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The Hartlobe Airborne Dual Antenna System for IFF

Part 1 - Mark X (SIF) System

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Electronics Division

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Abstract: The experimental model (Plan 1) of the Hartlobe airborne dual antenna system for IFF which was successfully flight tested by NATC had an inherent problem caused by gain-time-control (GTC) action in the interrogator receiver. An improved model, designated Plan 2, which overcomes the GTC problem, has been developed. The GTC problem resulted from the fact that the bottom transponder was allowed to reply to all signals above its sensitivity threshold, while the top transponder was triggered only when the bottom unit did not reply. At certain aircraft aspects, the reply failed to register because of the GTC threshold. This problem was overcome by circuitry which compares the signal levels in the two receivers and directs the reply via the antenna which produced the strongest received signal. It is proposed to implement the Hartlobe system by utilizing components of the AN/APX-72 transponder or other lightweight transponder capable of easy separation into rf and video portions.

INTRODUCTION

The Hartlobe antenna system for airborne IFF transponders was designed to provide effective dual-antenna coverage. By comparing the outputs of two receivers of equal sensitivity which were connected to top and bottom antennas, it was planned to switch the reply to the antenna with the stronger interrogation signal. The object was to try to overcome loss of signal during aircraft maneuvers and thus obtain an effective omnidirectional response pattern. A more detailed discussion of the importance of the problem and the deficiencies of other proposed solutions, such as rapid switching between top and bottom antennas, will be contained in Part 2, to be published at a later date. Part 2 also will contain a further discussion of the application of the Hartlobe system to Mode 4 operation.

The Hartlobe dual-antenna-system project has been divided into two phases. The first phase covers the design and construction of experimental flight-test models for Modes 1, 2, and 3, using switching in the video circuitry (Plan 1 and Plan 2) and the design of circuits to accommodate Mode C and Mode 4. Phase one also covers the design of circuitry for switching in the rf antenna leads (Plan 3 and Plan 4). The second phase will cover the construction of an engineering model of Plan 2, utilizing components of the AN/APX-72 lightweight transponder or some other transponder of similar construction.

A previous report (1) covers the broad concepts of the Hartlobe system and describes the four different plans (*i.e.*, circuit arrangements) which NRL proposed to develop and test. This report covers the design, construction, and bench testing of experimental models for Plan 1 and Plan 2. The construction and testing of experimental models for Plan 3 and Plan 4 are to be accomplished at a later date.

Flight testing of the Plan 1 experimental model in an F-4A aircraft has been completed at the Naval Air Test Center, Patuxent River, Maryland (2). A summary of this previous work appears in this report. Flight tests of the Plan 2 model are proposed for the near future. Flight-test models were completed and delivered to NATC in July of 1964. Flight tests will be under the direction of NATC and when completed will be reported by that facility.

PLAN 1 DEVELOPMENT

The Plan 1 system as originally conceived (Fig. 1) utilizes two complete unmodified transponder units, together with a comparator circuit to measure relative signal strength, plus facilities for switching the interrogation trigger pulse from the bottom to the top unit. The purpose of

NRL Problems R03-04 and R03-05; Projects RAV 03R001/6521/R008-01-01 and RAV 04R002/6521/F001-10-01. This is an interim report on one phase of the problem; work on this and other phases is continuing. Manuscript submitted Febraury 25, 1966.

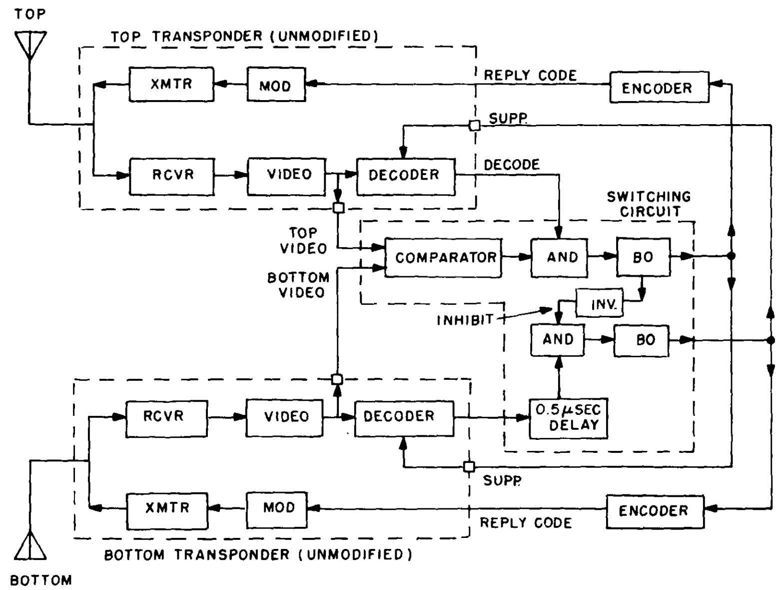

Fig. 1 — Hartlobe airborne transponder antenna system for IFF, Plan 1

the Plan 1 system was to utilize equipment currently available without modification. The main disadvantages, as reported previously (1), are: (a) the space requirements for two complete transponders at the present state of the art, (b) possible difficulty of meeting transponder delay and reply jitter requirements in this system using unmodified transponders in this manner, and (c) possible loss of close-in replies under certain conditions due to the effect of GTC action in the interrogator receiver on the IFF display. Nevertheless, it was felt that the Plan 1 approach offered a relatively simple method to test and demonstrate the basic principles underlying the Hartlobe system.

As development progressed on the Plan 1 system, it was found necessary to modify the basic design because the low dynamic range of the video signal outputs from the AN/APX-6B transponder receivers made it impractical to compare signal levels. In the revised system (Plan 1 modified), the comparator circuit has been eliminated and, instead, the bottom transponder is allowed to reply to all signals above its sensitivity threshold. The top transponder is permitted to reply only when the bottom transponder does not reply. Figure 2 shows the complete Plan 1 (modified) system for a single interrogation mode. A schematic diagram of the switching circuit is shown in Fig. 3.

The circuit operation of the system as shown in Fig. 2 is as follows. A signal at the bottom antenna sufficient to trigger the blocking oscillator in the bottom channel of the switching circuit will trigger the bottom encoder. When the bottom transponder replies, the top blocking oscillator in the switching circuit is momentarily suppressed, thus preventing trigger of the top encoder. A 0.25-μsec delay line is connected ahead of the top blocking oscillator to ensure that the inhibit action will precede the arrival of the trigger pulse from the top decoder. If, on the other hand, the signal at the bottom antenna is below the trigger threshold, the top transponder is free to reply to any valid interrogation whose signal strength is adequate to produce a decode.

Whenever the bottom transponder replies, the top transponder's decoder is suppressed by the blocking-oscillator pulse from the bottom channel of the switching circuit. In a corresponding manner, when the top transponder replies, the suppression pulse to the bottom transponder originates in the top channel of the switching circuit. This action prevents one transponder from receiving while the other is replying. Similarly, provisions are made to allow the Tacan equipment to suppress both transponders during Tacan transmissions.

In the system shown in Fig. 2, transponder delay jitter problems were overcome by means of a 0.30-μsec delay line in the bottom channel of the switching circuit. This delay line is necessary

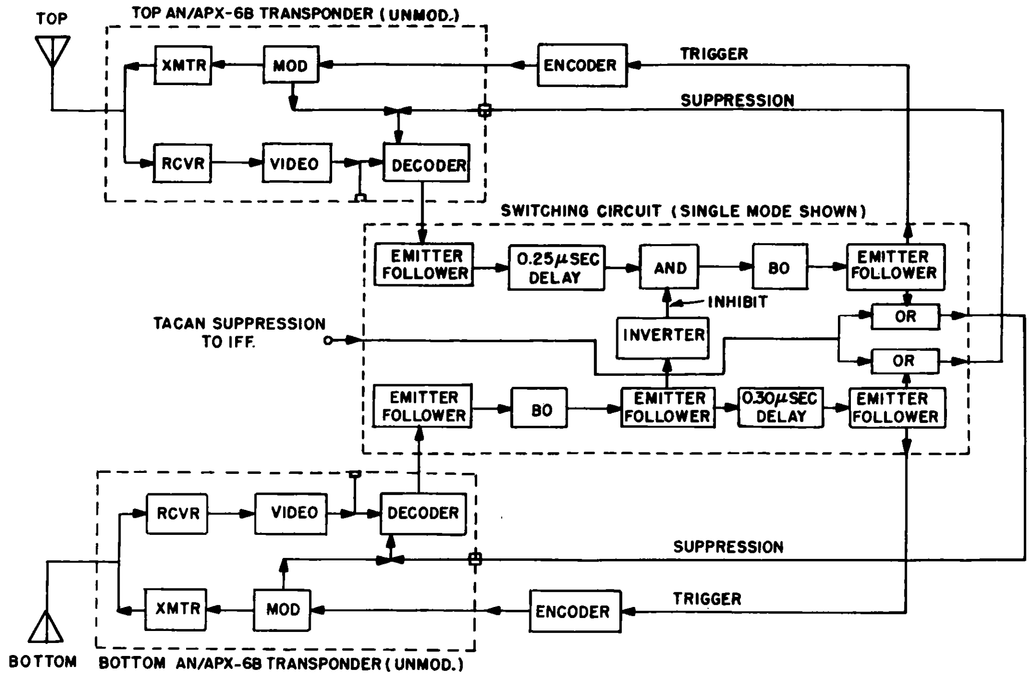

Fig. 2 — Hartlobe airborne transponder antenna system for IFF, Plan 1 (modified)

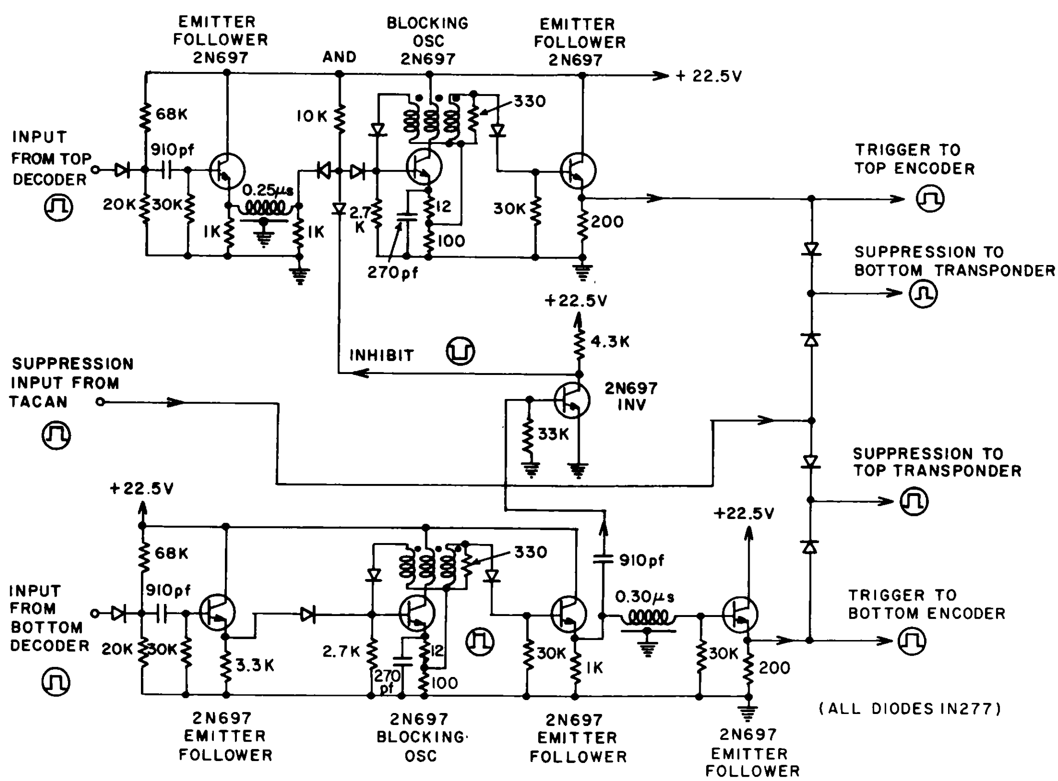

Fig. 3 — Plan 1 (modified) switching circuit

to balance the effect of the 0.25-μsec delay line in the top channel, so as to reduce transponder delay jitter during periods when replies are shifting from the top to the bottom transponder, or vice versa (*i.e.,* the transition period). It is essential that the two channels do not differ in overall time delay by more than 0.1 μsec.

