tracking if the signal reappears within 15 to 20 seconds. This memory condition prevents initiation of search action and loss of time in resumption of tracking by holding the tracking gates at a constant delay and the indicator at the last indicated correct mileage for the duration of the memory period. At the expiration of memory, the search action is resumed.

It can be seen that in the three conditions of search, track, and memory, the phantastron control voltage is derived in a different manner for each condition. A search-track relay is used to transfer the control grid of the servo-amplifier tube in a Miller run-up circuit from self-controlled to externally controlled operation. During search, a large capacitor coupling its grid to its plate is charged slowly from a negative voltage source through a high resistance. The action causes the phantastron control voltage and the time delay of the early and late gates to increase. This increase, beginning at a control voltage corresponding to somewhat below zero miles, rises to a voltage corresponding to more than 200 miles in approximately 30 seconds. In this manner, the gates are caused to search from zero to 200 miles in 30 seconds. Because the indicator meter is connected to the phantastron control voltage, the pointer sweeps slowly from zero to 200 miles at the same time.

Contacts provided in the indicator meter close when the pointer reaches full scale. These contacts are connected to the Miller run-up capacitor so that upon closing they quickly discharge it, causing the phantastron control voltage, early and late gate delay, and the indicator to return quickly to zero. This quick return is called "retrace." Immediately upon returning to zero, the cycle is repeated and another search from zero to 200 miles is begun. This search and retrace action continues until a reply signal is received and the range unit "locks on;" that is, changes to the track condition.

As soon as a synchronous reply signal is received, it is necessary to determine if it is of the proper spacing or mode. This decoding is accomplished by use of a magnetostrictive delay line similar to that described earlier for producing the interrogation or transmitted pulse spacing. The reply-signal spacing, like the interrogation spacing, is from 14 to 77 microseconds, in multiples of 7 microseconds. From the output of the receiver, these pulses are amplified and delayed through the magnetostrictive line. The line has 10 pickup coils with the one in use selected by the channel-selection mechanism, so that a delay is inserted equal to the spacing expected on the channel in use. Along with the undelayed receiver video, this delayed video signal is applied to the coincidence tubes.

Two tracking coincidence tubes are provided, and both are adjusted to require simultaneous application of three signals to secure output. The early coincidence tube requires an undelayed video pulse at its control grid, a delayed video pulse at its suppressor grid, and the early gate at its screen grid. The conditions for the late coincidence tube are the same except that the late gate is applied to its screen. The outputs of both coincidence tubes are coupled to the pulse detector so that coincidence occurring in either or both tubes will trigger the pulse detector. The pulse-detector output, when rectified and amplified by the relay amplifier, will operate the search-track relay and will transfer control of the servo-amplifier grid to the output of the time discriminator.

The input of the time discriminator is connected to the output of the coincidence tubes so that the outputs of the two tubes are compared. Equal signals at the outputs of both coincidence tubes will result in zero output from the time discriminator, but signals simultaneous with either the early or the late gate alone will result in a negative or a positive voltage, respectively, at the grid of the servo-amplifier tube. This voltage then will charge or discharge the grid-plate capacitor of the servo tube, altering the phantastron control voltage and the delay of the early and late gates. This action is a method of automatic tracking which keeps the three-microsecond overlap of the early and late gates centered on the second pulse of the reply signal, because the time of the second pulse is the only time all three signals are present at the coincidence tubes.

The dc output of the pulse detector also is used to charge the memory capacitor. This is a large capacitor with exceptionally low internal-leakage resistance, and it is used to maintain the bias on the grid of the relay-amplifier tube during signal interruptions of short duration. Retention of this bias for periods of 10 to 20 seconds prevents the search-track relay from operating. This provides the function of memory. Because there is no appreciable output from the coincidence tubes to produce tracking-control voltage during signal loss, the tracking gates and the distance indicator remain stationary until the memory-capacitor charge has leaked off.

The distance-measuring system includes a third reply pulse which is transmitted by the ground station for purposes of confirming the identification of the transponder in use. This third pulse is keyed at the ground station in synchronism with the Morse Code identification of the associated VHF navigation facility, and it occurs 10.5 microseconds after the second reply pulse. An identity detector and a pulse amplifier are included in the range unit for indication of the presence of this identification signal. The indication is made by means of a neon lamp which can be mounted remotely from the interrogator.

A series-regulator tube with its associated reference tube and control amplifier also is included in the range unit for accurate regulation of the plate supply to the phantastron and for stabilization of the delay produced by this circuit over wide limits of primary input voltages.

Power Supply.

The plate-power requirements of the interrogator are supplied by a single nonsynchronous vibrator and transformer with several rectifiers for producing the required voltages. The 250-volt positive plate supply is rectified by two Type 6X4W, high-vacuum, miniature rectifiers in a full-wave circuit. The remaining three rectifiers are encapsulated selenium units as follows: (1) two rectifiers in a half-wave doubler furnishing 2700 volts positive for transmitter high voltage, (2) single half-wave unit furnishing 480 volts negative for transmitter bias, and (3) single half-wave unit furnishing 500 volts positive for modulator plate voltage.

Because the Type 4X150G tube used in the output stage of the transmitter required 2.6 volts ac peak for its heater, it was necessary to derive this voltage from a special winding on the vibrator transformer. The heaters of all other tubes are operated in a series-parallel string from the primary dc power source.

A 15-second time-delay relay is provided to delay the major load on the vibrator by delaying application of the heater voltage to the Type 6X4W plate rectifiers and the Type 4X150G transmitter-output tube. This delay contributes to long, reliable vibrator life by limiting the instantaneous heavy load to the vibrator contacts when the primary power switch is closed. An additional 60-second time-delay relay is provided to prevent application of pulses to the transmitter until it has been thoroughly warmed.

Because the primary input power to the interrogator can be either 13.5 or 27 volts dc, terminal boards are provided in the power supply for changing connections to the vibrator-transformer primary and heater connections for the two voltages. A 13.5-volt vibrator is used, with a resistor inserted in its coil for 27-volt operation. Dual primaries are provided in the vibrator transformer with series or parallel operation, depending on the voltage of the power input. A 1/32-ampere fuse is located underneath the power-supply chassis for protection of the 2700-volt transmitter high-voltage supply.

Channel-Selection-Control Circuits.

The channel-selection function of the Model DIC interrogator is accomplished in the interrogator by rotary solenoid stepping switches called Ledex units. These units are used to operate ordinary wafer switches to select the proper crystals in the transmitter and receiver and to select the proper coils in the encoding and decoding magnetostrictive delay lines. The selector switches for the transmitter and receiver frequencies are controlled remotely by a switch in the control panel, and the mode switches (encode and decode spacings) are controlled by an electrical differential system also attached to the transmitter- and receiver-frequency Ledex units. There are 10 wafers of 10 positions each on the shaft of the receiver Ledex unit and one wafer of 10 positions on the shaft of the transmitter Ledex unit. These wafers are used to select the proper interrogation and reply spacings for the channel in use by controlling the mode Ledex unit. The problem is simplified because only 10 of the possible 100 combinations of spacings are used to make up Modes A through J, with the sum of the interrogation and reply spacings always equal to 91 microseconds. Thus, for Mode A, the interrogation spacing is 14 microseconds and the reply spacing is 77 microseconds; for Mode J, the interrogation spacing is 77 microseconds and the reply spacing is 14 microseconds.

