Improvement of Echo Suppression in DME Transponders

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SUMMARY

Experience gained through the use of ground and airborne distance-measuring equipment has indicated that air/ground path echo signals can be responsible for occasional loss or erratic indication of distance information when the interrogator and transponder equipments are operating properly and when it is known that interrogation and reply signals are being received This report describes the manner in which interrogation-path echo signals affect the performance of the transponder, and it indicates modifications which may be made to DME transponders to eliminate the ill effects of echo signals The techniques have been applied to the Model DTB transponders, but they are equally applicable to other distance-measuring equipment transponders employing paired pulses.

INTRODUCTION

Ground-station distance-measuring equipment (DME) transponders have been in commissioned operation in the United States for more than 7 years Model DTA transponders were installed along the New York to Chicago airway Most of these were commissioned in 1950 Since that time, 450 of the newer Model DTB transponders have been procured and approximately 250 have been installed throughout the country, commissioned, and placed in continuous operation Because only 13 Model DTA transponders were installed, this report concerns experience with certain performance characteristics of the later Model DTB transponders

It is noteworthy that the average out-of-service time for all of the commissioned DTB transponder equipments is less than one per cent Although this high transponder equipment-reliability factor is excellent, it is of limited significance unless the over-all system performance reliability also is high

Occasional reports have been received which, after analysis, indicated that both the interrogator and transponder equipments involved were functioning properly and that signals in reply to interrogations were being received by the interrogator. The symptoms of malfunctioning were occasional loss of distance information and/or short-term errors in distance indication, both of which were accompanied by frequent search operation of the interrogator indicator circuits Subsequent studies and investigation indicated that multipath interrogation signals probably were responsible for the effects Numerous flight tests on nearby DME facilities and observation of the received interrogation pulses in various circuits of the transponder equipment, as well as observation of the reply count, confirmed that under certain conditions echo signals resulted in reply count-down and/or a time-jitter Consequently, an investigation of the effectiveness of the existing transponder echo-suppression circuits was started This report describes the results of this evaluation and shows that the type of echo suppression originally provided is not sufficiently effective to prevent the effects noted

RECEIVER AND ECHO-SUPPRESSION CIRCUIT

Pulse coding is employed in the DME system for the principal purposes of discrimination against undesired signals from other DME interrogators operating on the same interrogation frequency but desiring distance information from another transponder, and for the prevention of interference from other radar or beacon equipments It provides a high measure of selectivity without requiring excessively complicated equipment and without being wasteful of the radio-frequency (rf) spectrum. The DME system utilizes 10 interrogation and 10 reply frequencies In addition to the 100 channels provided, further selectivity is afforded by the use

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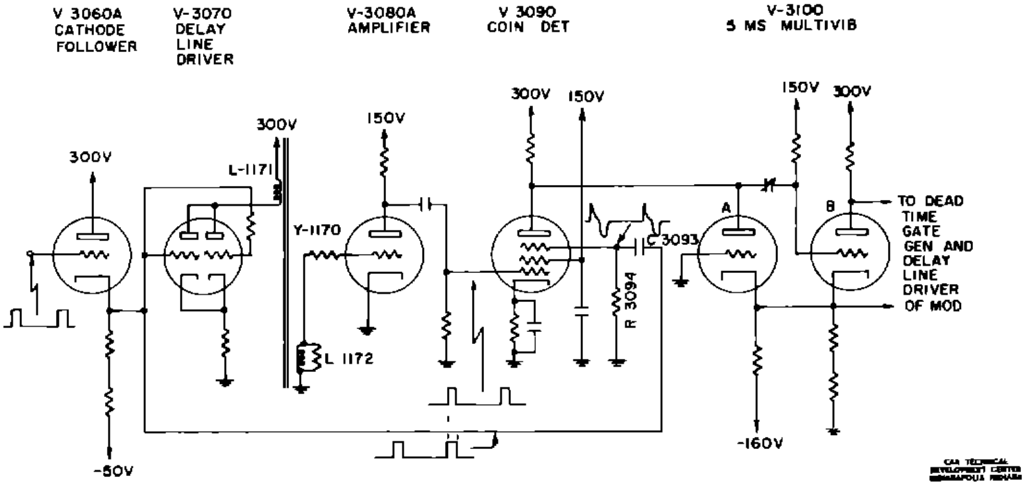