Figure 4 illustrates the flight-test installation of the Plan 1 (modified) system. The transponders, encoders, and the box containing the switching circuits were installed in the rear-seat compartment of an F-4A aircraft. The rear seat was removed to provide space for this installation. The system was designed to allow the pilot to select at will either the conventional IFF system (KY-311, with lobe switching between bottom and top antenna) or the experimental (Hartlobe) system by means of a toggle switch added to the pilot's IFF control box. This switch was added to facilitate comparison of the Hartlobe system with the original lobing switch system and is not required for the final Hartlobe system. The toggle switch operates two rf switching relays which, in turn, switch the two antenna leads from the lobing switch to the AN/APX-6B units. The toggle switch also grounds the "standby" control lead from the AN/APX-6B control box to switch the AN/APX-6B units from "standby" to "normal." When the pilot energized the toggle switch during flight tests, he had to switch the KY-311 unit at the same time from "normal" to "standby" by means of the function switch on the same IFF control box, thus preventing the KY-311 unit from operating during Hartlobe system operation. Although the pilot had full control of the KY-311 unit by means of the function switch, the AN/APX-6B transponder power and control leads were arranged so that the experimental equipment had to be energized and placed on "standby" just before flight by ground personnel.

A serious drawback of the Plan 1 (modified) system stems from the fact that the choice of reply path is based not on which received signal is the stronger, but rather on whether the bottom receiver input signal is strong enough to trigger a reply. As a result, the bottom transponder may reply at close-in ranges for some aircraft aspects in which the received signal is much weaker than that of the top unit. For this condition, the reply power from the bottom antenna may be sufficiently weak at the interrogator site that GTC action in the interrogator receiver will cause the reply not to register. This situation is discussed in detail in Appendix A.

PLAN 1 FLIGHT TEST RESULTS

The Plan 1 (modified) system was flown on several occasions at NATC, Patuxent River,

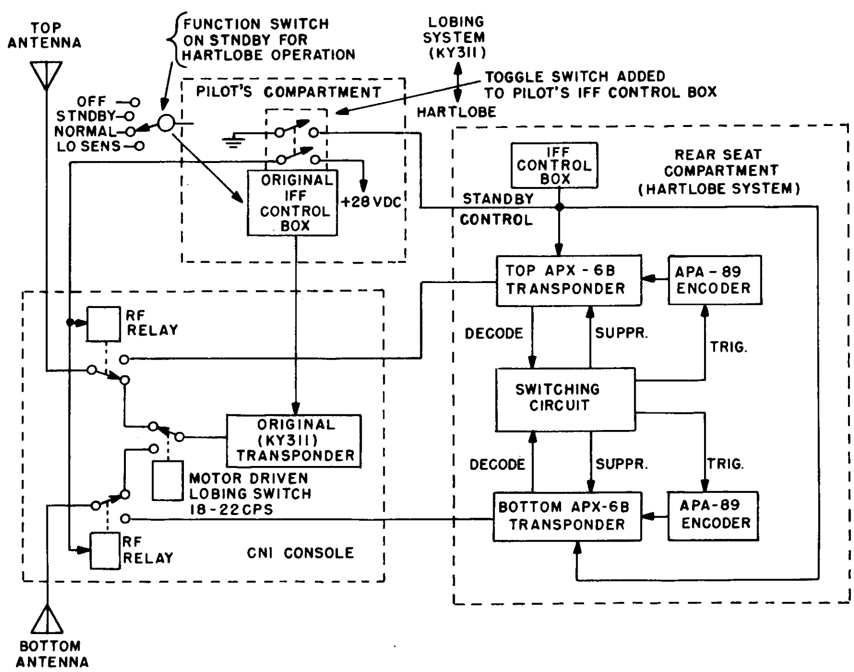

Fig. 4 – Flight installation of Hartlobe, Plan 1 (modified), and lobing switch systems

Maryland, twice against Sage facilities at Ft. Meade, Maryland, and against an E2A aircraft. Tests were under the direction of NATC; the test results can be summarized as follows.

During preliminary flights at Patuxent River it appeared that continuous coverage was obtained with the Hartlobe system throughout the 45-degree bank angle circles. However, as expected, for some aircraft aspects at short ranges (20 miles or less), bottom-reply strength was marginal. This behavior occurred whenever the bottom antenna was shadowed enough to cut the bottom receiver signal strength down near the trigger threshold level. In a few cases replies at close range were lost altogether due to gain-time-control (GTC) action in the interrogator receiver.

Limited Sage tests of the Hartlobe system were conducted in an F-4A aircraft while flying 45-degree bank-angle circles approximately 50 miles south of Ft. Meade, Maryland. During these tests the Sage computer target detector displayed a target symbol for 30 out of 30 successive antenna sweeps, with no split targets. Operation at 100 miles range resulted in nine hits (target symbols) for 12 successive antenna sweeps (75 percent hits).

During operation of the lobing-switch system, extremely low hit percentages were recorded (12 percent at 50 miles and 17 percent at 100 miles), but no split targets were displayed. Further tests indicated that the percentage of hits and the number of split targets were more directly affected by the computer target-detector threshold setting than by range. The test results demonstrated that a target threshold setting that recognized a target based on a smaller number of replies registered not only more hits but also more splits as well.

Data available from these tests are insufficient to provide a basis for evaluating the effect of transponder countdown, due to the operation of the lobing switch, on the number of misses and/or splits, since countdown can also be caused by:

1. Recovery time following replies to interrogations from other sites
2. AOC action due to overinterrogation rates
3. Transponder suppression by own Tacan transmitter.

A survey of interrogator sites, obtained through the cooperation of the Federal Aviation Agency, indicates that a significant amount of transponder countdown might have occurred due to overinterrogation. Since no circuitry was in use during these tests that would eliminate fruit (unsynchronized replies) or garbling (overlapping replies), and since only bracket decodes were used for target evaluation, loss of replies could not have been caused by either of these factors. It is significant that the lobing switch contributed sufficiently to the total countdown to produce a much higher percentage of misses for the lobing switch than occurred during operation of the Hartlobe system.

Favorable results were also reported for the Hartlobe system in flight tests with an E-2A aircraft. Unfortunately, insufficient data are available to allow detailed evaluation.

In summary, it appears that all objectives were met except at close range (20 miles or less). It is suspected that the occasional loss of signals at close range was due to GTC action in the interrogator receiver. This effect was anticipated. Plan 2 circuitry is designed to overcome this difficulty by comparing signal strengths in the two airborne receivers and replying via the preferred path in all cases.

PLAN 2 DEVELOPMENT

General

The purpose of the second step of this project was to design and build a system that could: (a) provide full capability with reliable operation in all three modes at all ranges, (b) provide a minimum of range jitter, and (c) demonstrate the use of a minimum of circuitry to result in a reduction of space, weight, and cost in production.

The Plan 2 system is shown in Fig. 5. As in the case of the Plan 1 system, it uses two transponder receivers and transmitters. However, only one decoder and encoder are required for Plan 2. A new switching-circuit assembly measures the relative signal strength in the two transponder receivers to decide whether to send the reply code from the encoder to the bottom or the top transmitter. In order to obtain relatively wide dynamic-range video for signal-strength comparison, each receiver is modified to make the video signal at the second detector available for external use in the comparator circuit. In order to use only one decoder, video outputs from the top and bottom receivers are mixed into a common decoder input channel. Only one encoder is needed to generate the reply code, which is electronically

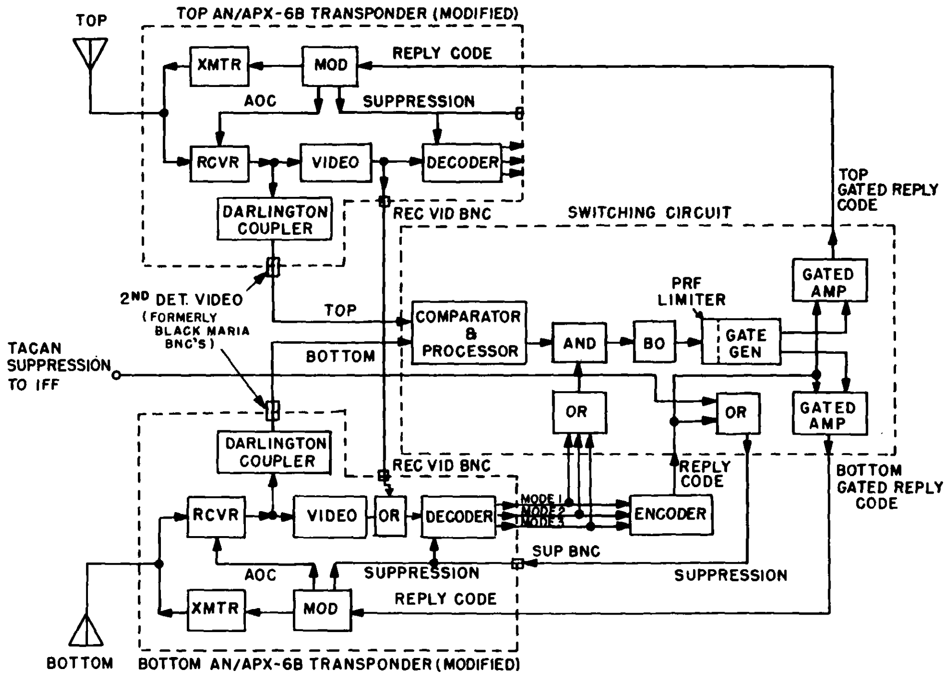

Fig. 5 — Hartlobe airborne transponder antenna system for IFF, Plan 2

gated to the bottom or top transmitter. Also, the decision and switching circuits are common to all three interrogation modes, which was not possible for Plan 1. The use of a common decision circuit together with elimination of one encoder results in an overall reduction of space and weight requirements for the entire system, as compared with Plan 1 (modified).

Since the Plan 2 system decides which reply path will be used by comparing the relative signal strength, it will avoid the difficulties previously encountered with the interrogator receiver GTC circuit. The Plan 2 system ensures that the reply is always transmitted by way of the stronger reply path. For this reason, it provides full reply capability at all ranges.

In addition, a reduction in range jitter during reply-path transition can be expected in the Plan 2 system as compared with Plan 1 (modified). This reduction is due partly to the use of a common decoder and encoder for both paths, and partly to the fact that signal levels in the two receivers are equal at transition. Both factors contribute to a reduction in reply delay differences.

A circuit difficulty encountered during tests of the Plan 2 system at NRL could lead to excessive triggering of the encoder and/or excessive bottom-transmitter duty cycle. However, the problem is not inherent in the basic Plan 2 system and can be eliminated by an improved circuit design, described in Appendix B.

Signal-Strength Decision

The decision as to whether to gate the reply code to the bottom or top transmitter is made by a decision circuit which consists of a comparator circuit, video processor, AND circuit, and blocking oscillator. The decision circuit is shown in block diagram form as part of Fig. 5 and in schematic diagram form in Figs. 7 and 9. The choice of reply path is based on the relative signal strengths of a valid interrogation, verified by the Mark X interrogation decoder in the transponder. The choice of reply path is based on only one video pulse of a valid interrogation, the last pulse, which occurs at almost the same instant as the decoder output pulse. Obviously, the choice of the reply path cannot be based on the signal strength of just any pulse, for reasons of susceptibility to interference and timing considerations. If the receiver video did not have to be verified by the interrogation decoder, then any rf signals at the receiver frequency, or manmade interference, or simply receiver noise, could cause an incorrect reply-path decision. If the decision were not made at the instant of the last interrogation pulse, but rather at any interrogation pulse (*e.g.,* the first pulse), then variation of delay between the reply-path decision and the last reply pulse could cause splitting of the reply code, so that part would be transmitted by the top antenna and the remainder by the bottom antenna.

Circuits

Video output for signal-strength comparison, as shown in Fig. 5, is coupled from the second detector through a two-stage emitter follower (Darlington) circuit to a BNC connector (formerly the Black Maria jack) on the front panel of the AN/APX-6B transponder. This output is capable of driving a 90-ohm cable, without affecting the signal, through the normal video path to the decoder. Figure 6 shows how the Darlington circuit was added.