A specific switching system was specified for use in the Model DIC interrogator for controlling the Ledex units from the control panel or channel selector in order to conform with channel-selector units already produced for VHF navigation receivers which incorporated switch wafers for use with DME interrogators. This system allows the use of a common control head for selecting the correct paired DME channel simultaneously with selection of a VHF navigation frequency. The pairing plan, Table I, is followed in selecting the channel of operation of all DME ground stations. For this reason, only the VHF frequency in use is marked on the control-head dials.

The specified switching system requires that a wire be grounded for each consecutive pair of whole-megacycle steps of the control for DME use between 108 and 117 Mc. An auxiliary wafer then is provided to indicate odd or even whole-megacycle steps by supplying a ground on the odd-megacycle steps. An odd-even relay then is required in the interrogator to position the receiver Ledex stepping unit to the odd or even whole-megacycle step of the pair.

The switching system also requires that one of ten wires be grounded for each one-tenth-megacycle step of the control, and this ground is used to position the transmitter Ledex stepping unit. This system allows the selection of any one of the 100 available channels with 16 wires, 10 for the one-tenth-megacycle steps, and 6 for the whole-megacycle steps.

In addition to selection of transmitter crystals and the mode-differential switch, the transmitter-stepping unit is connected mechanically through gears to a shaft in the transmitter for positioning the trimmer capacitors in the last three stages of the transmitter. This arrangement allows the transmitter to be adjusted for optimum output over a wide range of frequencies.

All of the Ledex units in the interrogator are arranged with split windings in the solenoid driving coils so that a series connection of the two windings is used for 27-volt operation and a parallel connection is used for 13.5-volt operation. A terminal board is included in the control unit on the interrogator to allow this connection change by soldering wire jumpers between the correct posts for each primary power voltage. A fuse is provided on the dust cover of the channel-selection mechanism for protection of the coils of the Ledex units. This fuse is accessible with the dust cover in place. Its rating depends on the power-source voltage in use.

Miscellaneous.

A compartment at the rear of the shockmount assembly has been used to house a centrifugal blower unit which furnishes circulating air for cooling. Air circulation is required to cool the Type 4X150G transmitter-output tube and to improve heat dissipation from the remainder of the unit.

A socket is provided at the rear of the shockmount to receive an optional relay for placing the interrogator in a standby condition if a VHF navigation frequency above 117.9 Mc is selected. This function is not needed if the interrogator is used with the channel-selector control head furnished with the unit. In this case, the relay is replaced by a shorting plug. If it is desired to operate the interrogator with a common control head in conjunction with a VHF navigation receiver, the shorting plug is replaced with the relay.

The transmitter and receiver of the interrogator are designed to use separate antennas. Two are furnished. These antennas are simple one-quarter-wavelength stubs of slightly different lengths in accordance with the center frequency of their respective bands. No special matching stubs or sections are needed because the impedance of the antennas at the feed point, when mounted on the aircraft skin, approximates that of the coaxial cable (52 ohms).

A test receptacle is provided on the front dust cover of the interrogator which makes available the video output of the receiver and the trigger output of the second modulator to facilitate connection of an oscilloscope and signal generator. This connection allows bench-checking without removal of the dust cover or disassembly of the interrogator. The 250-volt positive plate supply, 25-volt negative bias supply, 13.5-volt input, and 27-volt input also are connected to this socket for use with external test equipment if required.

The primary input power to the interrogator is controlled by a relay in the rear of the shockmount assembly so that the 13.5- or 27-volt aircraft supply is wired directly to the interrogator mounting and the OFF-ON switch which controls this relay can be mounted at any convenient position in the aircraft without regard to length of leads. No main power-source fuse or circuit breaker is included in the interrogator, and provision for this protection must be made externally by the installer.

TESTS

A number of tests were performed on the units, including bench tests, climate-chamber tests, and flight tests. The bench and climate-chamber tests were confined essentially to those necessary to insure compliance with the specification. In the flight tests, emphasis was placed on suitability of the equipment design for application and on related factors such as reliability, ease of operation by the pilot, and over-all performance.

Laboratory Tests.

In order to determine compliance with the environmental and performance provisions of Specification TD-125, tests were run at the contractor's plant with participation of representatives from TDC. A number of these tests are described in this section.

The transmitter-power output was found to vary with the channel or frequency of operation, at normal primary power voltages, from a low of about 620 watts near the center of the band to 765 watts at one end of the band. The transmitter output also varied with the primary power or battery voltage, on a channel near the center of the band, from about 540 to 620 watts for a battery-voltage change from 25.6 to 28.4 volts. The data on this test are shown in Fig. 7. A check of the transmitter-power output from 0° C. to +60° C. ambient temperatures, and input voltage of 28.65 volts for a period of one hour, indicated no deterioration of transmitter performance. This test, although in excess of the specification requirements, was made to reveal

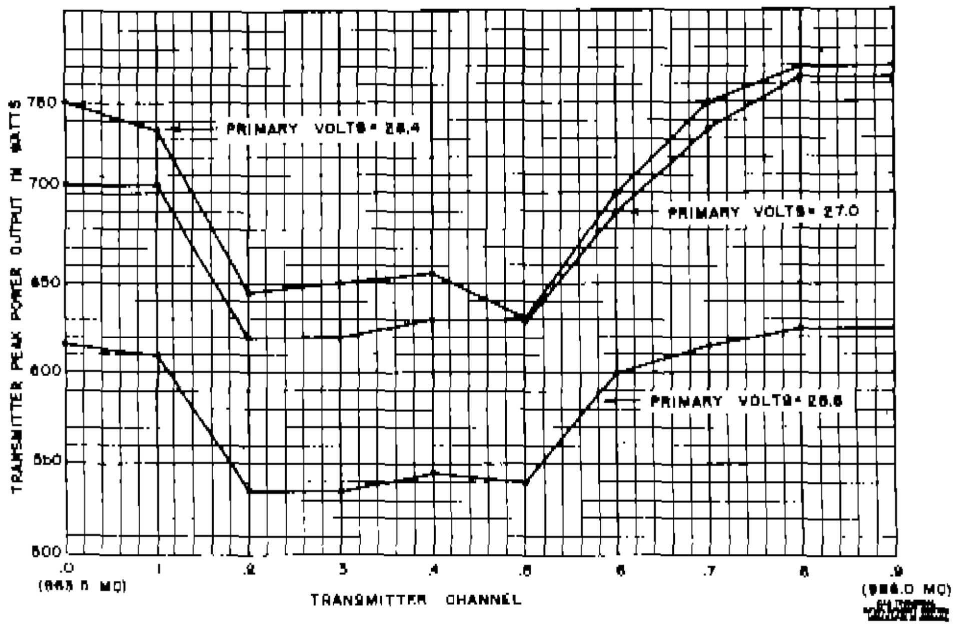

Fig. 7 Transmitter-Output Variation with Channel and Battery Voltage

marginal components, if any, which might be induced to fail by high-voltage and high-temperature operation.

The receiver sensitivity of the Model DIC interrogator was tested for both "lock-on" and track. The receiver lock-on sensitivity in each case was the minimum signal strength required to actuate the search-track relay. The track sensitivity was the signal strength required to maintain the unit in track condition after locking on. The track sensitivity was found to be consistently 3 db higher than the lock-on sensitivity in all tests. This difference in lock-on and track sensitivity is a condition common to all DME interrogators. It is attributed to the fact that a larger signal is required to actuate the search-track transfer relay or circuit, as the tracking gates pass the reply at relatively high speed, than is required to operate them when essentially at rest, as during signal tracking. This condition is evidenced in actual flight operation by the ability of the interrogator to track a signal when outbound from a ground station to several miles greater distance than it is able to lock on to the same ground station when inbound and searching for a reply. In the receiver-sensitivity data presented in Fig. 8, only the minimum lock-on signal is recorded, and in every case the track sensitivity can be assumed to be 3 db greater.

