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EVALUATION OF TECHNIQUES USED IN THE BUTLER TERMINAL AREA MODEL 1020 DISTANCE MEASURING EQUIPMENT

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16. Abstract

This report covers the evaluation of some techniques used in the low-power (terminal area) Butler 1020 distance measuring equipment (DME). The equipment was delivered to the National Aviation Facilities Experimental Center where laboratory tests were conducted. Laboratory tests dealt with the evaluation of the traffic-handling capability, echo-suppression circuitry, and the effects of first-pulse and second-pulse timing techniques. It was concluded that (1) with interrogation-pulse spacings of other than exactly 12 μs, first-pulse timing is effective in maintaining the reply delay between the first pulse of the interrogation to the first or second pulse of the reply constant, and (2) the echo-suppression circuits were effective in reducing the number of replies to false interrogations.

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INTRODUCTION

PURPOSE.

The purpose of this effort was to measure and compare the effects of first-pulse and second-pulse timing on distance measuring equipment (DME) reply delay and to evaluate false-DME echo-suppression circuits in the Butler Model 1020 DME ground station.

BACKGROUND.

The advent of DME with instrument landing systems (ILS) brings with it the requirement of a more accurate DME. A proposed method to increase this accuracy is to trigger the reply of the ground station from the first pulse of the interrogation pulse pair. Currently, the reply of the ground station is triggered from the second pulse of the interrogation pulse pair.

Another problem over the years has been false replies synchronous with, but delayed in time from the normal reply. To the airborne DME, this represents a potential false-distance "lock-on" if the DME should unlock from the normal reply and search out and lock-on to the false reply.

The Butler Model 1020 DME ground station, built under contract FA73-WA-3198 by Butler National Corporation, represents the new DME ground equipment which incorporates first-pulse timing to increase accuracy and various techniques to eliminate or reduce the false distance lock-on problem. The Butler equipment was supplied to the National Aviation Facilities Experimental Center (NAFEC) to support Subprogram 072-318, "Electronics Guidance for Category III."

DESCRIPTION OF EQUIPMENT.

BUTLER EQUIPMENT. The Butler DME ground equipment (figure 1) is a low-power 100-watt DME, housed in one cabinet with four equipment drawers. The transponder unit, monitor unit, control unit, and the test unit are each mounted separately in one of the four drawers. The equipment is capable of both "X" and "Y" mode operation and is all solid state with the exception of the radiofrequency (RF) amplifiers which contain tubes. Power must be externally supplied at 120 volts alternating current (Va.c.), 50/60 hertz (Hz). The Butler DME equipment tested was a single DME, but a dual DME is available.

Transponder Unit. The transponder consists of a RF section, intermediate frequency (IF) amplifier, decoder, receiver video, encoder modulator, RF generator, RF amplifier, and a power supply.

a. RF Section. The RF section has three major subdivisions; the duplexer, preselector, and first mixer. The duplexer is a passive element which permits the use of only one antenna for both receiving and transmitting. Selectivity of the incoming signal is provided by the preselector, which has