In Fig. 5, the video outputs of the bottom and top receivers are shown mixed together by means of an OR circuit located inside the bottom transponder, just ahead of the bottom decoder. Actually, the VIDEO BNC's of the transponders are coupled together with a 0.47-μf capacitor. The effect of the capacitor when used together with the existing cathode followers in the transponder video output circuits is that of the OR circuit shown in Fig. 5. No modification of the existing video and decoder circuits is required. As a result, the bottom and top transponders may be interchanged without disturbing system operation.

Figure 7 shows the comparator circuit. The video pulses are fed from the Darlington circuits, which have been added to the AN/APX-6B units, into the video inputs of the comparator. For satisfactory operation, the comparator must have high sensitivity in order to compare relative signal strengths near the system sensitivity threshold, yet it must also have wide dynamic range, in order to operate close-in to the interrogator site. Accordingly, for improved sensitivity, it was found necessary to provide two stages of differential amplification.

The transistors of the first stage operate close to cutoff at zero signal, so that for a given B

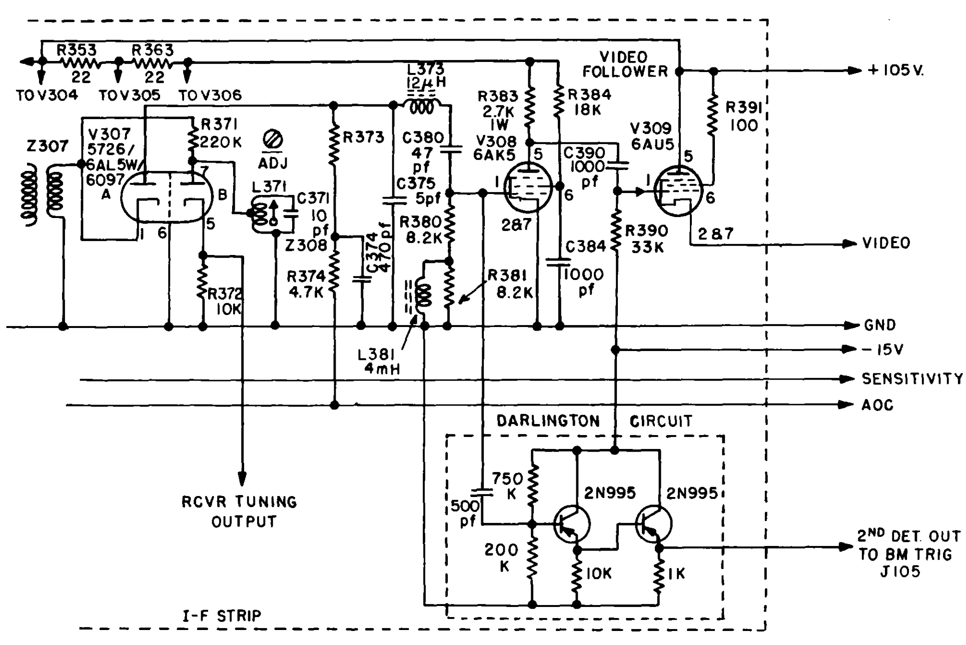

Fig. 6 — Plan 2, Darlington circuit added to i-f strip in AN/APX-6B transponders

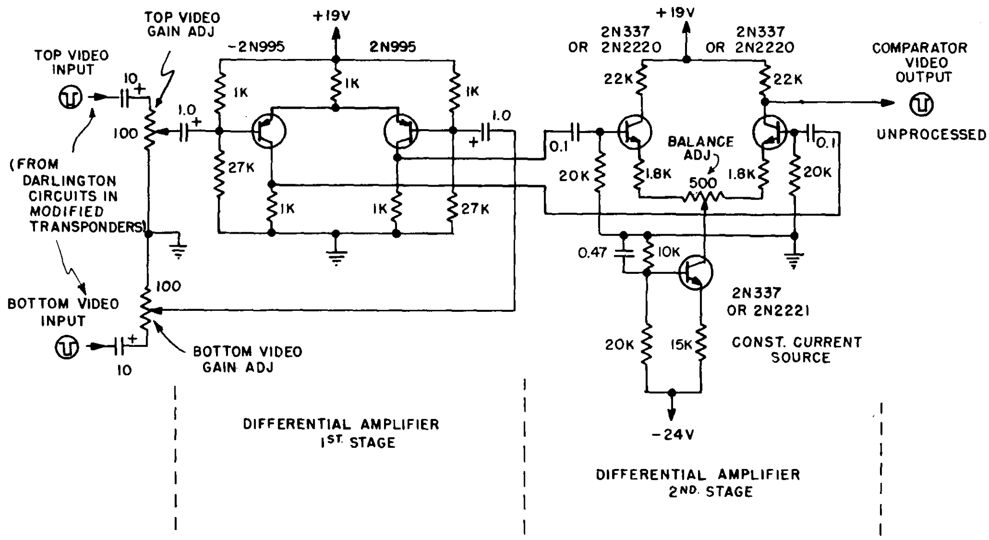

Fig. 7 — Plan 2, comparator circuit

supply voltage, the first stage is capable of wider ranges of signal input level without saturation. The first stage operates more nearly as a ratio amplifier than a differential amplifier, due to the emitter circuit used, so that saturation of the second stage at high input-signal levels is avoided by reducing the effective amplification of the lesser input signal.

The first stage does not provide common-mode rejection. This necessary function is performed in the second stage, which utilizes a constant-current source in the emitter circuit, rather than a resistor, for improved common-mode rejection.

The comparator and processor circuits are so designed that the reply will be transmitted by way of the bottom path if the bottom signal is equal to or stronger than the top signal. Only if the top signal is stronger than the bottom signal is the top antenna used for reply. In general, there is a gray zone near the condition of equal top and bottom receiver signal strength for which replies may be transmitted by way of either path. This gray zone is shown as a function of the applied rf signal level in Fig. 8, which shows the results of bench tests using typical AN/APX-6B transponder receivers. For the purpose of these tests, the two receivers were adjusted for equal trigger threshold sensitivities.

At any given bottom receiver rf signal level, the reply-path transition error can be found from the gray-zone curve shown in Fig. 8. By transition error is meant a reply on the antenna not receiving the strongest signal in the region where signal levels are nearly equal. At longer ranges (low rf level), transition error is chiefly due to the gray-zone width, caused by receiver noise, since the two receivers are adjusted for equal trigger threshold sensitivities.

At progressively shorter ranges (and higher signal levels) gray-zone width decreases, but the bottom transponder full-firing boundary of the gray zone begins to bend away from the condition of equal top and bottom receiver input levels. Generally, gray-zone bending is caused by differences in receiver gain characteristics and output pulse shape of the two receivers. The gray zone may bend in either direction, depending on the characteristics of the particular transponder receivers used.

Finally, at quite close range, the rf signal strength at either receiver may exceed the receiver saturation threshold, so that the video output amplitude from the receiver is no longer an accurate measure of receiver threshold. For these close ranges, transition error may be expected to increase somewhat.

Figure 8 shows that a maximum gray-zone width of 2.5 dB occurs at sensitivity threshold. Maximum gray-zone bending (representing the maximum error for the bottom antenna path) is less than 4.0 dB. At any given range, the sum of the gray-zone width and gray-zone bending,

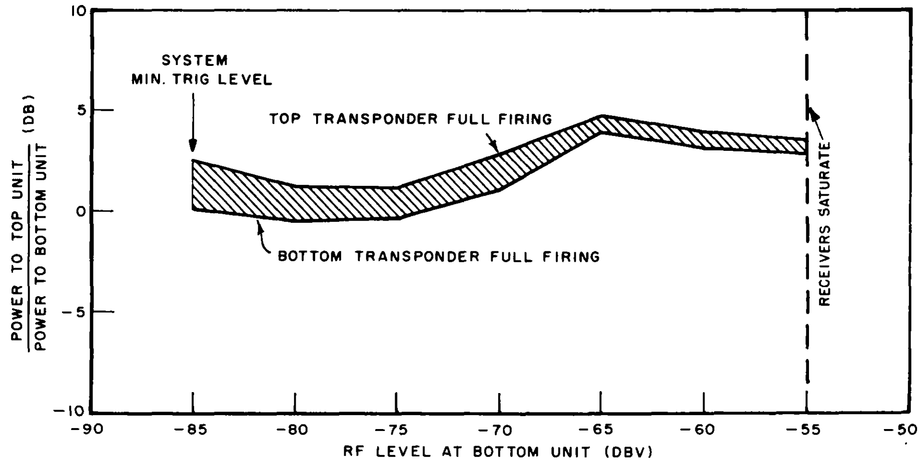

Fig. 8 — Plan 2, switching gray zone as a function of rf level with two AN/APX-6B units

which represents the transition error for the top reply path, does not exceed 5 dB. This error is well within the maximum allowable error determined by GTC considerations, as discussed in Appendix A.

Receiver saturation for the four AN/APX-6B transponders modified for Plan 2 occurred at 30 dB above threshold, though saturation levels as low as 21 dB above threshold have been observed for some AN/APX-6B's. When input signal strengths at both transponders exceed receiver saturation levels, the system can no longer determine which path is supplying the stronger interrogation signal, so that it can no longer determine which is the preferred reply path. However, the system will still reply to interrogations via the unit that has the highest saturated output level. From the GTC considerations discussed in Appendix A, 21 dB system dynamic range, though not ideal, is probably adequate for dual-antenna operation.

Figure 9 shows the processor, AND circuit, and blocking oscillator schematic diagrams. The comparator output signal closely approaches the true difference of the video outputs from the top and bottom receivers, but is quite noisy, has poor pulse shape, and has a level that changes relatively gradually with receiver input signal-strength ratio. Its polarity may be positive or negative, depending on whether the bottom or the top signal is stronger. The processor's function is to accept only the negative-going video signal from the comparator (corresponding to a stronger top receiver signal) and to produce a relatively noise-free, well-shaped video signal having fast rise and decay times and a flat top. The processor output signal must be entirely present, commencing at a definite input signal level, but be altogether absent for smaller input signal levels. Due to input trigger hysteresis and susceptibility to noise trigger, a regenerative type of pulse processor is not acceptable for this application.

The video-processor circuit, shown as part of Fig. 9, uses the well-established circuit technique of amplification of a selected slice of the comparator output signal, taken at a fixed voltage level and having a fixed height. The signal slice is taken at a level sufficiently high to reduce susceptibility to noise, yet sufficiently low to avoid appreciable increase in gray-zone width due to processing. The thickness of the slice is made sufficiently small so that a very slight increase in the top-to-bottom signal-strength ratio is adequate to raise the processor output level from zero to full output. The small slice thickness also assures the fast rise time necessary for use in the subsequent AND circuit.

The processed comparator video output is enabled by the decoder output in an AND circuit and proceeds to trigger a blocking oscillator. The output of the blocking oscillator triggers the gate generator, which in turn controls whether the reply is to be transmitted by way of the top or the bottom antenna.

