A TVOR AUTOMATIC-REBROADCAST SYSTEM

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SUMMARY

This report describes the development and testing of a TVOR automatic-rebroadcast system developed at the Technical Development and Evaluation Center, Indianapolis, Indiana This system provides a means whereby pilots who are using a TVOR facility on an airport which does not have a control tower or at which the control tower does not operate 24 hours a day may broadcast by radio an abbreviated flight plan which is rebroadcast by the TVOR This rebroadcast is then picked up by any other aircraft which is operating within that area and which is tuned to the TVOR facility Thus, all aircraft concerned can exchange pertinent information and can work out their own landing sequence or other traffic-separation problems

The automatic-rebroadcast system consists of the interconnection of a number of receivers tuned to prescribed communications frequencies in such a manner that aircraft transmissions on these frequencies are received and are rebroadcast on the TVOR frequency The system incorporates a priority handling of rebroadcasts and an automatic nonmandatory acknowledgment signal transmitted after each rebroadcast Standard control-tower receivers are employed, and the receiver modifications introduced to incorporate priority operation for rebroadcast do not change receiver characteristics with regard to sensitivity and reliability

The operational experience gained during the nine months of operation at Indianapolis indicates that the proposed application of an automatic-rebroadcast system as a means whereby pilots may set up their own traffic separation under certain conditions is entirely feasible

INTRODUCTION

The experience gained in the operation of very-high-frequency (VHF) omniranges indicated that there are many advantages to be gained by placing a VOR on an airport This led to the development of the terminal VHF omnirange, or TVOR[1], which offers accurate and reliable guidance for aircraft descending under instrument-flight-rule (IFR) conditions to minima that will place the aircraft in a position to land on a runway when the pilot establishes visual contact with the airport. The TVOR is not to be regarded as a precision-approach aid such as an instrument landing system (ILS), however, it offers more accuracy and more reliability under atmospheric static conditions and offers more ease of navigation and of orientation than any low-frequency or medium-frequency aid currently in use There are several advantages to TVOR installations on airports For example, many airports in the United States with low traffic density are serviced by commercial air carriers which are now being operated under visual-flight-rules (VFR) conditions only because of a lack of nearby aircraft navigational facilities The installation of a TVOR on these airports would be of tremendous aid in completing flights to these airports under IFR conditions However, the installation of TVOR facilities at low-traffic-density airports, most of which have no control tower, presents the problem of how to insure that aircraft maintain adequate separation at locations outside of control areas

The automatic-rebroadcast system, developed at the request of the Office of Federal Airways, provides a means whereby aircraft intending to make an approach on a TVOR may announce this intention on prescribed air/ground frequencies and may have this transmission rebroadcast over the TVOR frequency in order that any other pilots using the same TVOR navigational facility may become aware of the existing traffic and, by means of communication via the rebroadcast equipment, maintain their own traffic separation

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*Manuscript submitted for publication March 1954

[1] S R Anderson and T S Wonnell, "The Development and Testing of the Terminal VHF Omnirange," CAA Technical Development Report No 225, April 1954

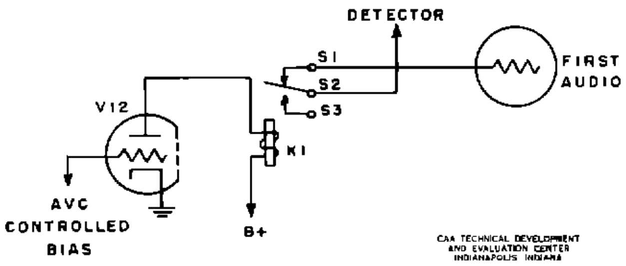

Fig 1 Carrier-Operated Relay Circuit for Type RUR Receiver

PRINCIPLE OF OPERATION

Basically, the automatic-rebroadcast system consists of circuitry which connects the audio outputs of three receivers to the speech amplifier of the TVOR transmitter Obviously, the employment of some priority-receiver operation circuit was required to assure that the first receiver energized by an r-f signal locks out the other receivers until the r-f signal is removed This prevents simultaneous rebroadcasts and consequent jamming