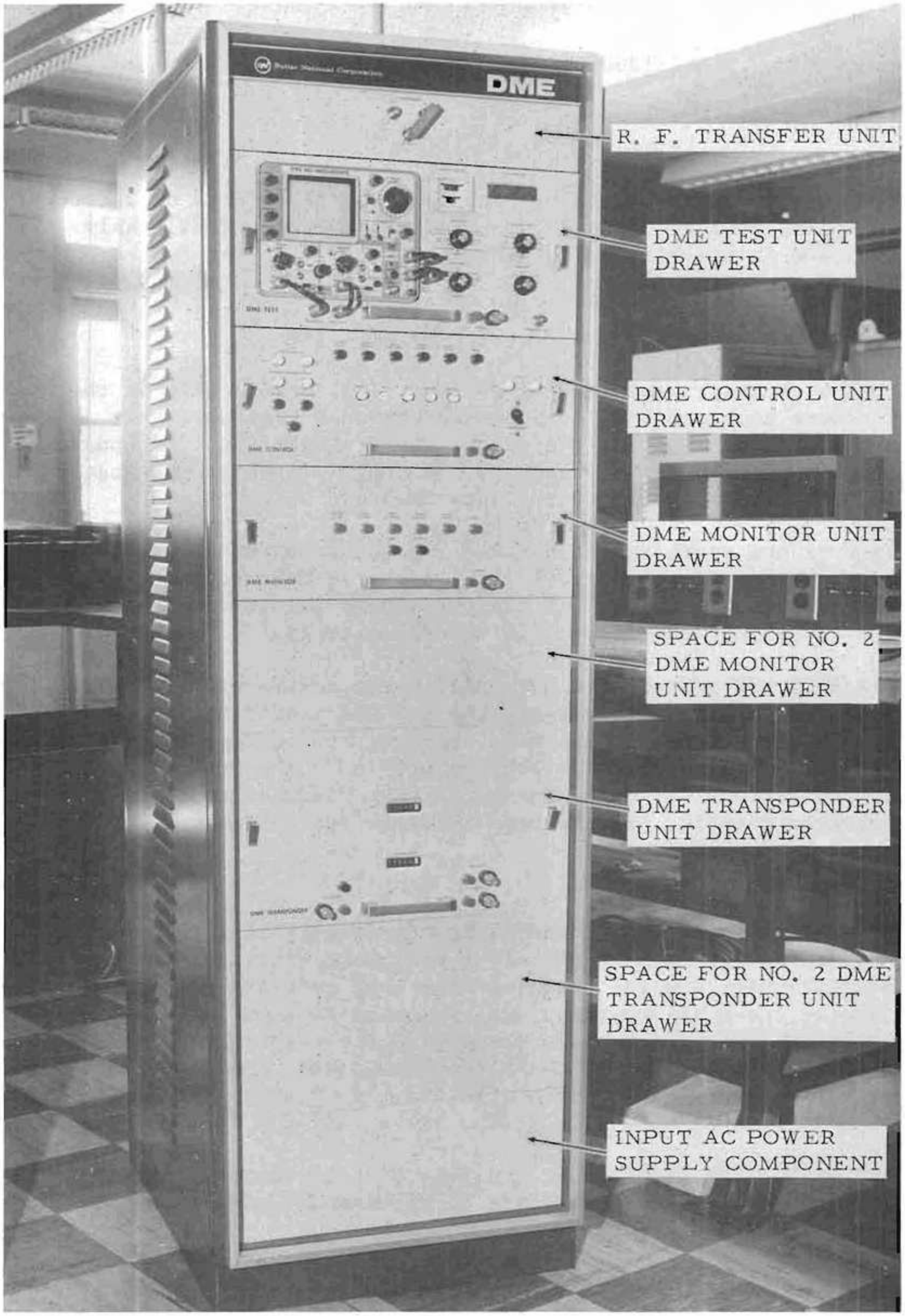


FIGURE 1. BUTLER MODEL 1020 DME

a bandwidth of 5 megahertz (MHz) minimum at the 3-decibel (dB) points. The selected incoming signals are mixed in the first mixer to provide a mixer output signal that is 63 MHz above or below the received signal, depending upon the operating frequency.

b. IF Amplifier. The first IF stage is a preamplifier, and the second IF stage is an amplifier which is selective to 63 MHz. The output of the second IF amplifier goes to a log amplifier (amp/log detector) where detection is accomplished logarithmically rather than linearly. The log IF video signal output of the log amplifier is applied as the log IF video signals out to the transponder receiver video, and also to a circuit where a d.c. voltage is developed to be used as a continous wave (CW) rejection control voltage for application to the 63-Mhz amplifier. Undetected amplitude-limited IF signals, obtained from the log amplifier at 63 MHz, are mixed with a 54.25-MHz oscillator, with a resultant difference frequency of 8.75 MHz which is then applied to a two-part filter for adjacent-channel signal rejection. The output of the two-part filter is detected, and the amplified video signal is applied to a differential amplifier. The other input of the differential amplifier is the automatic repetition rate control (ARRC) voltage developed in the decoder. This differential amplifier is used to maintain the number of replies received from the transponder between the minimum and maximum required pulse counts.

c. Decoder. Square-wave pulses from the half-amplitude finder, which represent on-channel triggers, are the input to the decoder. A control gate is used to check for proper pulse spacing, transmitter blanking, echo inhibit, and dead time. Pulse spacing is checked by sending undelayed signal pulses to the control gate and, depending upon the mode of operation, delaying the signal pulses a fixed amount and using this as the other input of the control gate. When the pulses are properly spaced (indicating properly spaced interrogation pulse pairs), one pulse from the undelayed pulse pair and one pulse from the delayed pulse pair arrive at the control gate at the same time. Transmitter-blanking, echo-inhibit, and dead-time signals are also applied to the control gate. An echo-inhibit signal is generated by the echo-suppression circuitry which may be adjusted to trigger at different interrogation signal strengths and for varying time durations. Dead time is generated whenever a pulse pair is decoded. Normally, dead time is set for 60 microsecond (μs), but can be adjusted for up to 150 μs. The transmitter sends out transmitter blanking signals whenever transmitting a reply. The transmitter blanking signal is used to inhibit the input to the receiver. If the pulse spacing of the interrogation pulse pair is of proper spacing and no transmitter blanking, echo inhibit, or dead time signal is present, the control gate will produce a decode pulse representing the interrogation pulse pair.