Suppression of the single (bottom) decoder when the top transponder fires is accomplished by feeding the video signal output from the encoder into the bottom suppression input (Figs. 5 and 10). Suppression of the bottom decoder

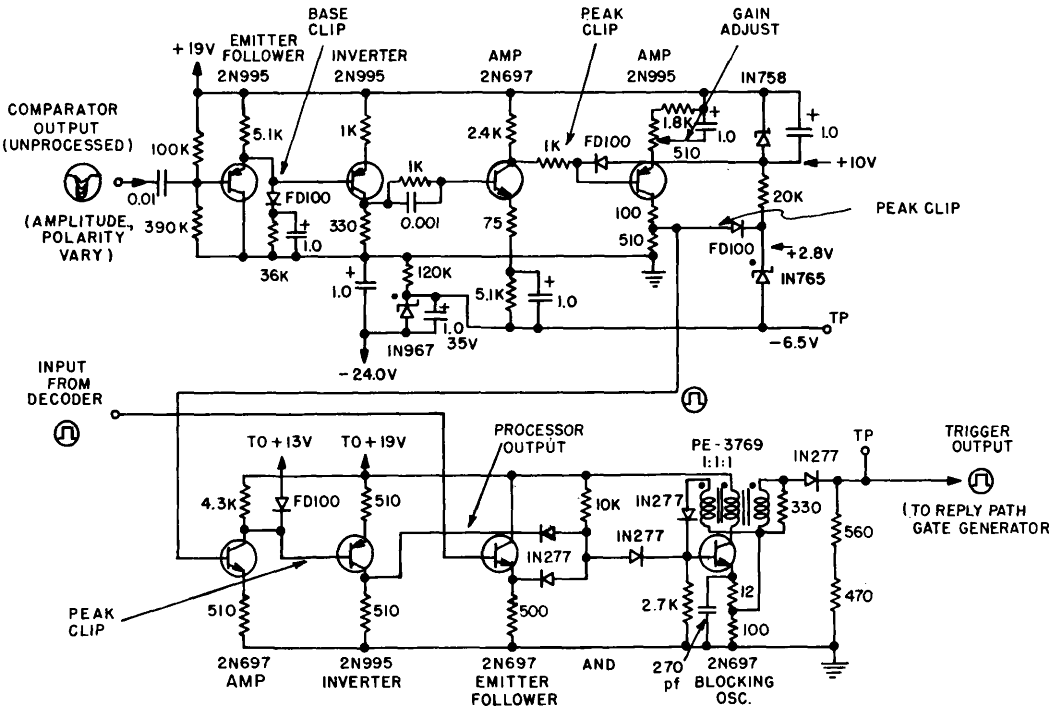

Fig. 9 — Plan 2, comparator video processor, AND and BO

when the bottom transponder fires is accomplished internally by existing circuits.

Figure 10 shows the reply-path gate generator and two gated unity-gain amplifiers, through which the reply code is directed to either the bottom or top transmitter modulator. With no gate applied by the gate generator, the bottom unity-gain amplifier passes the reply pulses, and the top amplifier is blocked. When a gate is triggered by the decision circuit, the bottom amplifier is blocked and the top amplifier passes the reply pulses. Coupling into the modulator of an AN/APX-6B requires special attention to impedance matching because of the extremely low input impedance of the APX-6B modulator driver, which is approximately 20 ohms. Special attention to good pulse response and unity gain is also necessary to avoid distortion of the encoder output.

The gate length of the flight-test model of the reply-path gate generator is adjustable within a range of 99 to 103 μsec and remains fixed within that range independent of the number of trains in the reply. The various requirements affecting choice of the gate length are discussed in Appendix B. In order to operate independently of internal transponder gating circuits and meet any new recovery-time requirement, yet pass one to four reply trains without resetting prematurely, a new reply-path gate generator having a regenerative length characteristic has been developed at NRL. (The regenerative length gate is also described in Appendix B).

A feature of the Plan 2 approach to the multiple-target registration problem is the fact that when reply-path transition occurs, there is very little possibility of an apparent range shift in a ground-system display. In a ground system equipped with automatic data-processing equipment, transponder delay jitter of more than 0.1 μsec can cause the target to jump to the next adjacent range bin in the data-processing equipment. This jump will cause an apparent range shift of over ten times that amount, resulting in display as a multiple target.

Transponder delay jitter in the Plan 2 system is minimized by the use of a common decoder and encoder for the top and bottom paths. Also, due to the fact that similar type receivers are used for the top and bottom receivers, and since the receiver levels at transition are nearly equal, receiver delay is also nearly equal for the two

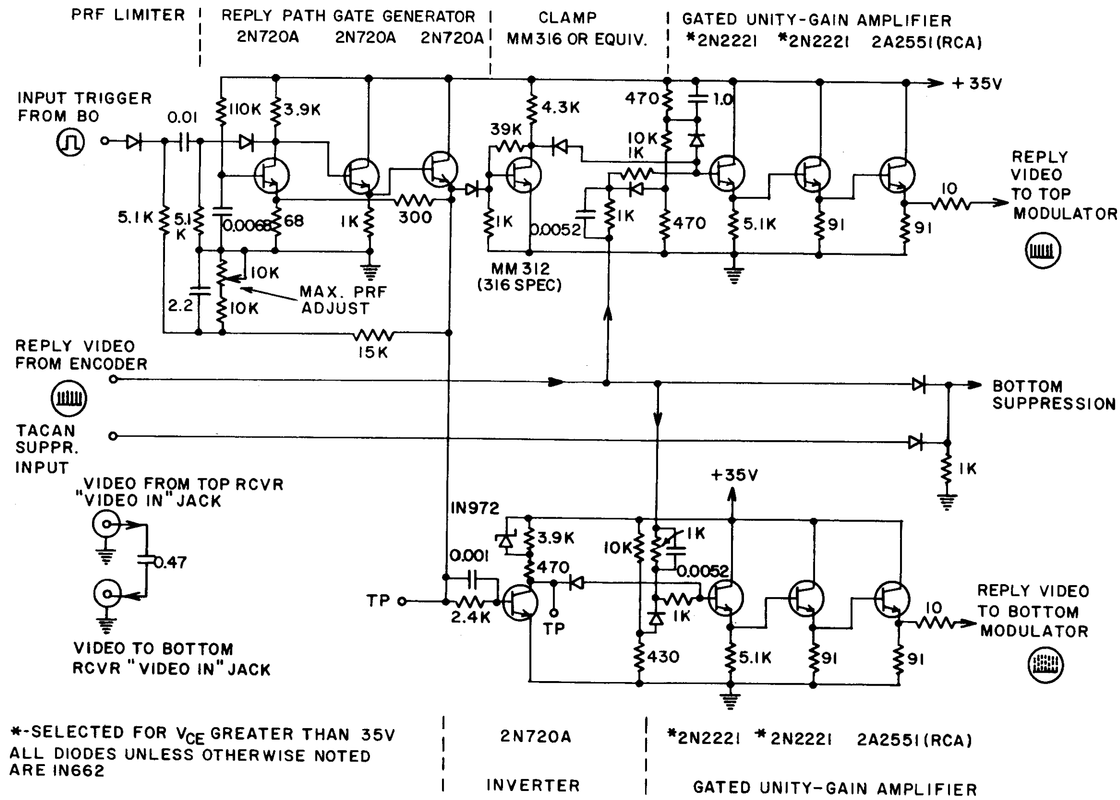

Fig. 10 — Plan 2, reply-path gate generator and gated amplifier

paths. (In contrast, the Plan 1 system used two different decoders and encoders, and transition to the bottom reply path occurs in the Plan 1 system whenever the bottom-receiver signal strength exceeds the sensitivity threshold, regardless of the signal strength at the top receiver. As a result, it is somewhat easier in the Plan 2 system to maintain transponder jitter at transition below the required 0.1 μsec.)

In the reply-path gate generator shown in Fig. 5, a prf limiter is used to prevent damage to the gate-generator transistors due to excessive power dissipation at very high interrogation rates. The limiter prevents the gate-generator prf from exceeding 1200 gates per second. (The reply rate for an AN/APX-6B transponder can run as high as 2200 replies per second, in the case of a Code 00 reply, due to dependence of reply-rate limiter action of the transponder AOC circuit on the number of pulses in the reply code. For the fixed 100-μsec gate length designed for Plan 2 flight-test models, the resulting gate-generator duty cycle can exceed 20 percent, without some method of limiting the gate cycle other than the AOC circuit.)

Early bench tests of the Plan 2 system (using the gate-generator prf limiter) revealed a problem, however. Whenever the top receiver signal dominates and the interrogation rate by way of the top receiver exceeds the prf limit of the gate generator, the AOC circuit will lose control of the bottom transmitter duty cycle, and there is no longer any protection against bottom-transmitter burnout. This situation could occur whenever the aircraft is close to several interrogators and is banking so that the top interrogation path is favored. However, only if a low duty reply code is used in the APX-6B transponder, so that the AOC circuit loses control of top-transmitter reply rate in favor of the prf limiter of the gate generator, will some interrogations coming by way of the top receiver be routed to the bottom transmitter due to gate countdown. Only under this condition will there be no control over the bottom reply rate. The top reply rate, on the other hand, is always limited by either the gate-generator prf limiter or the top-transponder AOC circuit.

Due to the fact that excessive interrogation by way of the top transponder could be easily avoided during the limited flight tests expected for the early version of the Plan 2 system, no change was made to correct this condition in the flight equipment. However, NRL has developed an improved low-dissipation regenerative-length gate, described in Appendix B, whose length varies with the length of the reply, thus reducing the need for the gate-generator prf limiter. Such a circuit will eliminate the bottom-transmitter burnout problem.

Application to Mode C

The Plan 2 system described in this section has been primarily designed to meet requirements for Modes 1, 2, and 3. However, the system can be readily adapted for use with Mode C as well, in the manner described in Appendix B. A primary difference between Mode 1, 2, and 3 on the one hand, and Mode C on the other, is the reply duration. The longest Mode C reply is only 20.3 μsec duration (or about 25 μsec in some equipment) and remains unchanged in "normal" and "emergency" operation. On the other hand, a Mode 1, 2, or 3 reply is 20.3 μsec in duration for "normal" operation, but increases to about 95 μsec duration for "emergency." The reply-path gate must be sufficiently long to include all the pulses of the longest reply, yet not exceed the allowable receiver recovery time.

Two alternative techniques are suggested in Appendix B. It is possible to use a common signal-strength comparator circuit and still perform the decision function separately for Modes 1, 2, and 3 on the one hand, and for Mode C on the other. This method allows use of separate gate generators for each of the two decision circuits, one with a controllable gate length for Modes 1, 2, and 3 of about 50 μsec in "normal" and 100 μsec in "emergency," and the second with a fixed gate length of about 35 μsec for Mode C.

A second technique uses a special regenerative-length gate whose length grows according to the reply duration. The second technique has been constructed and tested successfully at NRL.

Application to Mode 4

In a similar manner, the Plan 2 system can be extended to meet the requirements of Mode 4 operation as well. In the same manner discussed above, it is possible to perform the Mode 4 decision function separately from that of Modes 1, 2, and 3. By this means, it is possible to meet the individual requirements of the various modes, including suppression, recovery time, gate length, *etc.* Details will be discussed in Part 2, to be published subsequently.

In addition to the Plan 1 (original version) and Plan 2 systems, the previous Hartlobe report (1), which covered the broad concepts of the Hartlobe system, also discussed two other systems. The principal difference between these systems is the fact that whereas the Plan 1 and Plan 2 systems perform switching with video circuits, the remaining two perform rf switching, in order to reduce the number of transmitters required from two to one.

Figure 11 shows the Plan 3 system, using one complete transponder, an additional receiver, a dual-antenna decision circuit, one encoder, and one rf switch. It has the possible disadvantage that it requires two critical-length rf cables.

Figure 12 shows the Plan 4 system, using much the same equipment as for Plan 3. However, in order to eliminate the critical-length cables, two rf switches are used. As a result, though a reply signal transmitted through the bottom antenna passes through only one rf switch, a reply through the top antenna suffers the attenuation of two rf switches. (Each switch normally should introduce less than 1 dB attenuation.)

The earlier report (1) proposed, in addition, the possible use of a small transponder similar to the NRL small, lightweight transponder which was under development at the time the report was being prepared. Since then, a contract for the development of a production model of this transponder, the AN/APX-72, with full AIMS capability, has been awarded to the Bendix Corporation of Baltimore, Maryland. Component assemblies of this transponder should be available in the near future.