The receiver sensitivity was found to vary across the band, with the higher sensitivity values at near midband and the lower values near the edges of the band. A relatively moderate change of receiver sensitivity was noted with change in primary battery voltage, and a negligible change was noted with variations of ambient temperature from 0° C. to +60° C.

The receiver bandwidth was found to be 1.2 Mc at 6 db down and 6.9 Mc at 30 db down. This measurement was made, with the interrogator in actual operation, using a simulated reply signal at the antenna connector of the interrogator. This receiver passband, although not rejecting adjacent channel signals by receiver selectivity alone, met the requirements of Specification TD-125, and it is entirely satisfactory in practice with the 100-channel pairing plan shown in Table I. This table shows that additional protection is afforded by a change of several channels in interrogation frequency and by a change of several modes to the adjacent receiver channel in all cases. Under this condition of receiver bandwidth, the receiver and range unit are required to operate under more stringent "fruit" (nonsynchronous reply signals) due to reception of improperly spaced and random signals from ground stations on the adjacent reply frequencies, if relatively close to and within line-of-sight of the aircraft position. The most exacting requirements of performance of the range unit's search and tracking circuits would be imposed if the two adjacent reply channels were occupied by ground stations within range and if both of these ground stations were in use by a maximum number of aircraft; that is, 50 interrogator-equipped aircraft per ground station. For this reason, the fruit tests

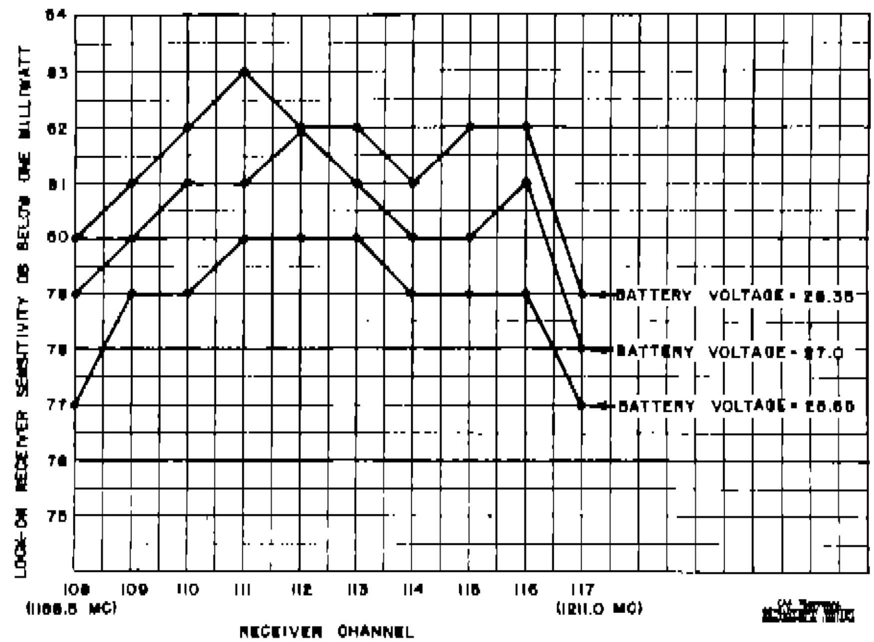

Fig. 8 Receiver-Sensitivity Variation with Channel and Battery Voltage

described later were somewhat more severe than would be required of interrogators with narrow bandwidth receivers.

A test was made of the spacing of the interrogation pulses radiated by the transmitter. This test insured that the encode-spacing parameter of the mode in use was within the limits of acceptance by the ground station under all conditions. The measurements of this spacing showed a maximum deviation of about 0.3 microsecond under all conditions of environment when checked on an interrogator which had been adjusted normally by test personnel under production-test conditions in use by the contractor. The only appreciable variation observed was under ambient-temperature variations from 0° C. to +60° C. when a change of −0.1 to +0.3 microsecond was noted in the Mode J spacing (77 microseconds), with the mean spacing measured at a room temperature of 27° C. This variation of spacing was the greatest recorded, because the temperature effect of the magnetostrictive delay line is greatest with long delays and is the largest factor in the variation of spacing in the interrogator. It is believed that with reasonable care in initial adjustment, the transmitter-pulse spacing can be maintained well within the ±1-microsecond tolerance of the ground station under all conditions for the greater portion of the life of the interrogator, with little or no adjustment.

The operation of the decoder was checked to determine that it accepted the expected deviation from the nominal value transmitted by the ground station without deterioration of performance. A further check was made to determine the degree of rejection of received pulse pairs of adjacent spacings (the next lesser and next greater spacing). The results of these tests are plotted in Fig. 9. The maximum rejection plotted is 50 db above normal tracking level, the value specified in Specification TD-125. At the time of the test, it was observed that in every case a further excursion of 0.5 to 1 microsecond from the mean value gave "infinite" rejection, or at least greater than the signal available for test purposes.

A further test of the decoder tolerance was made at temperatures from 0° C. to +60° C. A total change of 0.3 microsecond was recorded at the Mode A or 77-microsecond spacing in both upper and lower limits of the acceptance bands at minimum detectable level and 50 db above. A correspondingly smaller change was noted at shorter spacings. This change was attributed to the shift of nominal delay in the delay line with temperature rather than to any change in decoder action.

The accuracy of distance indication of the Model DIC interrogator was found to exceed by a wide margin the amended specification requirements of ±0.5 statute mile or 2.5 per cent, whichever is greater. Error curves taken from these data are shown in Fig. 10. The maximum error recorded in this test did not exceed 0.1 statute mile or 0.5 per cent on the 20-mile scale, and 1 statute mile or 0.5 per cent on the 200-mile scale, at a room temperature of 27° C.