The decoder also includes the maximum automatic repetition rate control (ARRC), which counts the number of decoded pulse pairs out of the control gate and sends a control voltage back to the IF amplifier where it regulates pulses through the IF amplifier. The control voltage limits the maximum pulse count. The maximum pulse count is adjustable and is normally set for 2700 pps.

d. Receiver Video. The receiver video contains four sections: The half-voltage finder, ARRC No. 1, encoder trigger, and echo suppression.

The half-voltage finder uses the log pulse output and the detected output (limited IF) from the IF amplifier to feed an "AND" gate. The detected output (limited IF) allows only on-channel log pulses to be applied to the half-voltage finder. The log pulse signal is applied undelayed to a peak rider and also to a delay line. Both the undelayed and delayed signals are brought together in a comparator, where an output is produced at the half-voltage point on the leading edge of the delayed log pulse input. The comparator output is used for two functions, the decoder trigger and encoder trigger. A provision is made in the half-voltage finder to reduce the effect of severe short-distance echoes.

The echo-suppression circuits may be used when echoes are present, otherwise these circuits are quiescent. The duration of the echo-inhibit signal is proportional to the strength of the interrogation pulse pair. To insure that random pulses, do not trigger the echo-suppression circuit, an AND gate is used. One input to the AND gate is the delayed log pulse signal from the decoder, the other input is the decoder pulse. If a log pulse is present at the input to the AND gate and a decoder pulse, which represents a properly spaced interrogation, is also present, the log pulse will be allowed to trigger the echo-inhibit circuit. The echo-inhibit duration is adjustable with respect to the strength of the interrogation pulse pair.

e. Encoder. The encoder contains three sections: the identification-pulse oscillator, a priority gater and a pulse-pair generator. The identification-pulse oscillator contains a sine wave generator that produces a 1350-Hz signal. The 1350-Hz sine wave is used to produce an output from the identification-pulse oscillator of 2700 pulse pairs per second (ppps). The priority gating circuits function is to regulate the keying of replies. The identity keying line takes priority and determines whether replies to the interrogations will be processed.

The pulse-pair generator produces a pulse pair out for every pulse out of the priority gating circuit. The pulse pair contains two pulses which are called the "first pulse out" and the "second pulse out." The pulse out of the priority gating circuit is delayed. The delay of the pulse is used to set the total system delay to the nominal value of 50 μs. This delayed pulse becomes the first pulse out. The first pulse out is then fed to two points; the modulator, to become the first pulse of the pulse pair, and to an adjustable delay. Once the first pulse out is delayed by the adjustable delay, it is called the second pulse out and is fed to the modulator to make up the second pulse of the pulse pair.

f. Modulator. The inputs to the modulator are the first pulse out and the second pulse out of the encoder which trigger separate cosine-squared generators. The outputs of these generators are fed to separate Darlington buffers and then combined for amplification. The combined pulses are then fed to an emitter-follower which drives three modulating transistors, each of which controls one tube in the low-power RF amplifier.

g. RF Generator. The oscillator is a Butler oscillator using fifth-overtone crystals to produce a frequency of 80 to 100 MHz. The output of the oscillator goes to a frequency quadrupler which consists of two doublers. The new frequency is fed to the fixed-gain first amplifier and then to the second and third amplifiers which contain automatic level-control circuits. The output of the third amplifier is fed to a tripler which also provides some amplification. The CW signal is now passed to the RF amplifier where it is modulated.

h. RF Amplifier. The RF amplifier consists of three ultrahigh frequency (UHF) planar triodes which are all operated with grounded grid and a CW-driven cathode. The carrier is keyed by switching each of the three cathodes with a transistor in the modulating unit. The RF amplifier produces 100-watts peak power into a 50-ohm load.

i. Power Supply. The power supply provides regulated +28 Vd.c., +12 Vd.c., +5 Vd.c., and -6 Vd.c. to the transponder. Regulation is provided by series regulators.