The automatic rebroadcast of air/ground communications over the TVOR is controlled by the action of carrier-operated relays in the receivers Each receiver incorporates a four-pole, double-throw, carrier-operated relay This relay operation is as follows No 1 pole activates and deactivates the receiver audio output, No 2 pole disables and restores the control bias circuit of the No 2 receiver, No 3 pole disables and restores the control bias circuit of the No 3 receiver, and No 4 pole disables and restores the TVOR identification and also charges an automatic-acknowledgment-circuit capacitor This circuit is described in detail later in this report

RECEIVER MODIFICATIONS

It was desired that the system would be capable of rebroadcasting messages received on any one of three frequencies, namely, 122 5 Mc, 126 7 Mc, and 3023 5 kc Two VHF and one HF receivers were obtained for this purpose

The VHF receivers are CAA Type RUR fixed-tuned receivers designed for aeronautical ground-station reception of amplitude-modulated radio-telephone signals and operated on a single preset crystal-controlled channel in the band 118 Mc to 136 Mc The receivers employ a double-conversion superheterodyne circuit and are equipped with automatic noise limiter, delayed and amplified automatic volume control, and carrier-operated squelch circuits The receivers are contained in a single enclosed vertical chassis unit with door panel for mounting in a standard 19-inch rack cabinet

The HF receiver used is a CAA Type RHZ fixed-tuned, single-frequency, ground-station receiver designed for the reception of radio-telephone signals from aircraft operating on a frequency to which the receiver has been pretuned in the range from 1,600 to 10,000 kc It employs ten tubes in a superheterodyne circuit with a crystal-controlled high-frequency conversion oscillator Automatic volume control, carrier-operated noise suppression, and a peak-noise limiter are incorporated

In order to keep receiver modifications to a minimum, it was decided to retain the carrier-operated relay circuitry as used in the VHF Type RUR receivers The basic diagram of this circuit is shown in Fig 1 When the receiver is turned off, continuity exists between relay contacts S1 and S2 When the receiver is turned on and the antenna is disconnected, V1 conducts and the plate current energizes K1, establishing continuity between relay contacts S2 and S3 When the antenna is connected to the receiver and the receiver is in normal operating condition, an r-f carrier causes an automatic volume control (AVC) voltage change which biases V1 to cut off and thus to de-energize the relay and establish continuity between relay contacts S1 and S2 Therefore, the modification on the Type RUR receivers consists of replacing the normal carrier-operated relay K1 with a four-pole, double-throw relay

Modification requirements for the HF Type RHZ receiver are more extensive than for the RUR receivers and include the installation of a relay current control tube and a four-pole,