The AN/APX-72 transponder appears to be ideally suited for use as part of the Hartlobe Dual Antenna System. Figure 13 shows the NRL

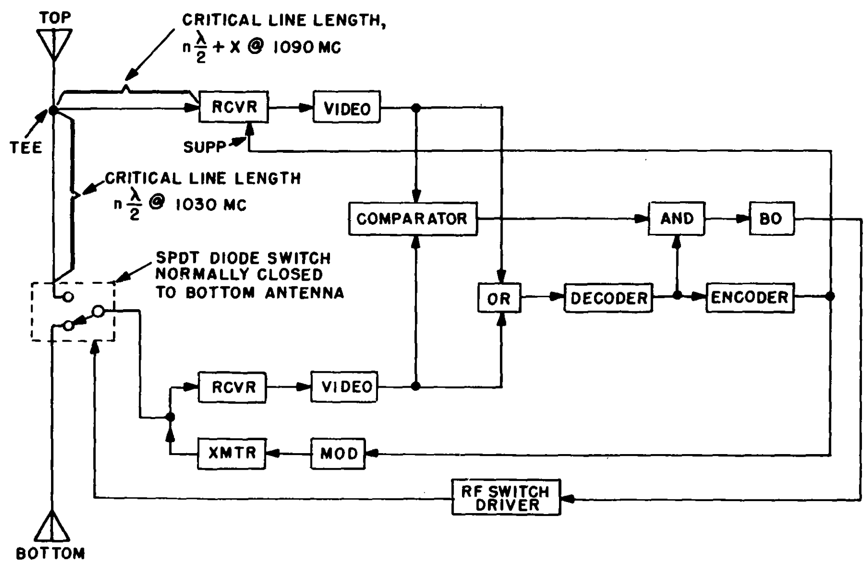

Fig. 11 — Plan 3, single transponder with one rf switch

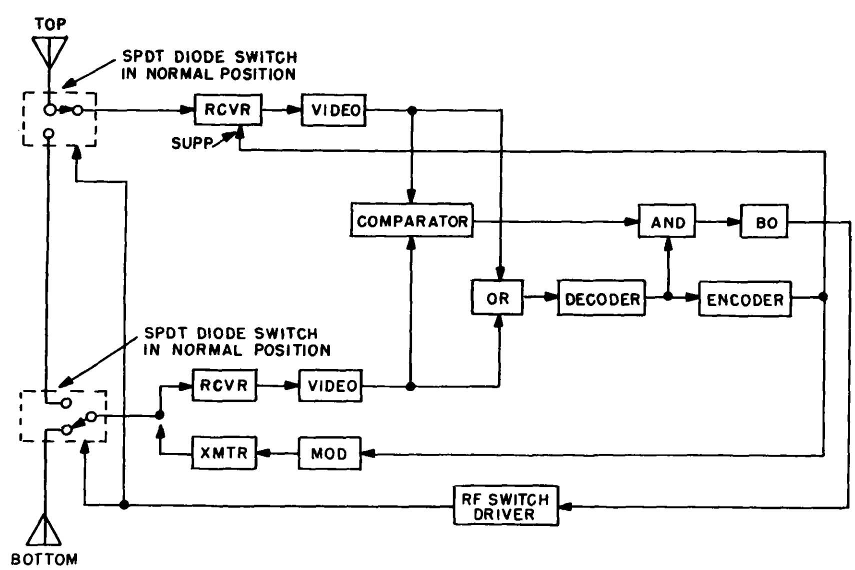

Fig. 12 — Plan 4, single transponder with two rf switches

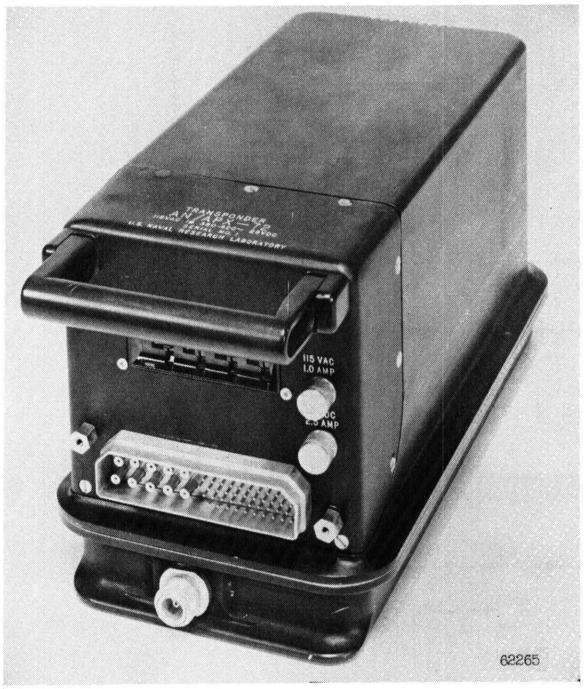

Fig. 13 — AN/APX-72 transponder (early NRL model)

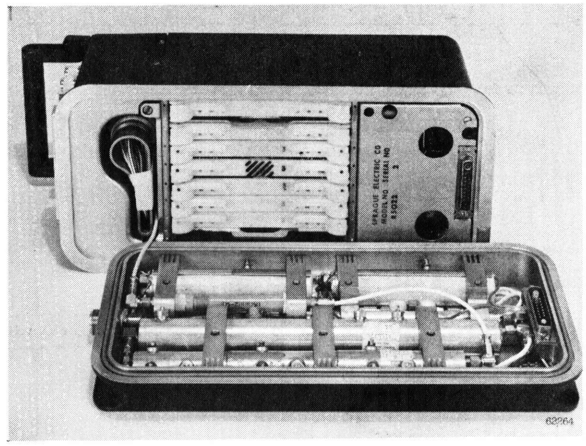

Fig. 14 — AN/APX-72 transponder, view of bottom of rf chassis

model of the transponder, which is essentially identical to the Bendix unit mechanically. The equipment is approximately 6 in. wide by 6 in. high by 12 in. long, weighs 12 lb, and is designed to meet airborne Class II environment.

Figure 14 shows the rf chassis of the transponder, including the entire receiver and transmitter circuits, separated from the video, decoder, and encoder circuits and the power supply. The rf chassis shown is 1-3/8 in. high by 5-1/2 in. wide by 11-7/8 in. long. The AN/APX-72 transponder is small enough so that use of its components will permit construction of a complete Hartlobe unit within the space now occupied by a single KY-311 unit or any transponder of similar proportions.

With the development of the AN/APX-72 transponder, it now appears quite practical to design the basic transponder in two parts, as shown in Fig. 15. An rf unit, containing all rf components together with a video amplifier and high-voltage power supply, could be small enough to be mounted next to or incorporated as part of the bottom antenna, allowing a reduction in rf cable losses. A video unit, containing a video processor, decoder, encoder, gate and suppression circuits, as well as a low-voltage power supply, could be mounted near the control box. (It has also been suggested that the video unit could be built into the control box.) The two units would be connected to one another only by several video cables and a power-control lead.

For the Hartlobe system, the units could also be used with an optional second rf box mounted next to the top antenna and an optional Hartlobe circuit board plugged into the video unit, as shown in dotted blocks in Fig. 15.

CONCLUSIONS

The excellent results obtained during flight tests, except at short ranges, for the Plan 1 (modified) system indicate that the Hartlobe antenna system provides good all-around coverage for the F-4 type aircraft, and similar coverage is anticipated for other types.

The Plan 2 system, which overcomes the basic deficiencies of the Plan 1 system, was constructed for Modes 1, 2, and 3 and bench tested, but not flown. The Plan 2 system will be expanded to include Modes C and 4 and when completed should provide full capability on all modes.

The use of components from small, lightweight transponders currently under development will permit construction of a complete Hartlobe transponder system that can be housed in the space now available for IFF in most aircraft.

The ideal ultimate configuration for the Hartlobe system would involve the use of two rf heads

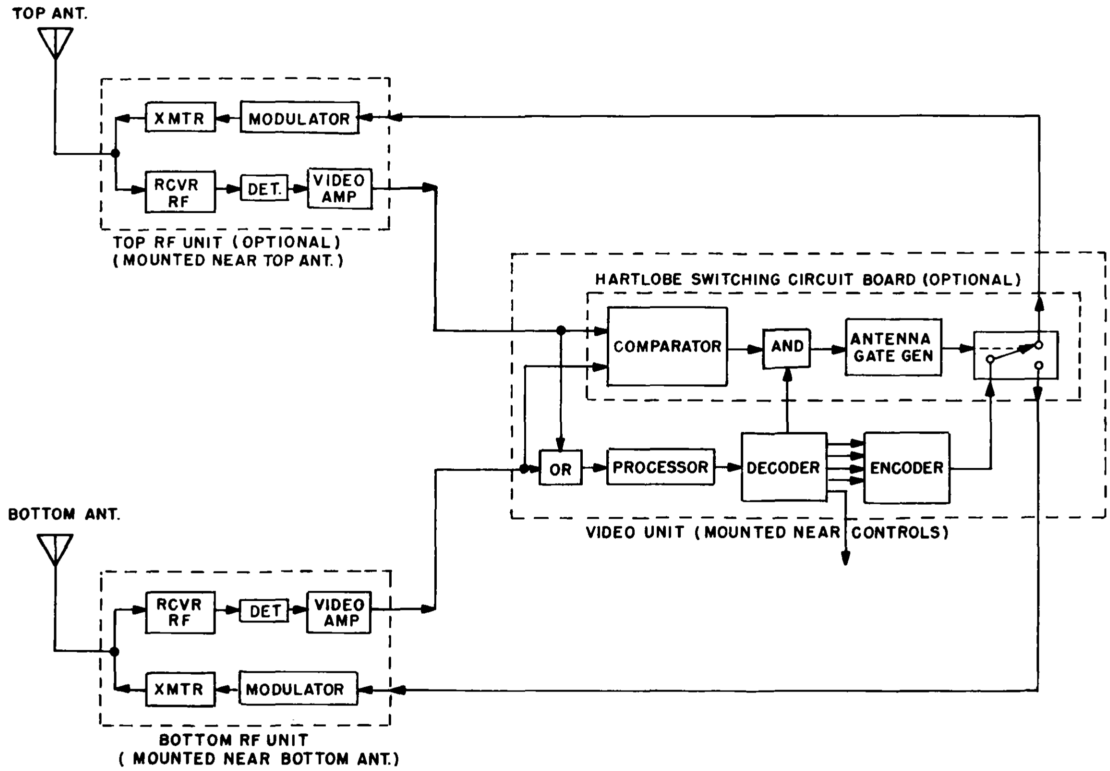

Fig. 15 — Two-unit IFF transponder with optional Hartlobe dual-antenna capability

integral with the two antennas and a combined unit incorporating video processors, decoder, encoder, suppressor, and comparator circuitry which would be located adjacent to or incorporated with the control box. This arrangement would eliminate the rf cable losses which become a major item on some aircraft.

RECOMMENDATIONS

1. It is recommended that a composite unit of the Hartlobe system be constructed using components from the AN/APX-72 transponder (or some transponder of comparable size) and that it be configured to fit into the IFF compartment of F-4 type aircraft.

2. It is recommended that one F-4 type aircraft be equipped with the Hartlobe system and that its operation be compared to that of other F-4 aircraft using conventional IFF transponders.

3. It is recommended that efforts be continued toward the development of rf heads integral with the antennas and the housing of the remainder of the Hartlobe system in, or adjacent to, the control box. This development could be readily accomplished by utilizing components of the AN/APX-72 transponder.

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Appendix A
THE EFFECT OF INTERROGATOR GTC ACTION ON THE OPERATION OF THE HARTLOBE SYSTEM

GTC VERSUS PLAN 1 AND PLAN 2

Gain-time control (GTC) in the interrogator receiver becomes a problem in the operation of the Hartlobe dual-antenna system if replies are transmitted via the airborne antenna that receives the weaker interrogator signal. Such an occurrence may result in a reply signal that is too weak to register in the interrogator receiver due to GTC action.

The GTC problem is of concern mainly in the Plan 1 configuration, because the system is designed so that the bottom transponder will reply in all cases in which it receives an interrogation signal decode, regardless of the signal level in the top unit. At the shorter ranges there is a high probability that replies received from the bottom unit, just prior to its fadeout during a banking maneuver, will fall below the GTC sensitivity threshold and be lost. This situation is demonstrated graphically by Figs. A1 through A5 and will be discussed in detail.

Plan 2 configuration was designed to eliminate the GTC problem by comparing signal levels and directing the reply to the antenna which received the stronger interrogation signal. There should be no problem with Plan 2 if the transponders have adequate dynamic range and if they are properly matched. A more detailed analysis will appear in the discussion of Figs. A1 through A5.