Monitor Unit. The monitor contains two sections: the signal generator and the signal monitor. The signal generator is the interrogation source used in maintenance and in monitoring the transponder. The signal monitor is used to monitor the transponder parameters.

The signal generator contains a pulse-repetition-frequency (PRF) oscillator, a pulse-pair generator, a pulse shaper, a diode modulator, an RF generator, and calibrated and level-set attenuators, and provides various synchronizing functions. In normal operation, the PRF is fixed at 100 Hz, and a signal is fed to the level-set attenuators to insert a 35-dB loss for every other pulse pair transmitted from the signal generator. The signal is attenuated 35 dB to monitor reply efficiency, but for reply delay monitoring no attenuation is inserted. The calibrated attenuator is used to set the output power at a known level.

For maintenance purposes, the PRF may be varied, and the RF generator contains five selectable frequencies ± 160 kilohertz (kHz), ± 900 kHz, removed from the interrogation frequency. This is done so that the monitor may check different parameters for maintenance.

The signal monitor contains a peak-power monitor, a half-amplitude finder, a pulse counter, an identification monitor, a delay counter, accept gates, and a reply-efficiency monitor. The signal monitor monitors six parameters: identification, system delay, pulse spacing, receiver-reply efficiency, power out, and transponder pulse count. Monitored parameters are applied to the control unit.

Control Unit. The control unit allows for the manual control of the DME. Control may either be local (from the front panel) or switched from a remote site. The control unit, using information from the signal monitor, will cause the system to shut down if a fault occurs.

Test Unit. The test unit, an optional feature, contains equipment used to service the DME. The equipment consists of a time-mark generator, a counter, and an oscilloscope. The time-mark generator was designed to enable accurate measurement of delay times on the oscilloscope. The counter is wired into the DME cabinet, and parameters of interest are brought to a wafer switch where the desired counter inputs can be selected.

THEORY OF OPERATION.

AUTOMATIC REPETITION RATE CONTROLS (ARRC). The automatic repetition rate controls are made up of two units, ARRC No. 1 and ARRC No. 2. ARRC No. 1 is used to maintain a reply repetition rate of at least 1000 ppps, and ARRC No. 2 is used to limit the reply repetition rate to 2700 ppps.

ARRC No. 1 uses all pulses that are within the bandwidth of the preselector in determining the minimum reply repetition rate. Only when two consecutive pulses are spaced 12 μs apart will the DME produce a reply pulse pair. Therefore the counter must count more than 2000 pulses/sec in order to maintain a reply repetition rate of 1000 ppps.

ARRC No. 2 counts the number of interrogations from the aircraft, monitor, and squitter. The input to the ARRC No. 2 is the output of the decoder. Each pulse out of the decoder represents a properly spaced pulse pair and will trigger a reply pulse pair. The reply repetition rate is determined by counting the pulses out of the decoder. If the reply repetition rate exceeds 2700 ppps, a control voltage will reduce the gain of the IF amplifier causing it to process only the stronger signals.

Both ARRC No. 1 and ARRC No. 2 use similiar circuits to develop a voltage which is inversely proportional to the number of pulses applied. Input pulses for the ARRC circuits drive a one-shot multibrator (MV) where the output is a fixed, predetermined-width rectangular pulse. The fixed, predetermined-width pulses are integrated before going to the inverting terminal of a differential amplifier.

A reference voltage is the other input of the differential amplifier. The output of the differential amplifer is a voltage inversely proportional to the number of pulses applied and is fed to the IF amplifier for limiting. Outputs of ARRC No. 1 and ARRC No. 2 circuits are fed through separate diodes to the IF amplifier. The ARRC voltage is applied to one terminal of a voltage comparator in the IF amplifier. The other terminal of the voltage comparator is interrogation pulses received through the preselector. Interrogation pulses will only be processed through the voltage comparator if their amplitude is greater than the ARRC control voltage.

If the reply repetition rate goes below 1000 ppps, ARRC No. 1 will take control and make the IF amplifier more sensitive so that more pulses will get into the system. If the reply repetition rate is above 2700 ppps, ARRC No. 2 will cause the IF amplifer to become less sensitive and process less pulses.

ECHO SUPPRESSION.