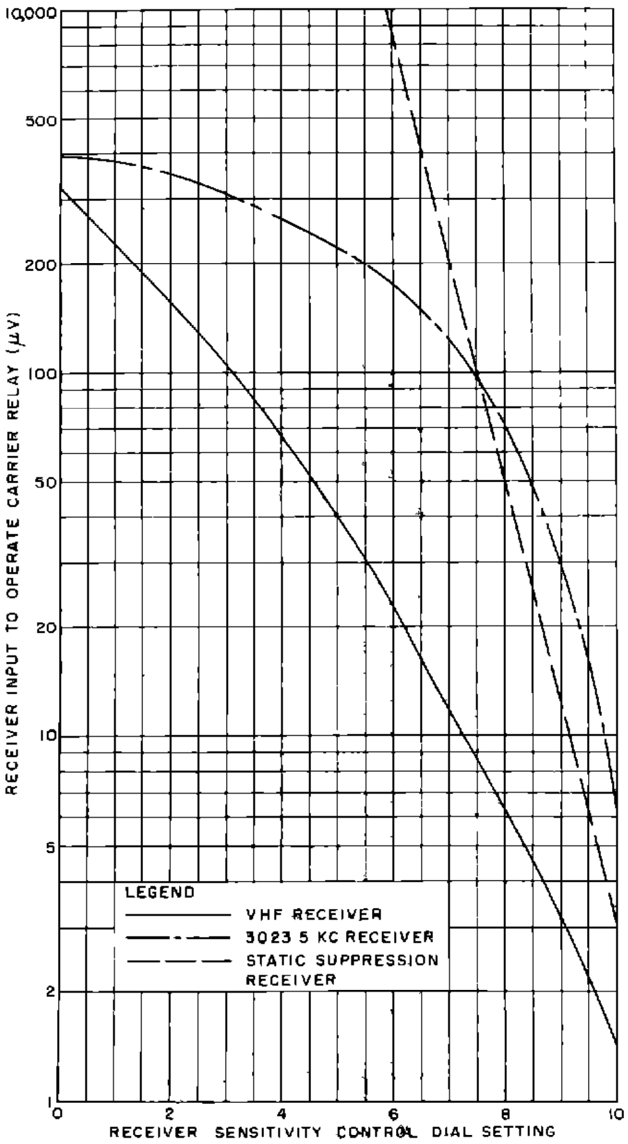

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Fig 2 Sensitivity of Relay Operation

double-throw relay After the receivers were modified, sensitivity curves were plotted Figure 2 shows the input signal, in microvolts, required to actuate the carrier-operated relay of the two types of receivers with varying settings of the receiver sensitivity control

The retention of the carrier-operated relay system of the Type RUR receivers, although greatly simplifying the receiver modification problem, introduced a new problem As indicated in Fig 1, the relay K1 has the switch contacts in the same position when the receiver is turned off as when the receiver is turned on and energized by an r-f carrier Therefore, it follows that, because of the priority system of interconnection, a receiver high-voltage power failure would disable the entire rebroadcast system This is prevented by installing, in conjunction with each receiver, a second four-pole, double-throw relay, and by energizing the relay field coil by the receiver-plate power supply The relay-switch contacts are connected to the carrier-operated relay so that a power failure of one receiver results in the failure of rebroadcast on one frequency only For further protection, the voltage to the field coil of the second four-pole double-throw relay must pass through the contacts of a relay, the field coil