Fig 1 Schematic of Receiver-Decoder Circuits

of pulses spaced at finite intervals The spacing assignments are in increments of 7 microseconds, beginning with 14 microseconds and extending through 77 microseconds The sum of the interrogator pulse spacing and the reply pulse spacing is 91 microseconds For example, an interrogator operating on Mode A interrogates with pulses spaced 14 microseconds apart, and it decodes replies spaced 77 microseconds apart

The peak radiated power from the interrogator antenna may be as high as approximately 1 kilowatt (kw) from the Model DIA interrogators, or it may be a nominal 500 watts from the later Models DIB, DIC, and DID interrogators It is apparent that aircraft near the ground transponders to which they are tuned will provide the transponder receivers with exceptionally strong interrogation signals Echo signals which arrive at the ground station over some indirect path (due to the interrogator signals being reflected from buildings, power lines, mountains, or other objects), under certain conditions, may affect the transponder performance

A portion of the Model DTB receiver-decoder circuit is reproduced in Fig 1 to facilitate an understanding of its operation. Assuming that only direct-path interrogation signal pulses are present, tube V-3060A receives the video interrogation pulses from the receiver after they are processed by the intervening echo-suppression, spike-eliminator, and amplifier circuits This tube, functioning as a cathode follower, supplies undelayed positive-polarity interrogation pulses to the grid of V-3070 and to grid 3 of the coincidence-detector tube V-3090 through a differentiating network consisting of C-3093 and R-3094 The plate-load impedance for V-3070 is a delay-line driver coil, consequently, pulses appearing at the plate create a magnetic field about the coil, resulting in propagation of magnetic energy toward the pickup coil L-1172 The signal voltage generated in the pickup coil, which has been delayed with respect to the signal at the driver coil by virtue of the distance between the coils and the properties of the magnetostrictive core material, is amplified by V-3080A and is applied to grid 1 of the coincidence detector The functioning of the coincidence detector V-3090 is apparent from Fig 1 which shows that the first interrogation pulse passes through the delay channel and arrives at one grid of the coincidence detector at the same instant that the second interrogation pulse arrives at the other detector grid through the undelayed channel, provided that the delay through the delayed channel is exactly equal to the spacing of the two interrogation pulses Under these conditions, the pulse appearing at the plate of V-3090 is utilized to initiate a dead-time gate during which time the reply pulses are transmitted.

It is important to note that the network consisting of C-3093 and R-3094 functions to narrow the undelayed pulses by differentiation and thereby provides the principal control over the pulse-spacing decoding tolerance The waveform of the differentiated signal is shown in Fig 2

A DME interrogator was operated in a nearby laboratory to obtain strong echo signals The direct- and indirect-path echo signals received are illustrated in A on Fig 3 This figure also shows the relative amplitudes of both signals It is apparent that strong echo signals were received just prior to the second direct-path interrogation pulse The differentiated undelayed pulses corresponding to the direct- and echo-path signals in A on Fig. 3 are shown in B on Fig 3. It is pertinent to note that the negative overshoot resulting from the echo signal immediately preceding the second direct-path interrogation pulse occurred, in time, at the position of the second direct-path interrogation pulse Under these circumstances, because the polarity of the two signals is opposite, whole or partial cancellation of the desired interrogation pulse occurs,

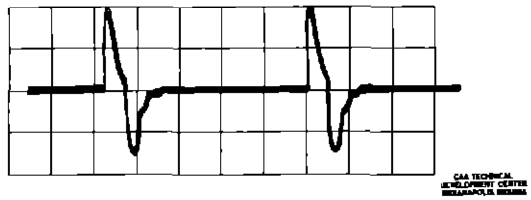

Fig 2 Undelayed Waveform at Grid 3 of Coincidence Detector

depending on the exact spacing and amplitude of the echo signal Because decoding of the desired signals cannot occur if the undelayed pulse is too low in amplitude or is cancelled out, a first effect is noted in which the transponder will not transmit a reply pair for each interrogation pair for the duration of the specified echo-signal conditions, and count-down of varying degrees occurs.