Long-Distance Echo Suppression. Long-distance echo suppression is used when echoes occur after the pulse pair. They can be adjusted "in" if echoes are a problem at the site or may be adjusted "out" if no long-distance echo problem exists. Information used to trigger the echo-suppression pulse is the video signal from the transponder receiver video and the decode gate pulse from the decoder. If both pulses, receiver video and decoder gate pulse, are present at the same time, a pulse will be produced to trigger a transistor which allows a capacitor to charge to a value which is representative of the incoming signal strength and then turns OFF the transistor.

The capacitor is allowed to discharge through a variable resistor which controls the rate of discharge. The discharging voltage is fed through a transistor to one input of a comparator. As long as the discharging voltage is above the reference voltage at the other terminal of the comparator, an output pulse will be generated. The width of the pulse will be the time that the discharging voltage is above the reference voltage. The reference voltage is adjusted by varying a voltage divider. If the reference voltage is higher than the value of the strongest interrogation, no suppression pulse will take place. When an echo-suppression pulse occurs, no data is processed in the decoder for the width of the pulse.

Figure 2 shows some of the effects of varying the discharge times on the echo-suppression pulse while the reference voltage and the signal strength are held constant. Four separate decay times are shown (a,b,c, and d), and their respective echo-suppression pulses are also depicted.

Severe Short-Distance Echoes. If echoes are short enough to exist between the pulse pairs, severe short-distance echo suppression must be used. Echo suppression is accomplished by resetting the half-amplitude finder after every pulse. In effect, this blanks out the half-amplitude finder between pulses and thus takes care of the short-distance echoes. Under normal conditions, when a pulse is generated at the half-amplitude of the incoming pulse, this pulse is sent to a one-shot (MV) whose output width is adjustable. The output of the one-shot (MV) is sent to the decoder as a decoder trigger, and is also used to reset the peak rider and back-bias a transistor to protect it. When the short-distance echo suppression is used, the same thing happens as above, but the pulse also is fed to the half-amplitude finder to reset it.

First- and Second-Pulse Timing. The Butler DME has the capability of having the normal second-pulse timing and, with a modification, first-pulse timing. The transponder decoder checks the pulse spacing of incoming interrogations and, if the pulse spacing is proper, decodes the pulse pair into a pulse used to trigger the encoder to produce a reply pulse pair. Both timing techniques use the same input signal from the on-channel triggers to trigger a MV which produces a 5-μs-wide pulse for every on-channel trigger (figure 3, points B and BB). The 5-μs wide pulse is used to generate a 0.2-μs-wide pulse. The 5-μs wide pulse and the 0.2-μs wide pulse are shifted in time