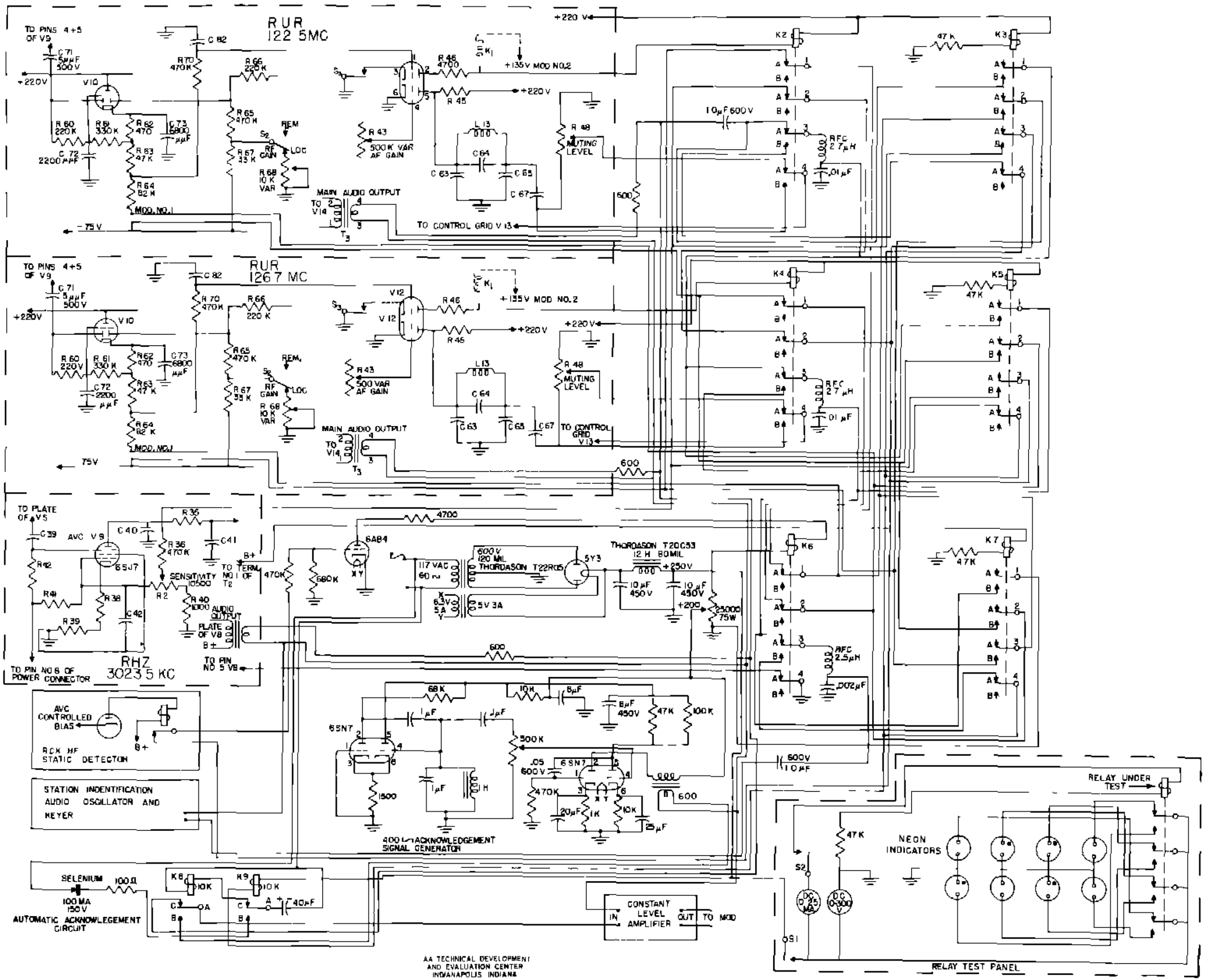

Fig 3 Automatic-Rebroadcast Circuit

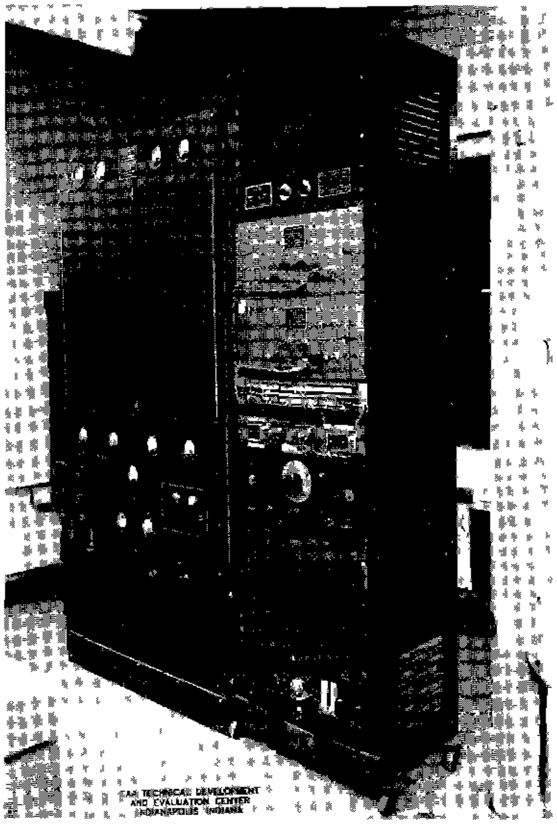

Fig 4 Automatic-Rebroadcast Equipment Installation

of which is in series with the filament of the triode control tube This prevents a burn-out of a control-tube filament from disabling the entire rebroadcast system Figure 3 shows the receiver modifications and relay interconnections of the automatic-rebroadcast system, and Fig 4 is a view of the experimental installation