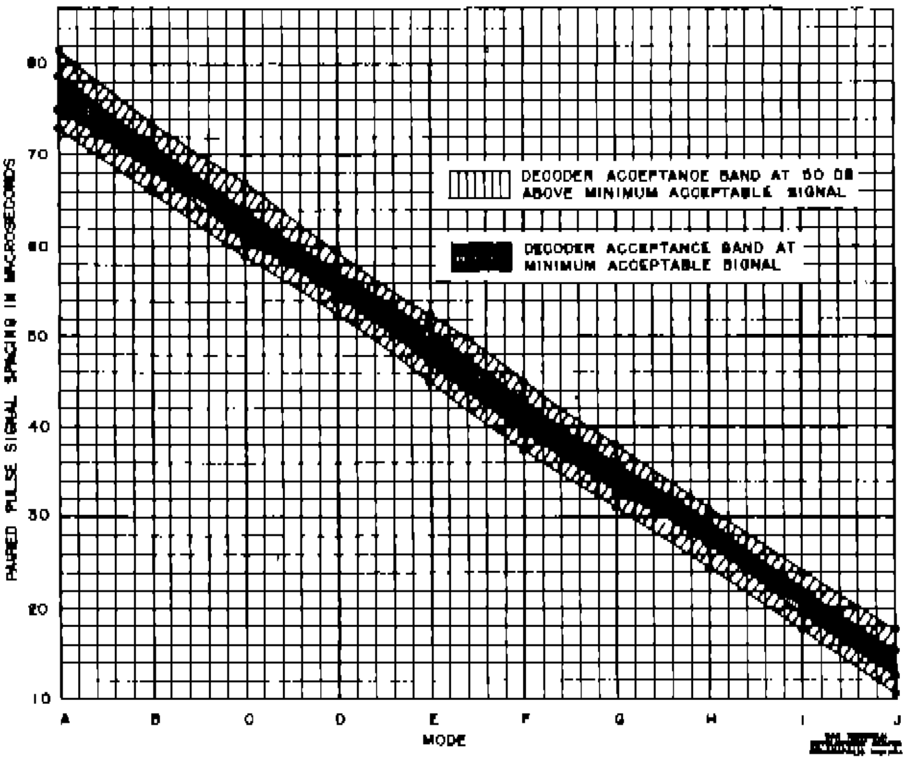

Fig. 9 Decoder Tolerance

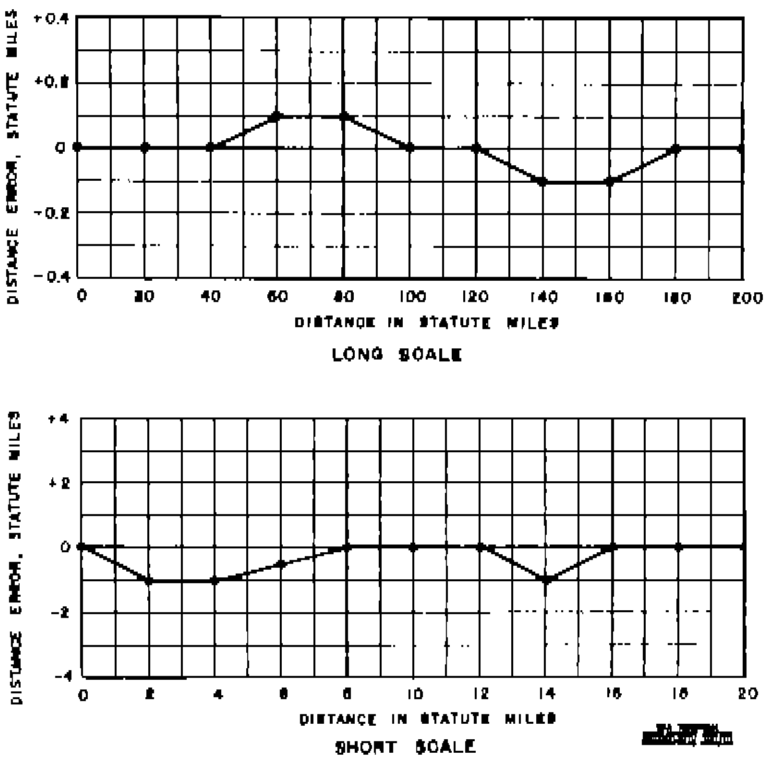

Fig. 10 Distance Error Curves

A shift of distance indication of 0.3 mile on the short range and 1 mile on the long range was observed when the ambient temperature changed from 0° C. to +60° C. This change was approximately the same when the temperature was reduced from +27° C. to 0° C. as when the ambient temperature was changed from +27° C. to +60° C. With careful original adjustment, therefore, the error introduced by temperature change could be held to about one-half the shift recorded. The error in distance indication with a ±5-per cent change of primary battery voltage was negligible.

The Model DIC interrogator was placed in an altitude chamber and the pressure was reduced to check its operation at high altitudes. The transmitter-output pulses were monitored continuously; and the search, lock-on, track, and memory functions of the interrogator were tested periodically during gradual pressure reduction to a simulated altitude of 30,000 feet. All functions of the interrogator remained normal up to 30,000 feet, when the transmitter output became intermittent, indicating arcing in the transmitter or other high-voltage circuits. The pressure in the chamber was lowered to a simulated 28,500 feet but the arcing continued, and the interrogator was shut off to prevent damage to the transmitter. Upon reaching room pressure, the interrogator was removed from the chamber and examined. No indication of damage or evidence of the arc-over point could be found. The interrogator then was placed in operation, and all functions of the interrogator were checked and found to be normal.

A number of tests were performed to determine the traffic-handling capacity of the unit. These tests were necessary because an interrogator, when operating on a ground station which is being interrogated by a number of other aircraft interrogators, must be able to sort or recognize the replies to its own interrogations. In addition to replies to other aircraft, it is possible that other ground stations using the same reply frequency may be within range of the aircraft. Any other transponders on the same frequency, of course, will be using another mode and receiving frequency. These unwanted and extraneous replies are unsynchronized and are known as fruit. In the case of replies to other aircraft from the same ground station, the fruit signals consist of pairs of properly spaced pulses. In the case of other ground stations on the same frequency, the fruit signals are improperly spaced. On a statistical basis, however, properly spaced pairs may be formed from improperly spaced pairs when individual pulses of different pairs bear the proper time relation to each other to form the assigned spacing. This process is known as "bunching."

Because the average rate per second of interrogation for all interrogators is assumed to be 30, and the maximum number of interrogating aircraft per transponder is 50, the properly spaced pulses used in the maximum fruit tests were at the rate of 1500 pairs per second. Because the bandwidth measurements of the receiver indicated that adjacent channel reception was possible and that this would allow additional fruit to enter the receiver, the maximum number of improperly spaced pairs was 6000 per second. The normal fruit level was one-half of these values, or 750 properly spaced pairs per second and 3000 improperly spaced pairs. In each case the spacing of the improperly spaced pairs was adjusted to the adjacent mode spacing; that is, 7 microseconds more or less than proper spacing. In all cases the fruit signals were adjusted to be at least 50 db above the normal reply-signal level, with normal replies held to minimum detectable signal level. The tests were accomplished by simultaneous insertion of properly and improperly spaced fruit signals into the receiver-antenna connection, in addition to the normal synchronized reply signal for the channel in use.

The pulse-repetition frequency (prf) or interrogation rate was reduced from the normal rate of 25 to 20 per second for these tests to simulate the worst possible case of interrogator-prf adjustment. A large number of readings were taken under both maximum and normal fruit conditions to eliminate the possibility of momentary erroneous readings due to the random nature of the unsynchronized signals. Each reading consisted of a complete search, lock-on, memory, and search re-initiation cycle so that all operational functions of the interrogator were checked. At each reading, the lock-on period was allowed to be of sufficient length to assure that the memory capacitor was completely charged, so that the maximum memory period to be encountered in actual interrogator use was generated.

More than 30 readings were taken under normal fruit conditions, and 40 were taken under maximum fruit conditions. No change in interrogator-performance characteristics was detectable under normal fruit conditions. Reply lock-on and track sensitivity, memory time, search time, and distance accuracy were recorded. The same tests, when repeated under maximum fruit conditions, resulted in a 4-db decrease in lock-on sensitivity and an average increase in memory time of about 2 seconds. On one occasion, the memory time was increased to 63 seconds. This condition was not repeated in 21 subsequent readings, however, and it was not considered to be a malfunction great enough to disable the interrogator under heavy traffic conditions.

At the conclusion of the fruit tests, a more accurate method of determining pulse rate was employed to check the fruit-generating equipment. It was found that the maximum fruit rates actually used were 6200 improperly spaced pairs per second and 1540 properly spaced pairs per second. The normal fruit rates used were found to be correspondingly high.