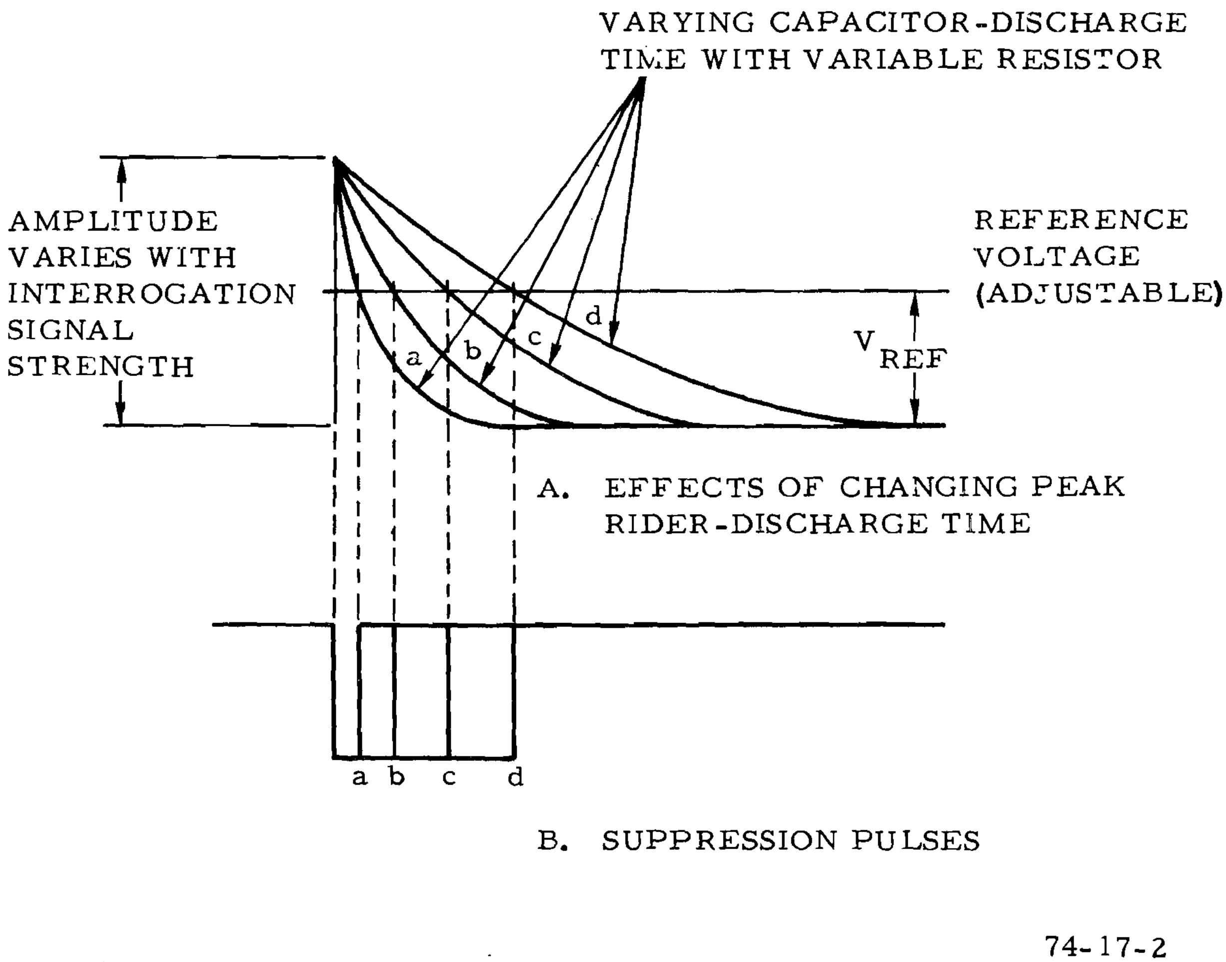


FIGURE 2. LONG-DISTANCE ECHO SUPPRESSION

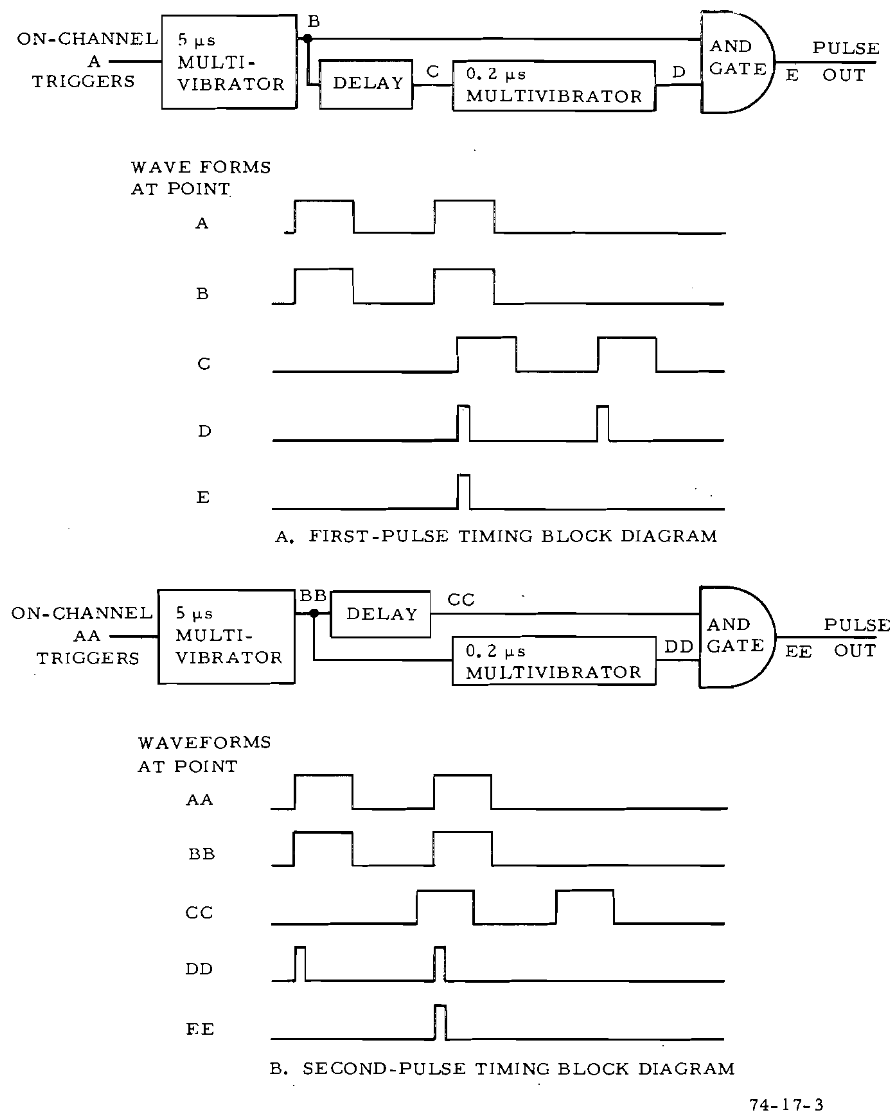


FIGURE 3. FIRST-PULSE VERSUS SECOND-PULSE TIMING, BLOCK DIAGRAM

with respect to each other. If the pulse spacing is correct, a wide pulse and a narrow pulse will occur at the same time, and the logic circuits will produce a decode pulse.

First-pulse timing delays the 5-μs-wide pulses out of the 5-μs MV by a fixed amount (figure 3, point C) and then sends the delayed 5-μs-wide pulse to a 0.2-μs MV (figure 3, point D). The undelayed 5-μs-wide pulses and the delayed 0.2-μs-wide pulses are fed to logic circuits. If the pulse spacing is correct, the second undelayed 5-μs-wide pulse of the pulse pair (figure 3 point B) will occur at the input to the logic circuit at the same time as the first 0.2-μs-wide pulse of the pulse pair (figure 3, point D), and a decode pulse will be produced (figure 3, point E).

Second-pulse timing sends the 5-μs-wide pulses to a 0.2-μs MV (figure 3, point DD) and to a delay line (figure 3, point CC). The delayed 5-μs-wide pulses and the 0.2-μs-wide pulses are then sent to a logic circuit. If the pulse spacing is correct, the second 0.2-μs-wide pulse of the pulse pair (figure 3, point DD) will occur at the same time as the first 5-μs-wide pulse of the pulse pair (figure 3, point BB). A decode pulse will take place if the pulse spacing is correct (figure 3 point EE).

The delays for both timing techniques are adjusted so that when the pulse spacing is correct, the 0.2-μs-wide pulse will be in the middle of the 5-μs-wide pulse. The logic is designed such that decoding will only take place if no transmitter blanking, dead time, or echo suppression is taking place. The 5-μs-wide pulses determine the decoder tolerance. As