Figure A1 is a graph of computed signal level at the airborne transponder for the most favorable aircraft attitude. At this attitude the airborne antenna is assumed to have a maximum gain of 3 dB over that of an isotropic antenna. Figure A1 was computed by the following basic formula:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \qquad \text{(A1)}$$

where P_r = received power (transponder)

P_t = transmitted power (interrogator)

G_r = receiver antenna gain (transponder)

G_t = transmitter antenna gain (interrogator)

λ = wavelength

R = range

The following values were assumed:

P_t (AN/UPX-11)	1500 watts
G_t (20 ft antenna)	20.5 dB
G_r (stub or slot)	3.0 dB
Cable loss, interrogator end	2.0 dB
Cable loss, airborne end	0.5 dB
λ (1030 MHz)	0.956 ft

Figure A1 also indicates threshold signal levels and saturation levels for the two transponder receivers that have been considered, the AN/APX-6B and the AN/APX-72.

Figure A2, curve a, is a graph of computed signal strength at the interrogator receiver (AN/UPX-11) *versus* range when the aircraft is operating at its most favorable attitude. Figure A2, curve b, is a graph of threshold sensitivity of the interrogator receiver *versus* range when GTC is in operation.

The difference in height between these two curves at any given range represents the maximum attenuation, due to a reduction of antenna gain during banking maneuvers, that will still allow a reply (from that antenna) to register. Figure A3 is a graph of the difference between the two curves of Fig. A2, indicating that the maximum allowable attenuation remains relatively constant with range and is approximately 15 to 18 dB. The same basic formula (Eq. A1) that was used to compute Fig. A1 was used also for Fig. A2, curve a, with the following assumptions.

P_t (AN/APX-6B or AN/APX-72 XP)	500 watts
G_t (stub or slot XP antenna)	3.0 dB
G_r (20-ft interrogator antenna)	20.5 dB
Cable loss, airborne end	0.5 dB
Cable loss, interrogator end	2.0 dB

Figure A2, curve b, was derived from the specification for the AN/UPX-11 interrogator.

Figures A4 and A5 provide an analysis of the GTC problem. They were derived from Figs. A1, A2, and A3. They are normalized graphs of both interrogator and transponder receiver thresholds plotted with reference to their nominal received signal level, with aircraft at most favorable attitude. The AN/APX-6B characteristic is plotted in Fig. A4 and the AN/APX-72 in Fig. A5. Transponder receiver saturation levels are also plotted. By way of comparison, it is apparent that the difference in decibels between receiver threshold and saturation is the same on Figs. A4 and A5 as it is on Fig. A1.

ANALYSIS OF PLAN 1 OPERATION

Refer to Figs. A4 and A5. As the aircraft banks and the signals into the bottom antenna diminish, the replies from that antenna will continue to register in the interrogator receiver until the level drops below the curve marked "AN/UPX-11 Interrogator Receiver Sensitivity Threshold." As the aircraft bank angle increases, replies will continue to be transmitted from the bottom antenna but will not register in the AN/UPX-11 receiver until the signal level drops below the bottom-transponder receiver threshold. At this point the top transponder will take over, and replies will again be received by the interrogator. The region between the two thresholds, in which replies will not be received, is shaded.

There is a larger shaded area for the AN/APX-72 transponder (Fig. A5) than for the AN/APX-6B transponder (Fig. A4) because the AN/APX-72 has 5 dB more sensitivity.

Flight tests conducted at NATC, Patuxent River Naval Air Station, confirmed that these omissions did, in fact, occur at the shorter ranges.

ANALYSIS OF PLAN 2 OPERATION

In Plan 2 operation, the reply is returned via the antenna that received the strongest interrogation signal. There will be no danger of operating in the shaded area so long as the gains of the two receivers remain equal. However, signal levels will cover a range of as much as 60 dB while the aircraft is traveling between threshold signal levels at a range of one mile. If receiver gains differ by 18 dB or more, there is danger of operation in the shaded area. This possibility emphasizes the importance of designing a system with a wide dynamic range.

Receiver saturation levels are plotted on Figs. A4 and A5. When both receivers are saturated, the choice of reply path will no longer be made on the basis of the strongest signal, but rather on the basis of which receiver has the highest signal output level after it has become saturated. If the two receivers track in gain fairly well up to the point of saturation, there appears to be little danger of trouble from saturation. This conclusion becomes obvious when we consider the fact that when the bottom antenna (for example) has rotated away from the direction of the interrogator sufficiently to cross the 18-dB gap between nominal interrogator received-signal level and the AN/UPX-11 receiver-threshold level, the signal input to the bottom antenna will also be reduced by the same amount. This reduction will, in most cases, prevent saturation of the bottom receiver. Since the problem occurs only when both receivers are saturated, it appears that there is little danger of making the wrong choice of reply path. In the case of the AN/APX-72 transponder (Fig. A5), the saturation curve is so far above the curve for the AN/UPX-11 receiver threshold that it would be virtually impossible to saturate both receivers at the time that the reply signal level was below the threshold of the AN/UPX-11 receiver.

The conclusion is drawn that there should be no problem with the Plan 2 circuit arrangement unless one receiver is badly out of adjustment.

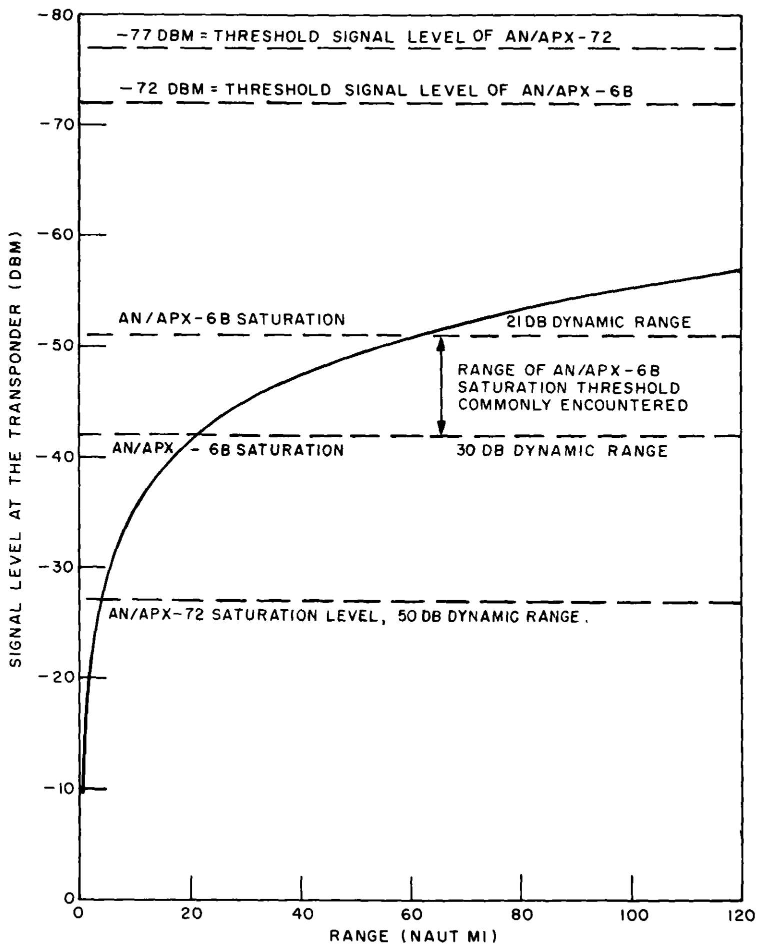

Fig. A1 – Computed signal level at transponder *versus* range with aircraft in most favorable attitude

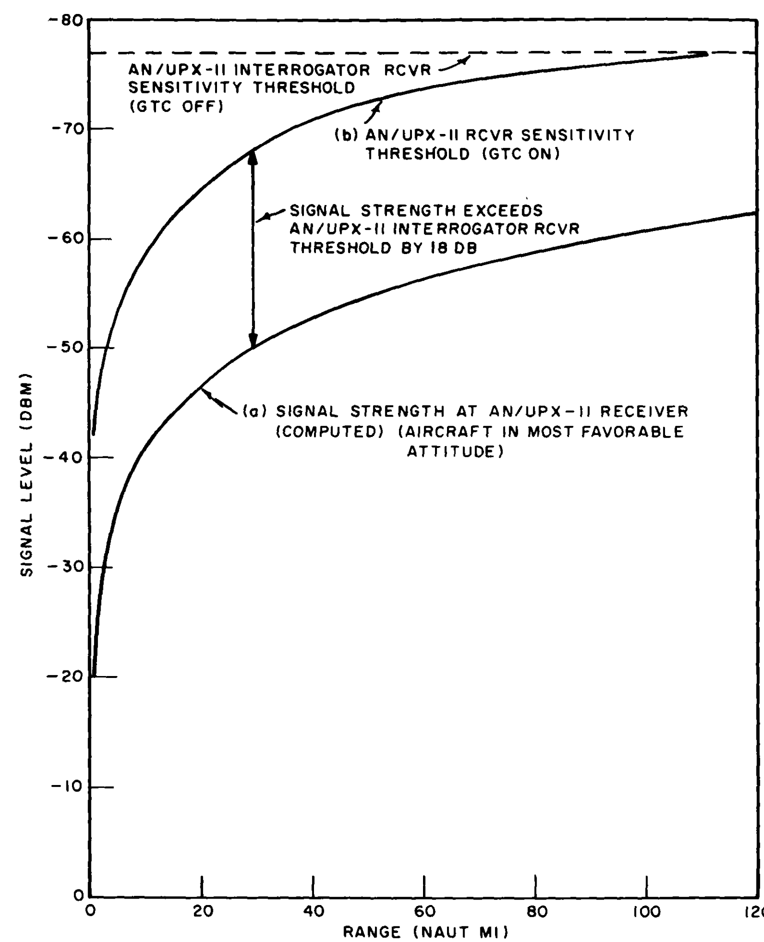

Fig. A2 – Computed signal strength at interrogator receiver *versus* range (curve a), and interrogator sensitivity *versus* range (curve b)

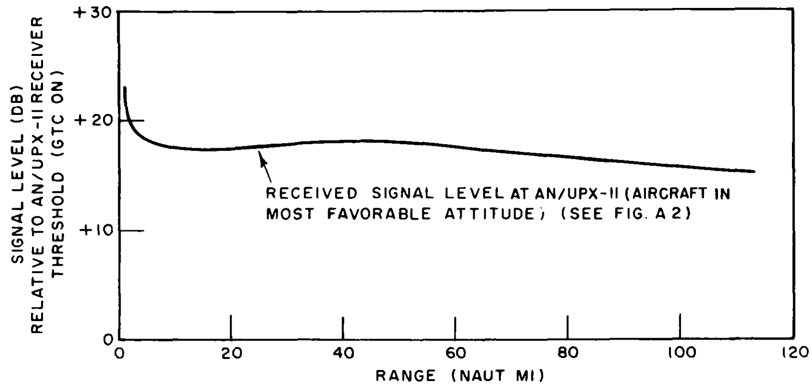

Fig. A3 — Computed signal strength in excess of sensitivity threshold *versus* range

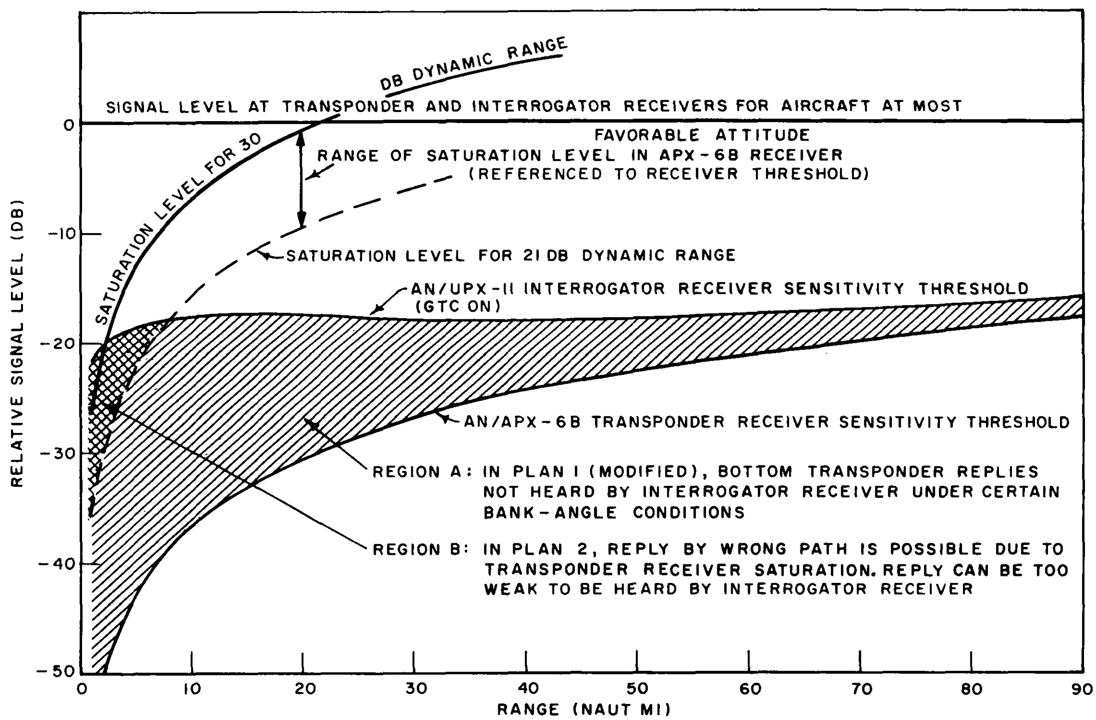

Fig. A4 — Graph of receiver saturation and sensitivity levels *versus* range to illustrate GTC problem areas for AN/UPX-11—AN/APX-6B combination