AUTOMATIC ACKNOWLEDGMENT CIRCUIT

Upon the completion of the modification and the interconnection of the three receivers, the equipment was installed at a TDEC experimental VOR facility The preliminary tests conducted on the automatic-rebroadcast system immediately revealed the necessity for including some type of acknowledgment information

It became obvious during the early tests that a pilot was unable to hear his own rebroadcast during the time of his transmission If the aircraft was equipped with two or more receivers, the pilot was unable to distinguish between rebroadcast and transmitter side tone On the other hand, in a small aircraft equipped with a transceiver-type radio, the receiver was de-energized during the period of transmission, as a result, the pilot could never be certain that his transmission had actuated the automatic rebroadcast equipment unless he received a reply from another aircraft as a direct result of transmission

A solution to this problem was found in the inclusion, in the automatic rebroadcast equipment, of circuitry which causes a 400-cps tone signal of three-second duration at the conclusion of each transmission which actuates any one of the three receiver carrier-operated relays The acknowledgment circuit, which consists of two single-pole, double-throw relays and accompanying components, is shown in Fig 5

When any one receiver is actuated by an air/ground radio transmission, the fourth set of double-pole, single-throw contacts on the carrier-operated relay completes a circuit and energizes relay K9 which breaks contacts A-C and makes contacts A-B This charges condenser C1 Upon completion of the radio transmission, the receiver carrier-operated relay

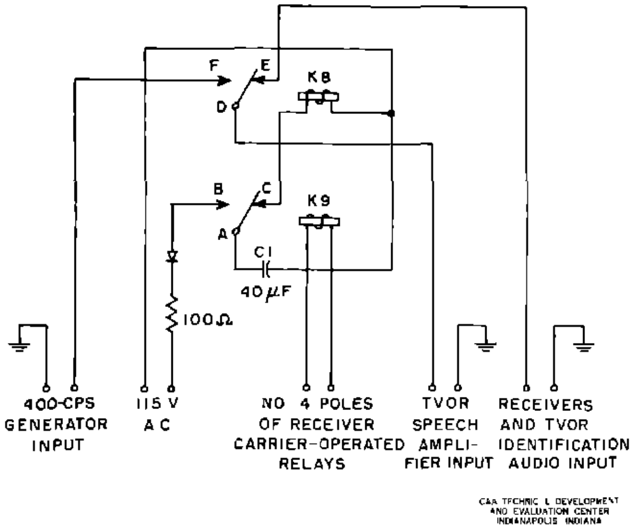

Fig 5 Automatic-Acknowledgment Circuit

de-energizes relay K9, which opens contacts A-B and closes contacts A-C This places the charged condenser C1 across the field coil of relay K8 The discharge of condenser C1 through the K8 relay field coil energizes the relay for a period of three seconds, breaking contacts D-E and making contacts D-F which complete the circuit from the 400-cps generator to the TVOR speech amplifier At the end of three seconds, the condenser C1 is discharged to the point where the relay spring returns its contacts to the normal nonenergized position The system is then ready for the next rebroadcast

The acknowledgment circuit is so designed that the three-second acknowledgment signal is not mandatory at the completion of each transmission If receivers are energized in rapid succession, condenser C1 has no opportunity to discharge through the relay field coil K8 Furthermore, the 400-cps acknowledgment tone may be interrupted while being transmitted at any moment during the normal three-second period of time In actual operation, the acknowledgment signal is a nonmandatory device signaling the pilot that his transmission has actuated one of the receiver carrier-operated relays at the TVOR