long as the 0.2-μs-wide pulse occurs within the 5-μs-wide pulse, decoding will take place. The determining factor as to when the decode will take place is the 0.2-μs-wide pulse. If the 0.2-μs-wide pulse used to decode is the first pulse of the pulse pair, the timing technique is first-pulse timing, and if the second pulse of the pulse pair is used, the technique is second-pulse timing.

DISCUSSION

GENERAL.

The Butler DME Model 1020 ground station was set up in the laboratory where familiarization, operational checks, and testing of the equipment took place. Butler has incorporated first-pulse timing to improve reply-delay and echo-suppression circuits to reduce the false-DME problem. Laboratory tests were conducted to check out these new features. The tests included checking the reply delay of first-pulse timing as compared to second-pulse timing with various interrogation pulse spacings, effectiveness of the echo-suppression circuits in reducing the false-DME problem, and effect of the echo-suppression circuit on traffic-handling capability.

Checking the reply delay of first-pulse timing as compared to second-pulse timing with various interrogation-pulse spacings was accomplished by measuring the delay time between the first pulse of the interrogation and the first pulse of the reply. The effectiveness of the echo-suppression circuit was determined by injecting a false interrogation signal into the ground station, with the echo-suppression circuit adjusted in and measuring the number of false interrogations that were processed. To determine the effect that echo suppression had on traffic-handling capability, the echo-suppression circuit was activated, interrogation loading was varied, and the number of interrogations processed was measured.

LABORATORY TESTS.