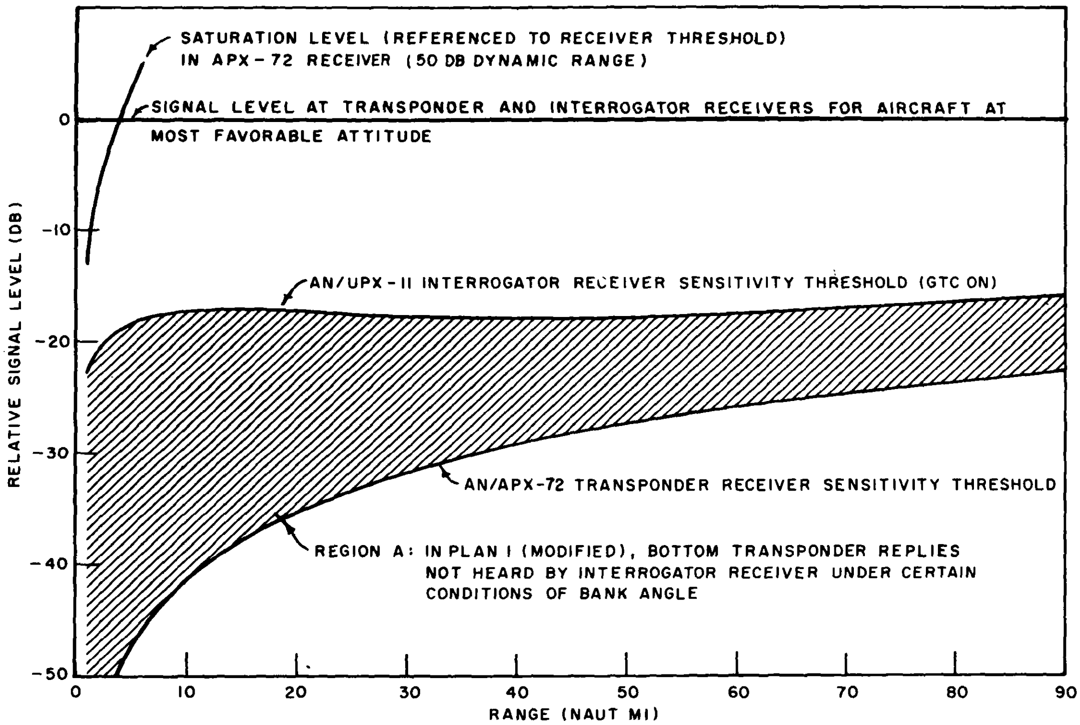

Fig. A5 — Graph of receiver saturation and sensitivity levels *versus* range to illustrate GTC problem areas for AN/UPX-11—AN/APX-72 combination

Appendix B
ANTENNA GATE CONSIDERATIONS

PLAN 2 GATE PROBLEMS

The antenna gate length used in the Plan 2 version of the Hartlobe dual antenna system must be sufficiently long to pass the entire length of a single reply regardless of the number of trains (normal, I/P, or emergency) in that reply. However, it must also be short enough to recover within the required transponder recovery time, so that the next succeeding reply will be transmitted on the proper channel without splitting the reply between the top and bottom channels.

The Plan 2 system, which has been breadboarded and is now ready for flight tests, uses a fixed gate length designed to meet all current requirements. The restrictions on choice of such a fixed gate length are discussed in the first portion of this appendix.

Though the present fixed-length gate generator will meet the current gate-length requirements, a new gate circuit will be required if there is any further reduction of the specified maximum receiver recovery time. In any case, whether or not there is any reduction of the receiver recovery-time requirement, a new gate-generator design should be incorporated, such as the low-dissipation regenerative-length gate circuit described in the latter portion of this appendix, to eliminate the need for a gate prf limiter. This change will eliminate the problem encountered in the Plan 2 flight equipment, described in the main body of this report, of loss under certain conditions of bottom-transmitter duty-cycle protection.

GATE-LENGTH CONSIDERATIONS

In general, the gate for the Plan 2 system is triggered at approximately the same instant as the decode pulse, roughly coincident with the P_3 interrogation pulse.

The shortest allowable gate length is limited by the fact that the gate must remain on, in the case of a reply by way of the top antenna, throughout the duration of the longest possible reply to any interrogation. In addition, the transponder delay included within the gate interval may be a maximum allowable delay. The minimum gate length is calculated as shown below for the worst combination of system tolerances, as well as for more commonly encountered tolerances for the AN/APX-6B transponder.

The longest allowable gate length is limited by the condition of two successive interrogations by way of the top antenna. Here, the gate must be able to turn off, recover, and be triggered back on within the shortest time interval to be expected between P_3 pulse of the first interrogation and P_3 pulse of the second interrogation. The transponder delay included within the gate interval may be the minimum allowable delay. Once again, the maximum gate-length calculations shown at top of page 22 include the worst case as well as conditions more commonly found for the AN/APX-6B transponder.

For the worst-case conditions, the maximum allowable gate length, 97.7 μsec (determined by the system recovery following the shortest reply),

Minimum Allowable Gate Length	Worst Case	Common Case
1. Transponder Delay	Max 3.5 μsec	Norm 2.6 μsec
2. Reply Pulse Spacing: 1st START to 4th STOP	Max 94.6	Norm 94.6
3. Reply Pulse Width, Last Pulse	Max 0.55	Norm 0.35
4. Approx. Reply Pulse Decay Time, 50% to 10% Amplitude Points	Max 0.20	Norm 0.20
	98.85 μsec	97.75 μsec

Maximum Allowable Gate Length	Worst Case	Common Case
1. Transponder Delay	Min 2.5 μsec	Norm 2.6 μsec
2. Reply Pulse Spacing: 1st START to 1st STOP	Min 20.2	Norm 20.3
3. Transponder Recovery Time (AN/APX-6B adjust) (Last reply pulse of 1st interrog., to P_3 pulse of 2nd interrogation)	Min 75	Norm 100
	97.7 μsec	122.9 μsec

is *shorter* than the minimum allowable gate length, 98.85 μsec (determined by the need to pass all of the longest reply). As a result, for the worst-case conditions, a fixed gate is not adequate.

However, for commonly encountered field conditions, the transponder recovery time is currently set to 100 μsec, rather than the minimum-equipment adjustment capability of 75 μsec, so that the allowable gate-length adjustment might range from 97.75 μsec minimum to 122.9 μsec maximum. The effect of temperature on gate length for most commonly used gate circuits is about 4 percent peak-to-peak shift, resulting in a gate-length variation well within the allowable range under conditions commonly found in the field. For these reasons, no difficulty is expected in the use of a fixed-length gate in this application.

GATE-GENERATOR DESIGN CONSIDERATIONS

If there is any future reduction of the specified maximum receiver recovery time, a new gate generator will be required whose length varies according to the length of the reply to be transmitted.

It is easily shown that a fixed-length gate will no longer be satisfactory under these conditions. As discussed earlier in this appendix, the minimum allowable gate length for a fixed gate would continue to be 98.85 μsec under the worst conditions, or 97.75 μsec for more commonly encountered tolerances of the AN/APX-6B transponder. On the other hand, the maximum allowable gate length (determined by the shortest reply code and by receiver recovery time) would be as shown below, calculated in the same manner described earlier in this appendix. It is assumed that the new receiver recovery time is 35 μsec maximum. Clearly, a fixed gate length would no longer be adequate, since the maximum allowable gate length, 57.7 μsec, is less than the minimum gate length of 97.75 μsec.

Either of two basic approaches might be used to generate a gate whose length varies with the length of the reply.

One possible method would use several different gate generators, as shown in the block diagram of Fig. B2, one for use on Modes 1, 2, and 3, and one for Mode C. The gate length for Mode 1, 2, or 3 operation would be controlled by the Emergency Enable bus, approximately 50 μsec for normal and I/P operation, and approximately 100 μsec for emergency operation. The gate length for a Mode C reply would be a fixed 35 μsec, regardless of operating mode, so that a separate gate generator is required as shown.

For comparison with the multiple-gate method shown in Fig. B2, a simplified block diagram for the Plan 2 Hartlobe dual antenna system is shown in Fig. B1.

A second alternative method (the recommended method) of providing a varying gate length is shown in Figs. B3 and B4. A special gate generator having zero apparent recovery time is combined with a gated auxiliary trigger input circuit to make a composite gate generator whose gate length

Maximum Allowable Gate Length	(For 35-μsec Receiver Recovery Time)	
1. Transponder Delay	Min	2.5 μsec
2. Reply Pulse Spacing: 1st START to 1st STOP	Min	20.2 μsec
3. Transponder Recovery Time	Min	35 μsec
		57.7 μsec

automatically grows to include the entire duration of the reply it is gating. The term "regenerative length" gate has been used to describe such a circuit, in that the gate appears to regenerate itself without interruption to accommodate the signal it controls. A circuit of this type tested at NRL has short fall time, good temperature stability, and is relatively noncritical with regard to adjustment of minimum gate length. It has been used in a similar manner quite satisfactorily with an AN/APX-6B transponder in another experimental application.

A zero-recovery-time gate generator can be devised as shown in the block diagram of Fig. B3. The output of a conventional short-gate generator can be stretched by delaying the gate, mixing the gate itself with the delayed gate, then shaping the combined gate to produce a flat top. This particular stretched gate circuit has a characteristic of interest for a number of applications. If the short gate is retriggered in the brief time interval after the short gate turns off, but before the combined gate turns off, the combined gate will increase in length, but will be continuous and unbroken. It is as if the combined gate has turned off, recovered, and been retriggered so rapidly there is no apparent break in the combined gate, giving rise to the term "zero-recovery-time" gate.

Though an early circuit developed and tested at NRL uses a delay line, a gate-stretcher circuit using an RC time constant and shaper shown later in this appendix has also been used for this purpose to reduce size and weight.

A varying-length gate circuit using a zero-recovery gate is shown in Fig. B4(a). The zero-recovery gate shown can be triggered initially only from the output of the dual-antenna decision circuit (the comparator-processor output ANDed with any decode pulse). Once triggered, as long as the short gate is on, the circuit will accept no triggers. However, the gate can be retriggered by reply pulses in the short time interval after the short gate turns off, but before the zero-recovery gate has ended. For this system, the short gate length is long enough to remain on from the P_3 interrogation pulse to the first STOP (SP) bracket pulse. (This prevents the gate from being retriggered by any reply pulse before the second START (ST) pulse.) Yet it is short enough so that the gate can also be retriggered by the START pulse of a possible third and fourth train. The delay is long enough to fill up the longest gaps between gates corresponding to the first, second, third, and fourth trains. A timing diagram for the zero-recovery-gate technique is shown in Fig. B4(b).

Though any conventional short-gate generator might be used, it must have an input trigger that isolates the gate from effects of triggers while the gate is turned on. In addition, the short-gate generator should have short recovery time, in order that the gate can fully recover in the short time available before the third or fourth START pulses retrigger the gate. The circuit used by NRL for the short-gate generator is similar to the three-transistor gate circuit shown as a part of Fig. 10 and provides recovery times on the order of 1 percent of the short-gate length, or approximately 0.2 to 0.3 μsec recovery times.