The selection of the 400-cps acknowledgment tone was based on the results of tests conducted to determine what audio frequency would provide a distinctive acknowledgement signal It was originally intended, in the interest of economy, to use the 1020-cps TVOR identification oscillator as a source of acknowledgement signal The automatic rebroadcast equipment was placed in operation using the same 1020-cps audio oscillator for acknowledgement and identification The operation of this equipment was observed for a trial period This arrangement proved to be very unsatisfactory and had sounded as if the keying motor had stuck momentarily after each rebroadcast No clear and distinct acknowledgement signal was evident After this trial period, a Hewlett-Packard audio oscillator was introduced as a source of acknowledgement signal, the frequency being varied above and below the 1020-cps identification signal It was determined that the most distinctive acknowledgement tone was a signal with a frequency of approximately 400 cps A 400-cps oscillator was designed and installed

LABORATORY TESTS

Relay Tests

The sensitive relays which are employed in the automatic rebroadcast system for carrier operation control are Potter and Brumfield 10,000-ohm, Type MN 17 DM, four-pole, double-throw relays The installation and preliminary check of relay operation revealed very satisfactory operation electrically A test set-up was then constructed to detect electrical or mechanical failure of the relays For this test, three r-f generators were turned on and off in

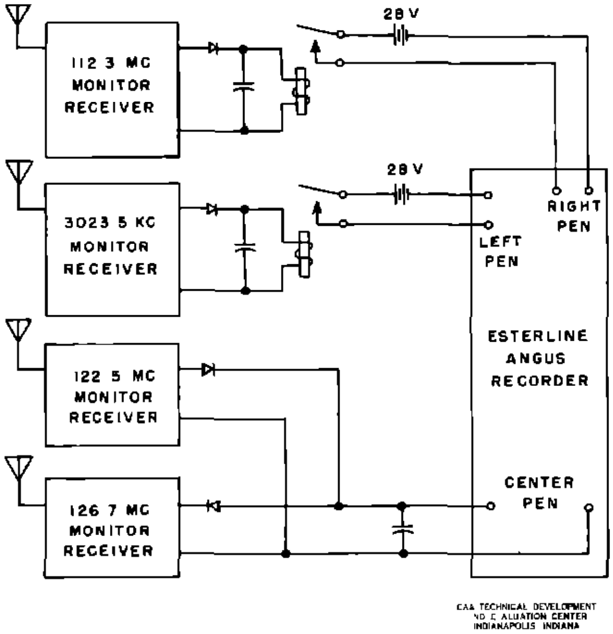

Fig 6 Automatic-Rebroadcast-System Monitor

sequence to energize in turn each of the receiver carrier-operated relays A 1000-cps audio oscillator and modulator was common to each r-f generator, and a second audio oscillator simulated the TVOR identification signal The receiver audio outputs were paralleled, rectified, and connected to an Esterline-Angus recorder The individual audio-output levels of the three receivers were adjusted to three easily identifiable levels of output on the recorder By this method, the recorded pattern of a full day's operation could be accurately examined in a few minutes This test was continued during working hours in the laboratory for a period of six weeks During this time, there were approximately 100,000 operations of each of the three relays during which time no mechanical or electrical failure occurred

Monitor Tests

With the installation of the automatic rebroadcast equipment in an experimental TVOR facility at TDEC, a monitoring device was constructed and installed in a laboratory approximately 2000 feet from the TVOR Figure 6 is a semiblock diagram of this monitoring equipment

In operation, the four receivers are tuned to the three guarded communications frequencies and to the TVOR frequency The rectified audio from two receivers actuates relays which energize the left and right marking pens of a recorder The rectified audio of the other two receivers is connected with reversed polarity to the center recording pen Thus, audio output from one receiver causes the pen to move to the left, and audio output from the other receiver causes the pen to move to the right In this manner, four recording operations were obtained with the use of one recorder With this monitoring equipment, it was possible to obtain a permanent record of transmissions on the rebroadcast guarded frequencies and then to check to see if a recorded rebroadcast was obtained from the TVOR This monitoring equipment was operated for a period of two months and provided valuable information as to the reliability of the automatic rebroadcast system