Flight Tests.

A number of installations of Model DIC interrogators were made in aircraft to evaluate the design and performance of the equipment in actual use. Three of these installations will be described.

A temporary installation was made in a Globe Swift aircraft. The main unit of the interrogator was installed in the baggage compartment. A small control box was constructed to house the channel selector, main power-control switch, and identity-indicator neon lamp. A small pushbutton switch was added to allow rapid repeated search when attempting to lock on to a ground station at less than 100 miles distance without requiring a search of the distances from 100 to 200 miles. After some experience with this installation, this control was not used in later installations. The control box was mounted on a shelf above the baggage compartment and within reach of the pilot.

The distance indicator was mounted on a bracket below the center of the instrument panel. This installation is shown in Fig. 11. A fuse holder for the external main fuse, mounted on a bracket below the lower right-hand corner of the instrument panel, is shown in Fig. 11 also.

All interconnecting cables were fabricated and bench tested with the interrogator before installation so that the installation was a simple one, and no difficulty was experienced in wiring. An existing one-quarter-wavelength stub antenna which originally was designed for use with the Model DIA interrogator was used in these tests. Because the Model DIC interrogator was designed for use with separate transmitting and receiving antennas, the two antenna connectors on the main interrogator unit were connected together and to the antenna by means of two short lengths of RG-58/U coaxial cable with UG-88/U (Type BNC) fittings on both ends and a UG-274/U (Type BNC) tee adapter fitting. No difficulty was experienced with this antenna arrangement, and performance was satisfactory during all of the tests.

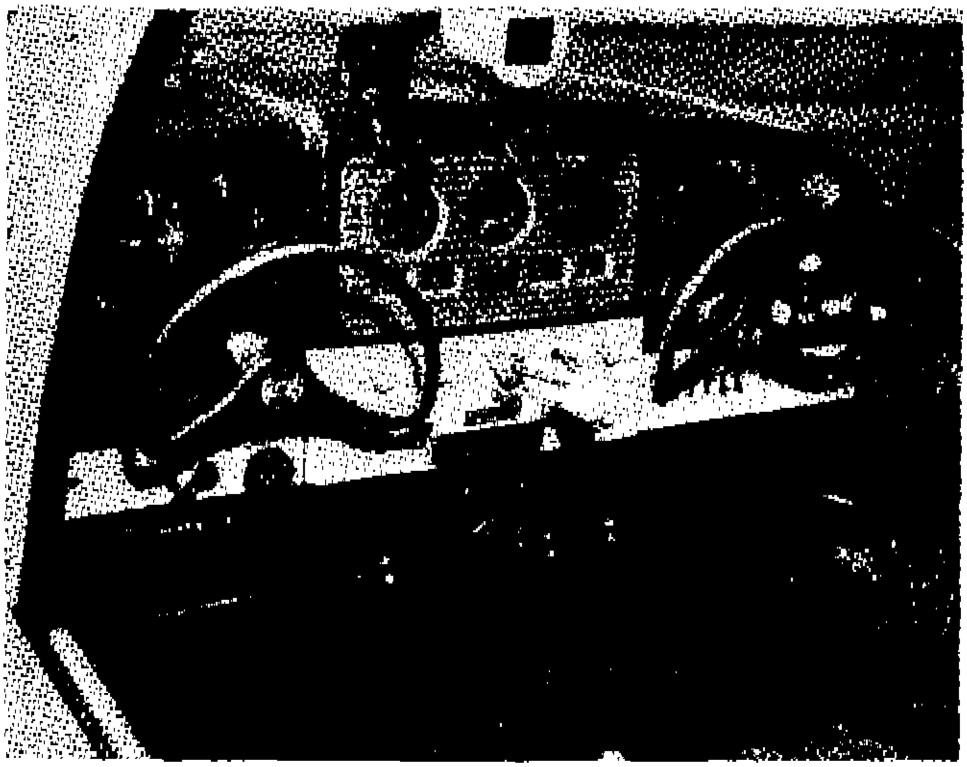

Fig. 11 Distance Indicator Installed in Globe Swift Aircraft

The electrical system in the Globe Swift aircraft utilizes a 12-volt battery and a 15-ampere generator. Some difficulty was anticipated with operation of the Model DIC interrogator because the total current drain of the unit is approximately 13 amperes when in operation. The anticipated difficulty did not arise, however, because care was exercised in the operation of the unit; and, except for short periods, the interrogator was operated alone, with all other electronic equipment in the aircraft turned off.

The Model DIC interrogator was operated in this installation for approximately 100 hours of flight time. During this time, observations were made on the performance of the unit as to distance accuracy, maximum ranges at various altitudes and on different ground stations, and the general reliability and usability of the equipment. The data recorded in the distance-accuracy tests are included, along with other flight-test data, later in this report.

Early in the tests with the Globe Swift airplane, it was considered desirable to accomplish modifications to the unit, if possible, to extend the low supply-voltage limits for satisfactory operation. It was found that when using the 13.5-volt connections to the unit, the low-voltage operation of the unit could be improved by shorting the 0.35-ohm filament-dropping resistor and by selection of the Type 5696 gas-modulator tubes. These changes allowed the unit to operate satisfactorily with a supply voltage as low as 11.5 volts rather than with the previous low limit of 12.75 volts.

Maximum outbound and inbound distance ranges were recorded on 13 ground stations. The results of these readings are tabulated in Fig. 12. In plotting these data, no consideration was given to the ground station and to the direction from the ground station. Experience has shown that these factors, as well as propagation conditions existing at the time, influence these readings to an appreciable degree. The data are presented as representative of the maximum ranges to be expected from the interrogator under actual operating conditions.

During this series of flights, several failures of component parts occurred in the equipment. These are discussed later. Due to the weight of the indicating instrument, 1.8 pounds, and to the arm with respect to its attachment point (see Fig. 11), some vibration of the instrument occurred during flight. This is believed to have placed excessively severe shock loads on the instrument movement. Two indicators which failed during the tests were returned to the factory for repair or adjustment. It might be significant that after examination of these and other indicators which failed, the manufacturer advised that changes have been made in the design and assembly techniques which improve resistance to shock and vibration. In this respect, appreciable failures have not been experienced with indicators received later from the same source.