When an aircraft is in flight, the phase of the indirect-path signal continuously varies with respect to the phase of the direct-path signal, and there is fluctuation of amplitude of the pulses as well as variation in time spacing between the second direct-path pulse and preceding echo pulses Under these conditions, count-down may persist in widely varying degrees for long periods of time.

A second effect of failure to decode direct-interrogation pulses under the foregoing conditions is time-jitter which usually occurs in conjunction with count-down If an echo pulse exists within approximately 2 5 microseconds preceding the second direct-interrogation pulse, and if it is less than approximately 20 decibels (db) down with respect to the direct pulse, no decoding of the direct pulses will occur but decoding of an echo pair will occur on the first signals when the ratio of maximum signal to adjacent preceding signal amplitudes is in excess of approximately 20 db Because the time and amplitude distribution of echo signals under flight conditions are essentially at random and constantly changing, the instantaneous interval between interrogation and reception of the resulting reply may vary as much as 20 to 30 microseconds

In practice, this time-jitter may or may not affect the accuracy of distance information For example, if the interrogator receives about 50 per cent undelayed reply pulses, the tracking gate probably will stay locked on the first reply pair The probability of the interrogator locking on the delayed reply pulses increases with the percentage of delayed pulses The behavior of the transponder-decoder circuits when echo signals are present is determined largely