THE HF-STATIC PROBLEM

The inclusion of the prerequisite that the frequency of 3023 5 kc must be guarded in the automatic-rebroadcast system presents a serious problem concerning the effect of atmospheric and precipitation static Precipitation static at times produces very high level r-f signals Such signals actuate the 3023 5-kc carrier-operated relay continuously for a period of time which may last for many minutes Because of the priority operation of the receivers, when precipitation static energizes the 3023 5-kc receiver the two VHF receivers are locked out of the system Thus, in effect, precipitation static effects a breakdown of the entire automatic rebroadcast system

The solution to the static problem consisted of installing a second high-frequency receiver which incorporates a carrier-operated relay This second receiver is tuned to an adjacent channel and has the carrier-operated relay connected to the first high-frequency receiver as shown in Fig 3, so that static received by the No 2 HF receiver disables the No 1 HF receiver This prevents static in the No 1 HF receiver from disabling the two VHF receivers Under conditions of precipitation static, the two VHF receivers are free to operate in the normal manner but the 3023 5-kc channel remains inoperative until the static condition subsides

The static-suppression receiver installed is a Type RCK receiver which is tunable over the 200- to 400-kc band and also from 1 3 to 30 Mc in four bands The modification of this receiver included the installation of a relay current-control tube and a relay The r-f input to the static-suppression receiver required to energize the carrier-operated relay is shown in Fig 2 The setting of the sensitivity control on this receiver was established experimentally To date, on two occasions the effect of precipitation static has been observed, and a sensitivity control setting of position eight (55-microvolt input) was required in each case to energize the carrier-operated relay

RECEIVING ANTENNAS

Two receiving antennas are required for the automatic-rebroadcast equipment, one for the HF receivers and another for the VHF receivers Special consideration must be given to the effect of receiving antennas on TVOR performance It is well known that objects which contain horizontal members and which are in the immediate vicinity of the TVOR produce course errors and scalloping in an amount dependent upon their size and their distance from the TVOR This fact dictates the use of a rigid vertical VHF antenna

In a previous investigation, the effect of vertical conductors in close proximity to a TVOR was studied One test consisted of mounting an adjustable aluminum mast on a truck and driving around the TVOR with the mast approximately ten feet from the counterpoise edge The height of the mast was varied during these tests from 26 to 16 feet TVOR azimuth recorded at this time showed no effect resulting from the placement or height of the mast

A second test was conducted to determine the proper location of a two-stack coaxial communications antenna at a TVOR site This antenna extended ten feet above the counterpoise, and tests conducted by moving the antenna around the counterpoise at a distance of 17 feet from the TVOR antenna revealed that no bearing errors resulted However, a slight increase in TVOR polarization error was measured This error was removed by moving the antenna to a point 60 feet from the TVOR antenna Theoretical computations revealed that a vertical radiator two inches in diameter and 25 feet high located 60 feet from the TVOR antenna would produce 0 063° course scalloping in a TVOR

The required use of vertical receiving antennas is entirely compatible with the polarization characteristics of aircraft VHF transmitting antennas All aircraft VHF transmitters use a vertical antenna or an antenna which produces a vertically polarized radiation component The VHF receiving antenna used in the experimental automatic-rebroadcast installation at TDEC consists of a three-stack coaxial vertical antenna located 60 feet from the TVOR

The HF antenna may be either horizontal or vertical A long horizontal wire has no effect on TVOR performance if the wire extends radially from the TVOR antenna However, such an antenna would constitute a hazard on an airport Therefore, a vertical antenna consisting of a standard 20-foot nylon-guyed whip antenna and a CAA Type 1294 matching unit located 60 feet from the TVOR antenna was used

FLIGHT TESTS

Flight tests were conducted on the automatic-rebroadcast equipment in order to determine the maximum distance an aircraft could be from the TVOR and obtain an automatic rebroadcast The first test was a distance-range check of the two VHF frequencies, 122 5 Mc and 126 7 Mc The two Type RUR receivers at the VOR were connected in series to a three-stack coaxial vertical antenna which was tuned to 122 8 Mc Two airborne transmitters were used, a Collins