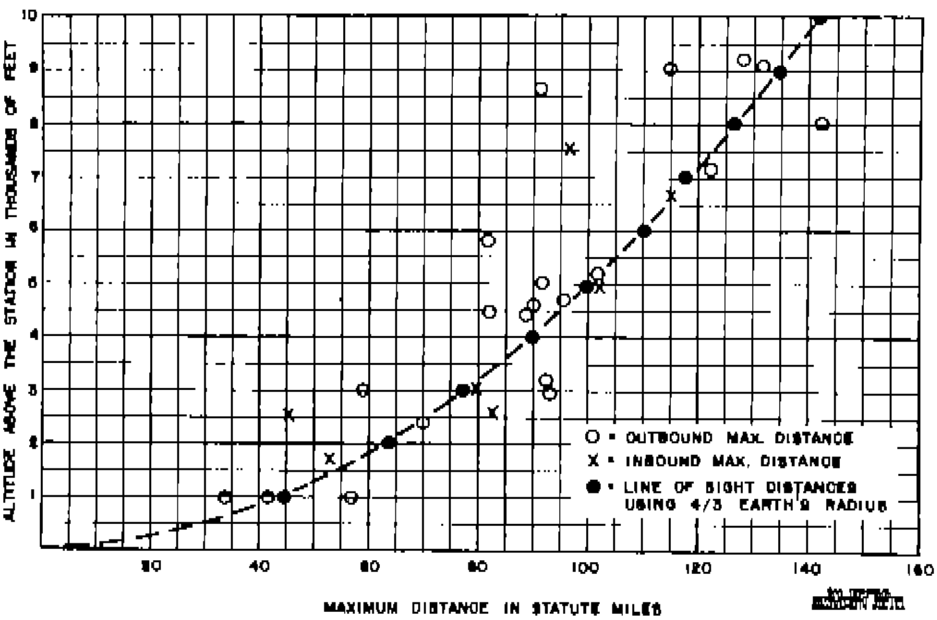

Fig. 12 Maximum Distances

A dual installation of Model DIC interrogators was made in a Douglas DC-3 aircraft, N-183. The main interrogator units were installed in the rear of an experimental equipment rack which extends well into the cabin of the airplane. The main interrogator location required about 42 feet of cable to the control box containing the channel selector and power switch. All control wires in this cable were No. 20 AWG wire; and, although contrary to recommended procedure, they permitted entirely satisfactory operation. The antennas used with both interrogators in this installation were one-quarter-wavelength broadbanded single antennas designed for use with Model DIB interrogators. Connections to the transmitting- and receiving-antenna connectors were made with short random lengths of RG-58/U coaxial cable, with a tee adapter fitting to a single RG-8/U transmission line about 18 feet long. The RG-8/U cable was used for the 18-foot length in this installation to reduce attenuation and to improve performance. Both indicators of the dual installation were mounted on the aircraft instrument panel. They were used on all flights after the equipment was placed in operation. The interrogator connections were arranged for the 27-volt supply in this airplane.

Data were recorded on the performance of this equipment, and many observations were made by pilots for approximately 252 hours of flight time. Maximum range performance was similar to that of the Globe Swift installation except that at altitudes of 5000 feet and above, longest ranges were about 5 per cent less than those observed in the Globe Swift airplane. Distance-accuracy data were recorded on these interrogators on a number of test flights, and these data are included later. Maximum lock-on ranges of 176 statute miles and outbound tracking to 182 statute miles have been obtained with this installation at an altitude of 10,800 feet above sea level. These observations were made just south of Louisville, Kentucky, operating on the VOR-DME ground facility at Crossville, Tennessee, which is located on a mountaintop with an elevation of 3048 feet above sea level. During the flight time on this installation, more than 60 ground stations were interrogated in the midwestern and eastern parts of the United States. At no time was failure to lock on or track due to frequency drift or "mismoding" (incorrect code or decode spacings).

During the flight tests of this installation, several equipment failures occurred. These will be discussed later in this report. One failure of an indicator movement was experienced; this was attributed to a defect in manufacture, because this aircraft was equipped with a shock-mounted instrument panel on which the indicators were mounted. This indicator was returned to the supplier for repair, and his investigation confirmed the assumption of a manufacturing defect.

A single installation of a Model DIC interrogator was made in another Douglas DC-3 aircraft, N-182. In this installation, the interrogator unit was installed in the regular equipment rack in the aircraft, and the indicator and control box were installed on a panel in the cabin for use by a flight-test engineer. This installation, although requiring relatively short control leads of less than 4 feet, required 38 feet of cable to the antenna location on the aircraft. The antennas used were the Type DIC/3 transmitting antenna and Type DIC/4 receiving antenna furnished with the interrogator. These were installed on the belly of the airplane near the trailing edge of the wing. The antenna cables used in this installation were RG-58/U coaxial cable.

About 80 hours of flight time were recorded on this installation. The distance indication and control of this interrogator were not available to the pilot or copilot of the aircraft, and they were used only when specifically useful or of interest to the flight engineer. The general performance of the equipment was below that experienced with other installations because the maximum distances of operation did not exceed 110 miles at altitudes of 10,000 feet above the station. Maximum distances of operation at lower altitudes did not seem to be affected as severely, because several ground stations within 100 miles of Indianapolis were tracked out to more than 40 miles at 1000 feet altitude above the station. The lower level of distance coverage of this installation was attributed to comparatively large attenuation in the two 38-foot lengths of the small RG-58/U antenna cables. Using the cable manufacturer's published data on attenuation of this cable, the attenuation due to cable loss was estimated to be 7 or 8 db at the frequencies in use. This amount of attenuation was effective on both the interrogation (transmitting) and reply (receiving) paths. It was somewhat surprising that the performance obtained was not degraded to a greater extent by the comparatively large cable loss involved.

A fourth installation of a Model DIC interrogator was made in a Beechcraft Bonanza airplane, Model A-35. The main unit of the interrogator was installed in the baggage compartment of the airplane. The shockmount was bolted to the plywood floor of the baggage compartment, with sheet-aluminum stiffeners under the mounting feet. The antennas used in this installation were the regular antennas designed for use with the Model DIC interrogator, Types DIC/3 and DIC/4. They were installed on the belly of the aircraft almost directly beneath the interrogator installation. This location of the antennas allowed very short lengths of RG-58/U cable to be used for both the receiving and transmitting antenna cables. The antenna cables in this installation were less than 18 inches in length. The spacing between the two antennas was 17 inches, and they were in a line perpendicular to the longitudinal axis of the airplane.

Due to lack of instrument-panel space, the channel-selector control, indicator, main power switch, and external main fuse were mounted on an auxiliary panel installed below the lower left-hand corner of the instrument panel. The control and indicator wires were No. 20 AWG wire. They were cabled and routed aft behind the upholstered trim on the left side of the cabin to the main interrogator unit in the baggage compartment.

The interrogator used in these tests was connected internally for 13.5-volt operation as the aircraft employs a 12-volt electrical system. The main power lead to the interrogator was connected to the electrical system beneath the instrument panel in the airplane. It was routed in the same manner as the control and indicator cables to the interrogator in the rear, after passing through the main power fuse of the DME on the auxiliary panel. This lead was No. 10 AWG wire designed to minimize voltage drop.

The installation in the Bonanza airplane was flight tested for approximately 119 hours, and it proved to be very satisfactory from the standpoint of maximum distance range. This was attributed to the short cable lengths used in the antenna connections and the relatively advantageous antenna location on the airplane. When in level flight with landing gear retracted, the DME antennas on the belly of this airplane are located very near the lowest point on the belly, with a clear, unobstructed radiation path in all directions. Maximum distances up to 188 statute miles were obtained with this interrogator installation, with numerous observations of more than 150 statute miles. The maximum of 188 miles was recorded on the Crossville, Tennessee, ground station (Channel 113.4) when flying at 13,000 feet msl about 20 miles from Owensboro, Kentucky. At this point the interrogator unlocked, and it failed to lock on at a greater distance. On this same flight the interrogator locked on solidly to the Crossville signal at 162 statute miles inbound, at 9900 feet msl near Hartford, Kentucky. Lock-on distances of 154 statute miles were obtained when inbound or tangential to the station at 12,800 feet msl on the Nashville, Tennessee, ground station (Channel 114.1) and 151 statute miles at 14,400 feet msl on the Indianapolis, Indiana, ground station (Channel 116.3).