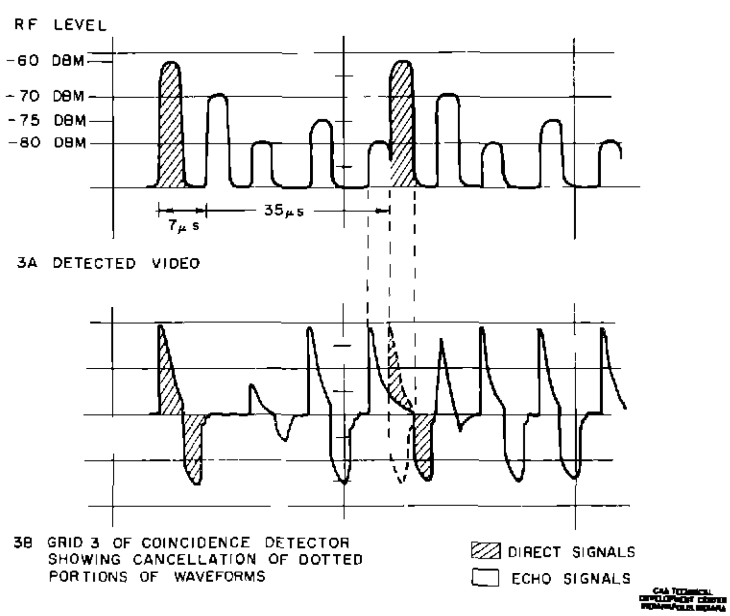

Fig 3 Typical Direct and Echo Signals

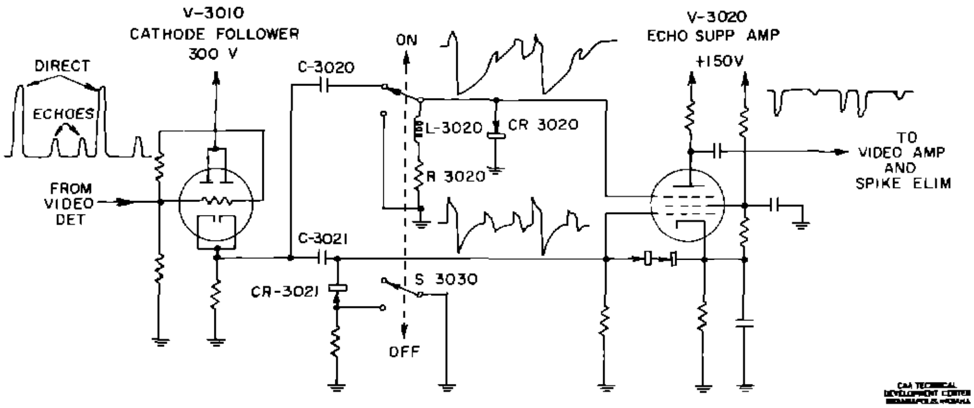

Fig 4 Schematic Diagram of Original DTB Echo-Suppression Circuit

by the amplitude and spacing of echo pulses with respect to the leading edge of the second direct-interrogation pulse. It can be seen that transponders operating with wide interrogation-spacing modes are least susceptible to air/ground echo effects, however, such effects may become objectionable at modes in which the interrogation-pulse spacing is of the order of 14 to 28 microseconds

The effects of echo signals are reduced in the Model DTB transponder by the operation of the echo-suppression circuit This circuit is shown in Fig. 4. Its operation is such that with the suppression circuit switch S-3030 in the ON position, an interrogation pulse at the cathode of V-3010 is applied to grids 1 and 3 of V-3020 Condenser C-3020 charges through CR-3020 during the pulse. After the pulse, C-3020 discharges through R-3020 and L-3020, producing a damped wave. The initial negative swing drives V-3020 to cutoff, thus blocking any echo pulse immediately following the interrogation pulse As the wave returns above the cutoff voltage, echo signals are passed The gain of V-3020 must return to normal by the time the second interrogation pulse arrives The effect of the suppression circuitry on echo signals is illustrated in Fig. 5 It is seen that echo signals occurring immediately after the interrogation pulses are suppressed effectively and extraneous replies are prevented, however, the effect on subsequent echo signals between the two direct-path interrogation pulses is reduced and becomes negligible just prior to the second direct pulse, and count-down and/or jitter may occur as previously described.

IMPROVED ECHO SUPPRESSION

It has been shown that suppression of echo signals preceding the second direct-interrogation pulse by approximately 3 microseconds is necessary to prevent count-down and jitter Tests have indicated also that improvement in performance by modification of the video portion of the existing circuitry is unlikely Because very little information is available to indicate specific types of echo signals which are most troublesome, the problem is best treated on the basis of minimizing the possibility of malfunctioning due to echo signals of all types and characteristics The maximum freedom from echo-signal effects can be obtained only by complete elimination of echo signals from the critical positions An effective method of accomplishing this is through the application of a negative gating pulse to one of the grids of the receiver intermediate-frequency strip If a gating pulse of appropriate amplitude and 3 microseconds duration is applied to the grid return of V-3560 as shown in Fig. 6, and if it is positioned to precede the second interrogation pulse by 3 microseconds, no echo signal will appear at the detector output because V-3560 is driven to cutoff by the gating pulse In the absence of an interfering echo signal, the decoder will function normally with no jitter effects unless the direct-path interrogation signal level drops below the decoding-threshold level momentarily due to loss of the direct signal The decoding circuits will operate properly on the first pair of pulses to be received which have the proper spacing and the normal minimum required amplitude Succeeding echo pulses are ignored effectively.

Laboratory tests applying this technique were conducted in the manner illustrated in Fig 7 It was not possible to produce jitter or count-down at any direct- or echo-signal level, or