17L2 with approximately 6-watt output and an Aircraft Radio Corporation T-11 with approximately 1-watt output fed into a quarter-wave vertical antenna One transmitter is representative of an airline type, and the other is representative of a light-plane type

The flight test consisted of flying 1,000 feet above ground on a radial away from the VOR and pressing the microphone button every 10 seconds The microphone button was held down approximately 2 seconds and then released The 400-cps acknowledgment-signal reply provided the information that rebroadcast had been accomplished, and this procedure was continued on the outbound radial until the acknowledgment was no longer received The flight test was then repeated on the same radial headed toward the station

A similar flight test was conducted on 3023 5 kc The airborne 3023 5-kc transmitter consisted of a light-plane General Electric AS1B transceiver with approximately 10-watt output and connected to a fixed, long-wire, inclined antenna The flight-test procedure was identical to that used during the VHF tests The results of these flight tests are shown in Table I

TABLE I

Automatic Rebroadcast Distance Range

Type Transmitter	Power Output (watts)	Frequency	Distance Range: Headed To Station (miles)	Distance Range: Headed From Station (miles)
Collins 17L2	6 1	122 5Mc	40 8	40 6
Collins 17L2	5 7	126 7Mc	34 4	33 1
ARC T-11	0 8	122 5Mc	31 0	30 1
ARC T-11 (repeat data)	0 8	122 5Mc	30 0	29 6
GE AS1B	10 0	3023 5kc	10 1	10 7

OBSERVATIONS AND COMMENTS

The automatic-rebroadcast equipment has been installed at an experimental TVOR facility and has been operated approximately nine months During this time, a continuous observation of the rebroadcast operation has been conducted during working hours Several pertinent observations are noted

1 It has been observed that many aircraft transmissions have poor voice quality Undoubtedly this comes as no surprise to a control-tower operator, but it is an important factor when pilots begin setting up their own traffic separation Heretofore, they have listened to control towers and range stations which have good speech quality

2 The speech modulation of aircraft transmitters seems to vary from values of over 100 per cent to less than 10 per cent This great range in percentage of modulation makes it necessary to use in the TVOR a high quality, constant-level speech amplifier similar to that used at VOR facilities

3 The automatic acknowledgment circuit provides pilots with a very convenient method of checking their transmitters for output A momentary press of the microphone button, followed by the acknowledgment tone reply, gives the pilot immediate assurance of transmitter carrier output

4 The modification and interconnection of existing available receivers for use in the rebroadcast system is relatively simple One minor precaution should be observed, that is to provide for arc suppression at the relay contacts associated with the acknowledgment circuitry Arcing generates noise and eventually will produce contact failure Any noise generated by a relay enters the r-f section of the receivers, re-energizes the carrier-operated relays, and, in effect, sets up a feedback-type operation of the relays

CONCLUSIONS

The TVOR automatic-rebroadcast system described in this report is a straightforward and simple modification and interconnection of standard CAA-type communications receivers These receivers guard specified communication frequencies and rebroadcast signals received on those frequencies from the TVOR

The operational experience gained in nine months of operation of an experimental installation indicates that the proposed application of such equipment as a means whereby pilots may set up their own traffic separation is entirely feasible The reliability of the equipment is comparable to that of the communications receivers employed, and it proved to be excellent during tests conducted at TDEC The use of this system would be equally applicable in conjunction with a TVOR, VOR, or control tower where the control tower does not operate 24 hours a day

The VHF receiving antenna should be located not less than 60 feet from the TVOR antenna and should be of the vertically polarized type

It is strongly recommended that the guarding of 3023 5 kc be deleted from the automatic broadcast system for two major reasons First, the majority of aircraft equipped with VOR equipment also have VHF transmitters Second, the guarding of a high-frequency channel requires the installation of additional equipment to prevent the interruption of rebroadcast service during conditions of precipitation static

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