All flight time in the Beechcraft Bonanza aircraft was accumulated with the same interrogator, and only one failure was encountered. A failure of the 15-second, thermal, time-delay relay unit in the power supply necessitated removal of the interrogator. This failure occurred at 83 hours. While in the laboratory for the relay replacement, checks were made on the interrogator, and the receiver sensitivity was found to have deteriorated to approximately 75 dbm from the sensitivity of 78 to 80 dbm at original installation. Replacement of a Type 6136 tube in the intermediate-frequency strip of the receiver restored the original sensitivity. The transmitter-power output also was found to be down to about one-half of its original value of 700 to 800 watts. Replacement of the two Type 5696 gas-tube modulators increased the output to its original level.

In cross-country flights, this installation of the Model DIC interrogator was flown in operation with most of the operating DME ground stations east of the Mississippi River, and satisfactory line-of-sight operation was secured on all stations. No failures to lock on or to indicate distance due to interrogator-channeling parameters occurred.

A quantity of actual in-flight distance-accuracy observations were made with all four of the Model DIC interrogator installations. These data, although probably not as precise as laboratory measurements, serve as a double check on laboratory-calibration methods and reveal gross errors or lag in tracking action not readily apparent with a reply signal of constant or static delay (distance) as used in ground-calibration methods. The lower order of precision of flight-accuracy checks is due primarily to pilot errors of up to one-fourth mile in estimating the exact position over a ground checkpoint, even at medium altitudes of several thousand feet, and to the less favorable environment existing for careful observation of the indicator, especially in the presence of appreciable turbulence. The results of these checks show an average error of 0.656 mile for 181 ground checkpoints. This average was taken without regard to negative or positive errors. Considering the direction of the error which would tend to cancel pilot errors in readings, the average error was -0.254 mile for the same readings. These observations were the result of the combined recorded readings of at least 8 persons, taken at altitudes of from 1000 to 8000 feet above ground and using a total of 9 DME ground facilities. The maximum error in miles was -2.5 statute miles at a distance of 72.5 miles from the ground station at approximately 4900 feet above the ground. On several occasions, errors of up to 0.4 mile were recorded directly over a ground station after correction for altitude. In the readings used in these averages, the larger errors all were recorded on the 200-mile scale, and nearly all were confined to distances below 100 miles. At the higher altitudes necessary to secure long-range operation, accurate determination of the time directly over a ground checkpoint becomes increasingly difficult. As a result, very few flight observations of accuracy were attempted at the longer distances.

As mentioned in the equipment description, the Model DIC interrogator incorporated a provision for reduction of transmitter-power output and receiver sensitivity when switching to the short or 20-mile-distance scale. This interrogator was the first and only design to make this feature available. The amount of reduction in both cases is adjustable by means of service adjustments on the bench. The provision for reduction of these characteristics of the interrogator was a result of difficulty with earlier interrogators, and with the prototype Model DIC, with multipath signals or "echoes." This condition occurred on both the interrogation (airborne transmitting) and reply (airborne receiving) paths, and it was caused by the arrival of signals from reflecting objects relatively near the ground antenna at either the interrogator or ground transponder-receiver input at a time after arrival of the signal by the direct path. These reflected signals or echoes followed the direct-path signal by a time interval equal to that required to travel the additional length of the reflected path. These reflected signals on the interrogation path, if of sufficient strength and at certain delays, can cause an erratic reply from the ground station; and in severe cases they will momentarily block all replies to an aircraft interrogation. Certain techniques have been developed at TDC and by Hazeltine Electronics Corporation, the major ground-transponder supplier, which when used singly or in combination will eliminate the effect of echoes at the ground station. A further improvement has been made by reduction of the transmitter power of the airborne interrogator at short distances where echo signals are most likely to occur and where full power is not required for interrogation.

The effect of reflected signals on the reply path is that of "confusing" the interrogator tracking gates. One or more extraneous reply signals with the proper spacing for decoding enter into the tracking circuits closely following the direct signal. Under these conditions the distance indication will fluctuate erratically, and in severe cases it will unlock completely during the time required for the airplane to travel several miles. At short ranges, a reduction in interrogator-receiver sensitivity will improve or eliminate this condition by aiding in discriminating against the unwanted reflected signals which are almost certain to have less strength than the signals via the direct path. Under some conditions of aircraft attitude, the strength of the reflected signals can exceed that of the direct-path signals; but these occurrences are rare, and the relatively short time in which such conditions prevail causes them to have no great significance.

Experience in flight testing the Model DIC and other interrogators has shown that any noticeable echo effect on interrogator operation is confined to a distance of a few miles from the station and that it varies with the position of the aircraft, the site, the mode spacing of the channel in use, and propagation conditions existing at the time of observation. It has been noted that multipath effects are present more often during temperature inversions (for example, early morning) and underneath stratus cloud decks at low altitude, although they are not confined to these instances nor are they always present on a given station during these conditions

With full transmitter-power output and receiver sensitivity, the Model DIC interrogator showed erratic distance readings up to 6 statute miles, both inbound and outbound, when crossing directly over some ground stations at low altitudes. Although this was observed in a small number of cases, it was considered significant and was observed on at least 3 separate ground facilities. At least once at each of 3 different stations, the interrogator unlocked and searched at distances of 2 to 4 statute miles upon crossing directly over and at 1000 to 3000 feet above the ground station, and it did not lock on again until a similar distance outbound was reached. These instances occurred early in the flight-testing period; as a result, an effort was made to determine the amount of output and sensitivity reduction necessary to eliminate the effects of multipath signals. By trial it was found that a reduction of transmitter-power output of the order of 10 db was excessive. Turns and shadowing of the direct-signal path by the airplane fuselage or wings caused drop-out of the tracking condition after expiration of memory. This occurred at distances of 15 to 20 miles from the station. A similar noticeable limitation of performance was observed with a 10-db reduction of receiver sensitivity. A reduction of 5 db in both transmitter power and receiver sensitivity was found to eliminate multipath conditions, but further tests were conducted to determine the minimum amount of reduction necessary. The final settings selected and in use during most of the flights on all airborne installations at TDC included no reduction in transmitter power and approximately a 5-db reduction in receiver sensitivity on the 20-mile range. The selection of these adjustments was governed, in the case of the transmitter, by the improvement in multipath rejection afforded in the ground-station receiver by echo-suppression circuits in a large number of stations, and because the frequency of the occurrence of echo interference has been observed to be less on the interrogation path. In the case of the receiver, at least a 5-db reduction has been necessary to reduce echo interference to a negligible level.

The results of these tests are difficult to assess owing to the large number of uncontrollable variables involved, and complete solution of this problem will require a large amount of flight experience on each ground station which exhibits a tendency to produce echoes. Early in the tests, complete failure of distance indication occurred in several instances; however, later flights using a reduction of 5 db in receiver sensitivity produced only erratic movements of the distance pointer of ±0.1 mile increments at not more than 4 miles inbound to or outbound from the station. In one comparative test of the Model DIC interrogator simultaneously with two other interrogator models in the same aircraft, the effect of reflected signals was less on the Model DIC than on the other interrogators. During this test the other two interrogators unlocked at 2 to 4 miles from the station at 1000 feet altitude and remained inoperative until 3 to 6 miles beyond the station; the Model DIC interrogator exhibited only erratic or "jittery" mileage indication from 2 miles inbound to 2 miles outbound. The degree of erratic readings did not exceed 0.2 mile. On several subsequent passes across the station with the Model DIC interrogator switched to the 200-mile range (full receiver sensitivity), it was observed that the multipath effects were greater on the Model DIC than on the other interrogators. Unlocking occurred 2 to 4 miles before failure of the other interrogators and persisted approximately 2 miles longer outbound. In a comprehensive flight-test program on multipath effects, one necessarily would be confronted with numerous difficulties. These include inability to control or forecast propagation conditions at the time of the test, and the necessity for treating each ground station as a separate problem with respect to reflecting or shadowing objects on the ground. For this reason, further flight tests to investigate echoes were limited to those occasions when appreciable echo effect was observed.