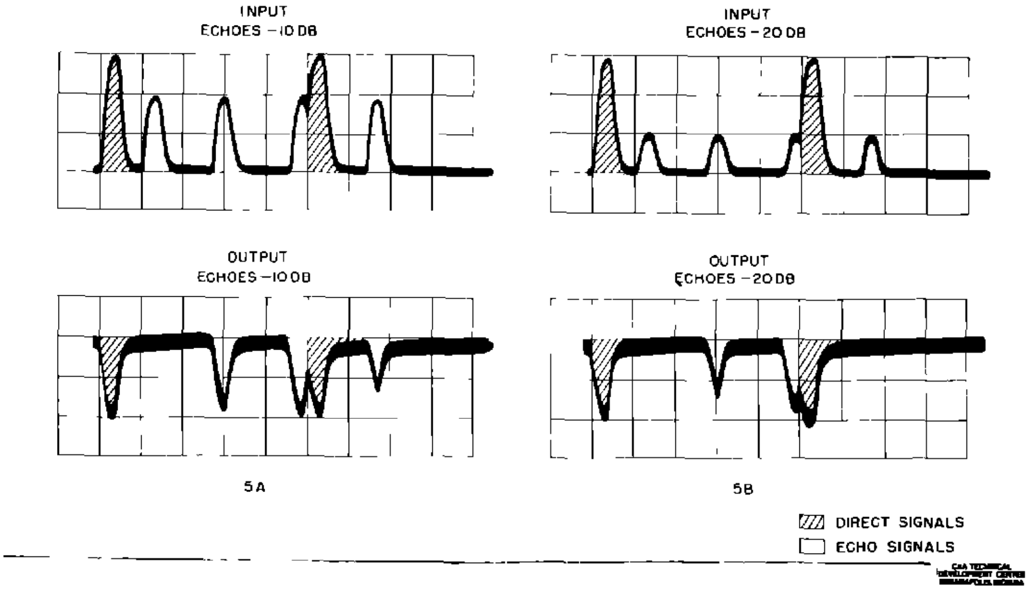

Fig 5 Relative Amplitudes of Direct and Echo Signals with Echo-Suppression Circuits Operating

with eight-microsecond simulated echo-signal pulses The wide simulated echo signals were applied to determine the effects of solid blocks of echo signals resulting from possible receiver saturation

This type of suppression requires a very high order of stability in the positioning of the gating pulse. This can be obtained by positioning an additional pickup coil on the decoder-delay line on the side of the driver coil opposite the decoder-pickup coil Because the delay line is temperature-controlled, the pulse position will be held constant within the limits of other coils on the delay line The pulse width will be adequately constant because of the video limiting in the previous stages and the resultant constant amplitude of the driver pulses. A dual triode is required to amplify and invert the pulse. Circuitry and component values may be chosen to shape or otherwise control the pulse if required. Application of the gating pulse to the

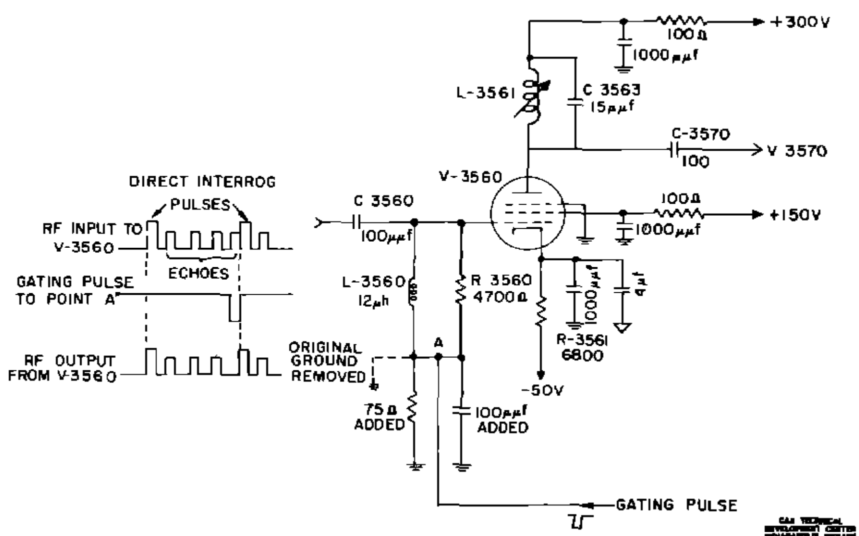

Fig. 6 Partial Schematic of Receiver Intermediate Frequency Strip Showing Application of Gating Pulse