A regenerative gate-generator circuit is shown in Fig. B5, which uses the RC time constant technique of providing a zero-recovery gate. The circuit performs all the functions of the zero-recovery gate, the right OR, and right AND shown in Fig. B4(a). It consists of a short-gate generator, an RC time-constant stretcher, and shaper and inverter circuits to provide the proper polarity gates to enable the top and bottom gated video amplifiers. A reply trigger AND circuit is also shown, to allow reply triggers to retrigger the short gate only when the combined gate is on.

Special care in the design of the short-gate generator provides a relatively short recovery time by discharging a timing capacitor through the necessary low impedance after the gate shuts off, without providing excessive peak current drain or power dissipation. Some care can also be taken to minimize power dissipation in the shaper and gating circuits as well. This allows the circuit shown in Fig. B5 to be operated with up to 100 percent duty cycle without damage, eliminating the necessity for any prf limiter preceding the short-recovery gate generator.

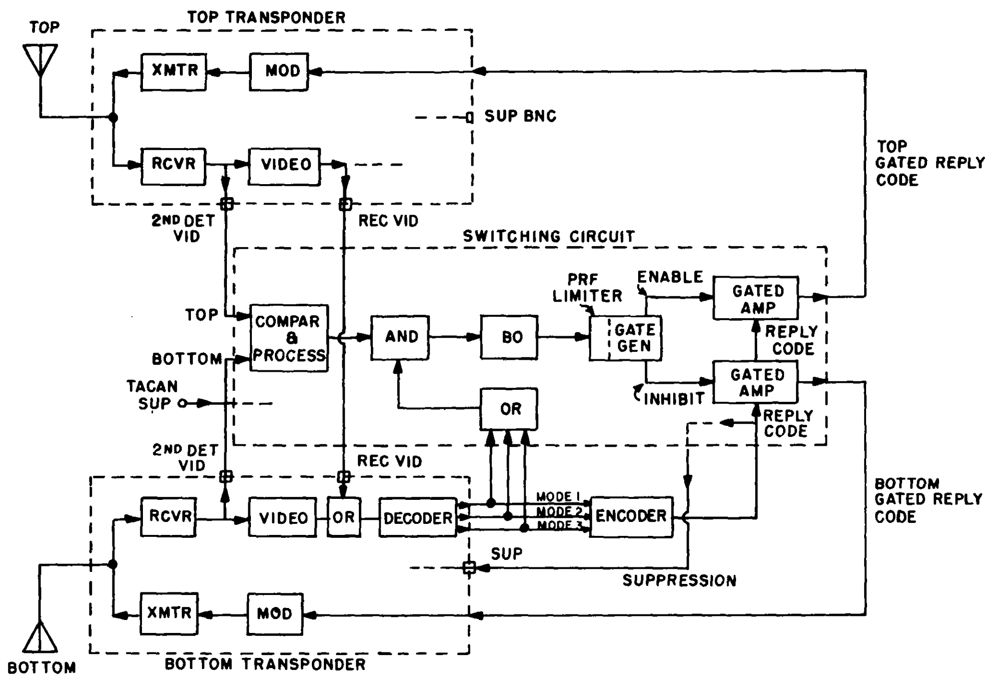

Fig. B1 – Hartlobe airborne transponder antenna system, Plan 2
(actual arrangement of flight-test models)

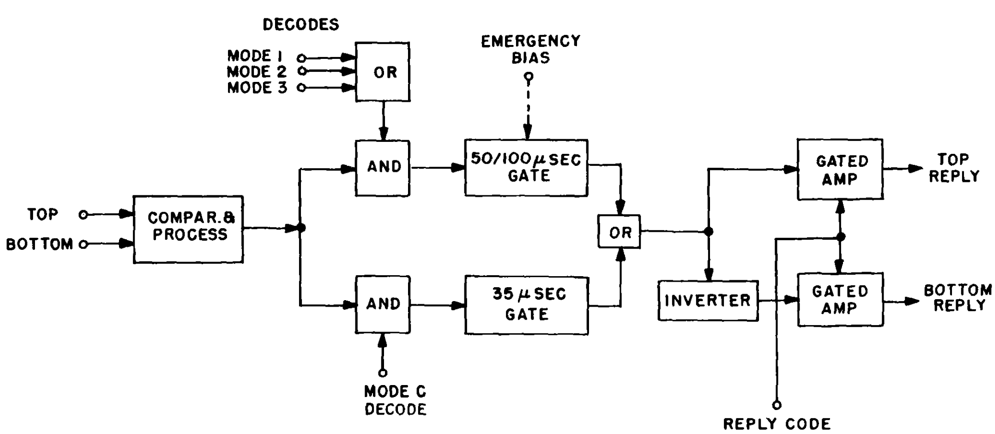

Fig. B2 – Improved switching circuit using multiple gate generators (see Figs. B3 through B5
for recommended version using regenerative-length gate)

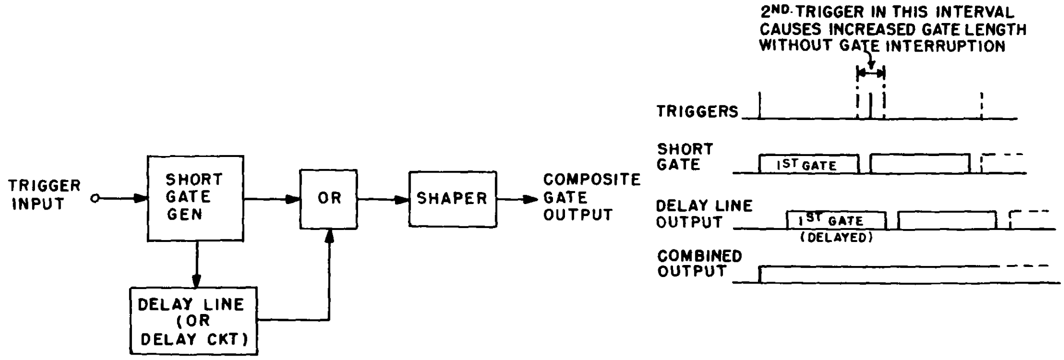

Fig. B3 — Zero-recovery-time gate generator

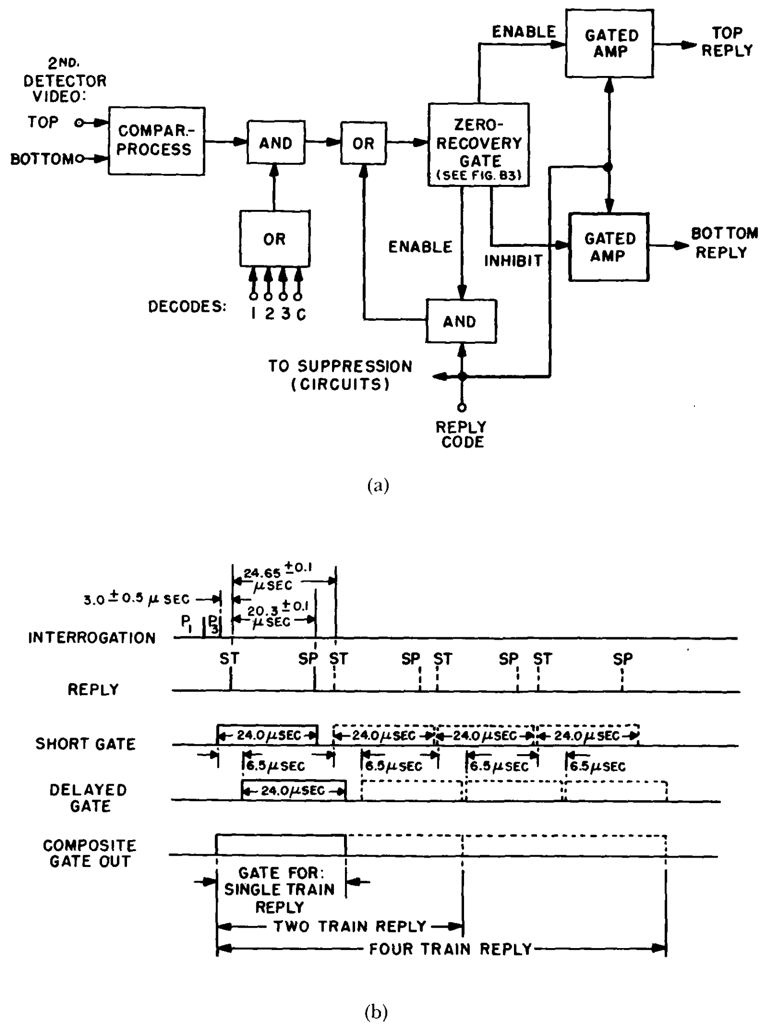

Fig. B4 — Improved switching circuit with varying-length gate

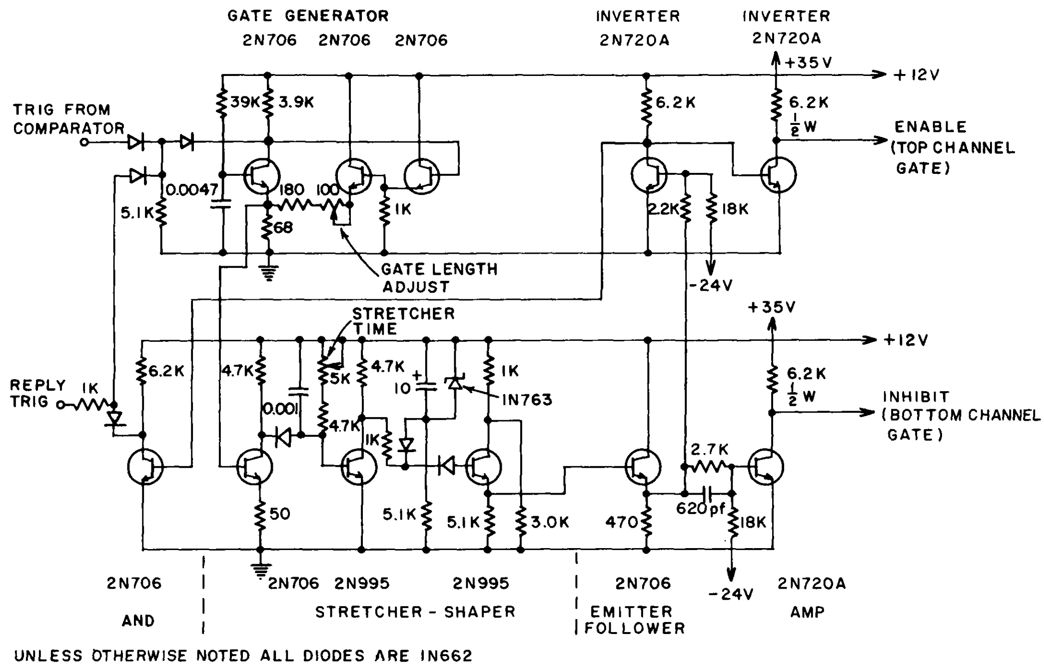

Fig. B5 — Regenerative-length gate generator for Plan 2

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13. ABSTRACT

The experimental model (Plan 1) of the Hartlobe airborne dual antenna system for IFF which was successfully flight tested by NATC had an inherent problem caused by gain-time-control (GTC) action in the interrogator receiver. An improved model, designated Plan 2, which overcomes the GTC problem, has been developed. The GTC problem resulted from the fact that the bottom transponder was allowed to reply to all signals above its sensitivity threshold, while the top transponder was triggered only when the bottom unit did not reply. At certain aircraft aspects, the reply failed to register because of the GTC threshold. This problem was overcome by circuitry which compares the signal levels in the two receivers and directs the reply via the antenna which produced the strongest received signal. It is proposed to implement the Hartlobe system by utilizing components of the AN/APX-72 transponder or other lightweight transponder capable of easy separation into rf and video portions.

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	ROLE	WT	ROLE	WT	ROLE	WT
Identification systems						
Radar equipment						
Aircraft antennas						
Dual antennas						
IFF						
AIMS						
Hartlobe						
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