At the beginning of the flight-test program, the circuit-component failures exceeded the anticipated number. Investigation of these troubles was undertaken with the assistance and participation of the contractor. In a number of cases, minor circuit changes were incorporated by the manufacturer as a result of experience. These modifications were included in subsequent production units and in earlier units. Of appreciable value was the fact that the contractor continued to flight test and improve interrogators identical to those delivered under the contract during and after deliveries were made. The results of these flights were very helpful. After the initial high failure period was passed, reliability of the interrogators increased to a satisfactory level in a short time.

In general, no specific pattern of failures of certain components could be detected, although several component failures were repeated. The failures of two indicators in the Globe Swift installation and one in the installation in N-183 already were mentioned. In addition to these, two indicators were found defective when unpacked and tested, and these were returned for repair or replacement under the guarantee provisions of the contract. No detailed information on the cause of these defects is available, although no further indicator failures occurred after the first 75 hours of accumulated flight time on all units, indicating that the source of trouble has been eliminated.

The second most frequent cause of failure was shorted bypass capacitors in several circuit locations. In two interrogators the same capacitor, a bias supply bypass in the transmitter, shorted and removed negative grid bias, thereby damaging the selenium bias rectifier and isolating resistor and blowing the high-voltage fuse. In one case, the high-voltage fuse failed to blow, and cathode resistors of two transmitter tubes were burned by excessive cathode current.

Several other bypass capacitors failed in the receiver intermediate-frequency strip plate decoupling network and filament decoupling circuits. In every case of capacitor failure, the defective capacitors were glass, end-seal, hermetically sealed paper capacitors. These were a relatively new, high quality type designed for extremely high temperature operation. They were the product of a well known manufacturer. Initial production units of a few of the capacitor manufacturers which were incorporated in these interrogators were not representative of presently available units of this type. After the initial series of about six capacitor failures, a marked improvement was noted in reliability of these units.

Two failures of the antenna assemblies occurred due to fatigue, which caused brass radiator rods to break off at the point of attachment to the center conductor. This failure was traced by the contractor to excessive play in the Teflon insulators used in the original antennas. Later units were supplied with a nylon insulator which held the radiator rod more rigid and prevented movement of the rod under vibration. The improvement in antenna design was demonstrated by performance of the later units.

The other component failures were scattered, single occurrences such as a failure of a thermostatic time-delay plug-in relay, which was replaced by an improved unit in the later design; and failure of the transmitter power-adjustment potentiometer which was replaced by a four-position tap switch and fixed resistors in the later design.

Tube failures have been relatively small in number for equipment of this type and complexity. Two failures of Type 5696 modulator tubes occurred, and on another occasion two tubes were replaced to secure greater output from the transmitter. The low rate of tube failure is attributed to the large percentage of reliable tube types in the design, and it is believed to be an important factor in the high reliability achieved in the latest units produced. Several other tubes failed earlier in the program, but they were of different types.

CONCLUSIONS

It is concluded that development of the Model DIC interrogator has produced a new lightweight distance-measuring interrogator suitable for use by civil aircraft for air navigation and traffic control procedures. Introduction of direct crystal control to the interrogator has been a major contribution to airborne DME. Provision for reducing the receiver gain at short ranges is another advancement. The power requirement of the interrogator has been reduced from that of earlier designs to a practical value, making the equipment suitable for use in single-engine executive and personal aircraft. Of major importance is the fact that the same unit may be connected for either 13.5-volt or 27-volt dc supplies. No additional inverter equipment is required.

The Model DIC interrogator met and exceeded every requirement of Specification TD-125 and exceeded it in incorporating the design features mentioned as well as in accuracy of distance measurement. The maximum range performance of the interrogator exceeded expectations.

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.

1.3 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 required 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 Paragraph 2.5.5.1, Wide Bandwidth.

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 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.

2.6.1.1 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 with ±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, or 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)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
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.

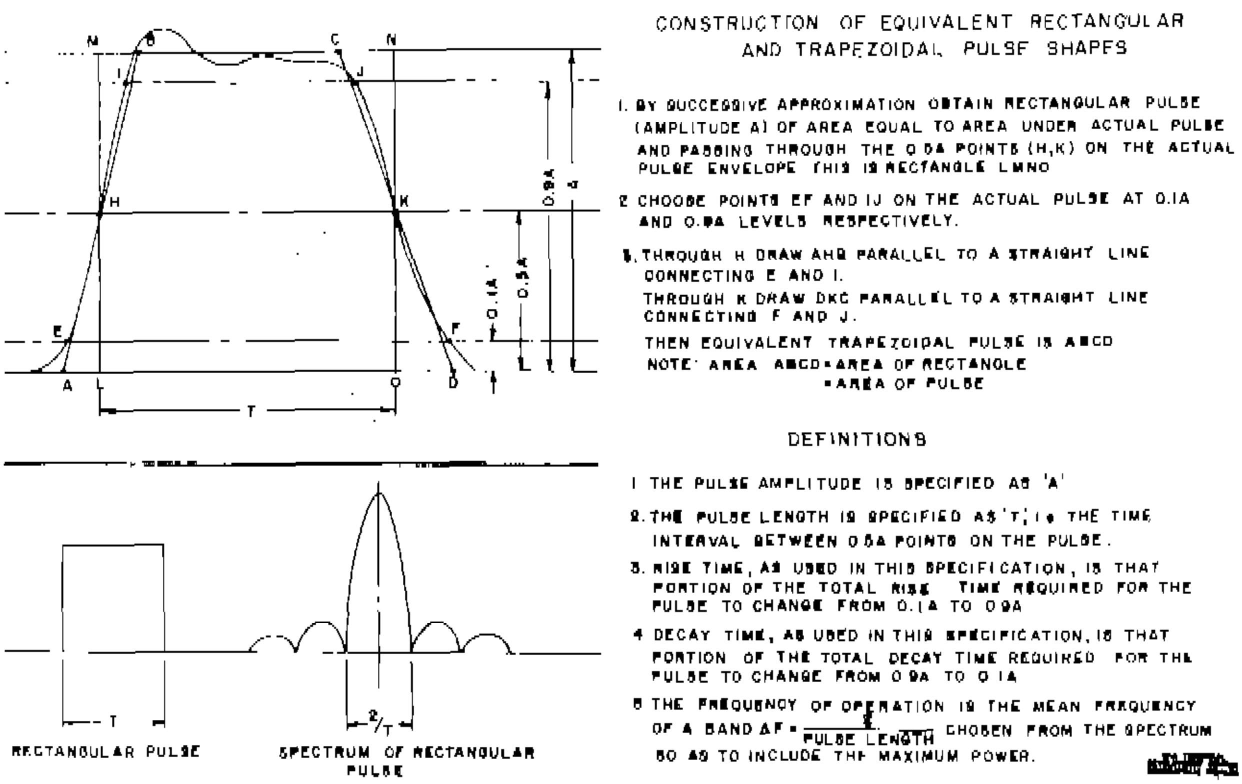

Fig. 1 Definition of Pulse Shape and Radio-Frequency Spectrum