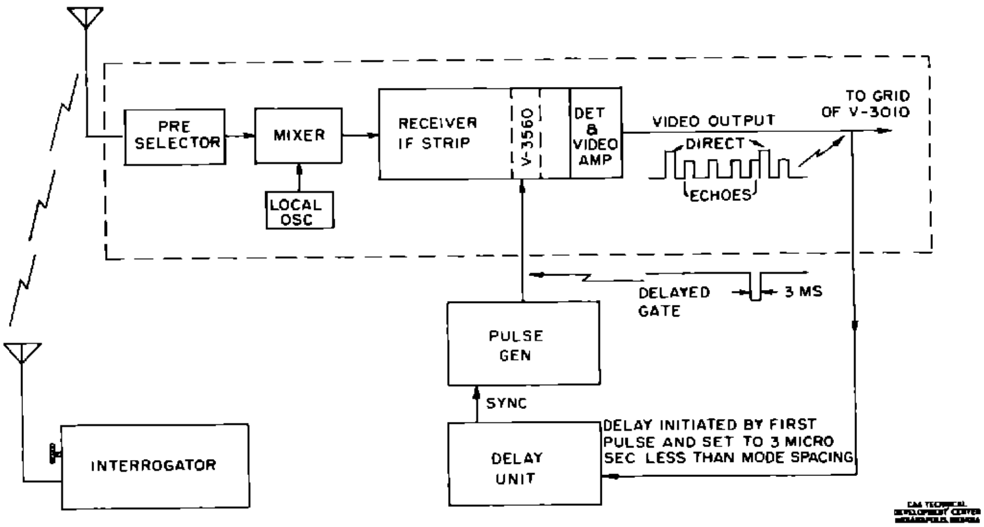

Fig 7 Test Setup for Determination of Effectiveness of Gating Pulse in Suppressing Echoes

intermediate-frequency strip through a shielded lead from a point having a source impedance of less than 1000 ohms is desirable to maintain fast pulse rise and decay intervals The suggested method of incorporating the required circuitry is given in general terms. A complete unit was not constructed because the experimental arrangement illustrated in Fig 7 established the effectiveness of the technique, and there is insufficient justification for detailed modification instructions until the seriousness of the echo problem is firmly established by analysis of field operational and user reports

Consideration was given to the effect of addition of the proposed negative echo-suppression gate upon the presently evaluated DME traffic-handling capacity in the presence of additional transponders It may be assumed that the proposed 3-microsecond gate would be initiated by each of approximately 5000 random noise pulses present at the decoder-delay line with a normal automatic gain control (AGC) setting Further, under conditions of full traffic capacity,[1] it may be assumed that 2475 pairs of fruit pulses per second (4950 pulses) could be received by the operating transponder and could initiate the 3-microsecond suppression gate It appears that this total of approximately 10,000 spurious pulses could result in an additional dead time of approximately 30,000 microseconds per second An examination indicates that the effect of the additional 3 per cent random dead time upon transponder efficiency would be essentially insignificant

CONCLUSIONS

Previous tests have shown that the original Model DTB echo-suppression circuits are effective to a large degree for certain types of echo signals, therefore, all facilities should be operated with the echo-suppression circuits in operation. Echo signals of certain types and spacings are not effectively discriminated against by the present circuits, however Determination of the loss of distance information due to echo signals is not difficult, but special techniques are required Reports on routine flight tests which consistently show loss of distance information over the same areas should be regarded as a fairly reliable indication of echo effects Although the seriousness of the echo problem has not been established on the basis of the percentage of the total number of operational facilities which are not providing satisfactory service due to echo-signal effects, suitable techniques for eliminating such effects have been established, and implementation of the modifications can be accomplished at relatively low cost if required

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[1] "ANDB/DME Component Characteristics," Appendix C, DME Traffic Handling Capacity, Air Navigation Development Board, May 1, 1951