FIRST-PULSE VERSUS SECOND-PULSE TIMING TESTS. Prior to performance tests, the monitor-pulse spacing and the transponder reply delay were set in accordance with the Butler Instruction Manual for the Model 1020 DME. The pulse spacing was set for 12 μs, and the reply delay was set to 50 μs. Equipment used for the test consisted of the Butler transponder unit, Butler test unit, Dumont 766H oscilloscope, and a scope camera, as depicted in figure 4. The Dumont oscilloscope was externally triggered from the trigger output of the test unit. By externally triggering the oscilloscope, the output of the reply-delay terminal, and the time-mark generator, would be in sync, and the Dumont oscilloscope could be used to accurately measure the time between the pulses. Time was measured from the first pulse of the interrogation to the first pulse of the reply with both first-pulse timing and second-pulse timing as the interrogation-pulse spacing was set for 10, 11, 12, 13, and 14 μs. A picture was taken of the interrogation pulse pair and the first pulse of the reply. The reply pulse pair was always spaced at 12 μs and does not change with different interrogation-pulse spacing.

TRAFFIC-HANDLING CAPABILITY TEST. Testing the traffic-handling capability of the DME with respect to the echo-suppression circuits consisted of randomly interrogating the ground station and measuring (1) the number of interrogations to the DME ground station, (2) the number of replies from the transponder to these interrogations, and (3) the total number of pulse pairs transmitted from the transponder. The interrogation rate was varied from zero ppps to 5000 ppps with the echo-suppression gate set at a specific width. The echo-suppression gate widths used were 0, 50, 100, 200, and 400 μs.

Random interrogations were produced externally and these interrogations were applied through the DME monitor to simulate interrogations to the ground station as depicted in figure 5.

An AN/ARM-22 Radio Test Set subpart pulse generator was used to provide pulse pairs with random periods to externally modulate a Hewlett-Packard 612A UHF RF generator operating in the pulse 2 mode. The output of the RF generator is a modulated carrier, which has constant-amplitude pulse pairs that may be changed in amplitude by adjusting the RF generator output level. The modulated

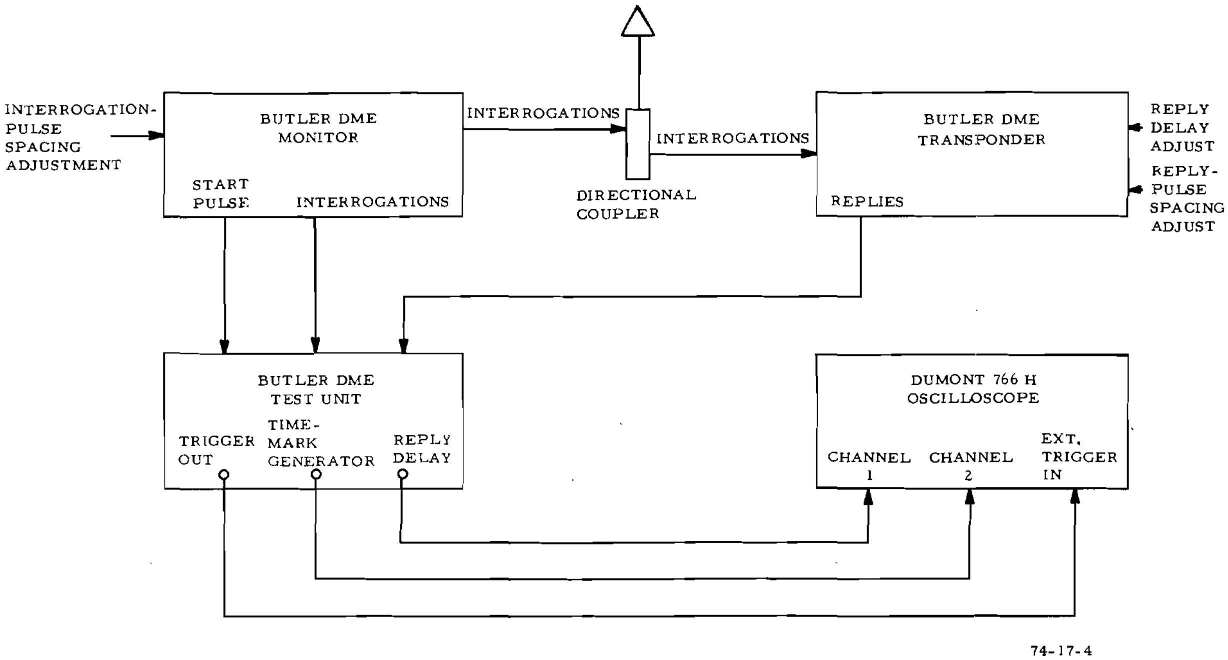


FIGURE 4. FIRST-PULSE VERSUS SECOND-PULSE TIMING, TEST CONFIGURATION

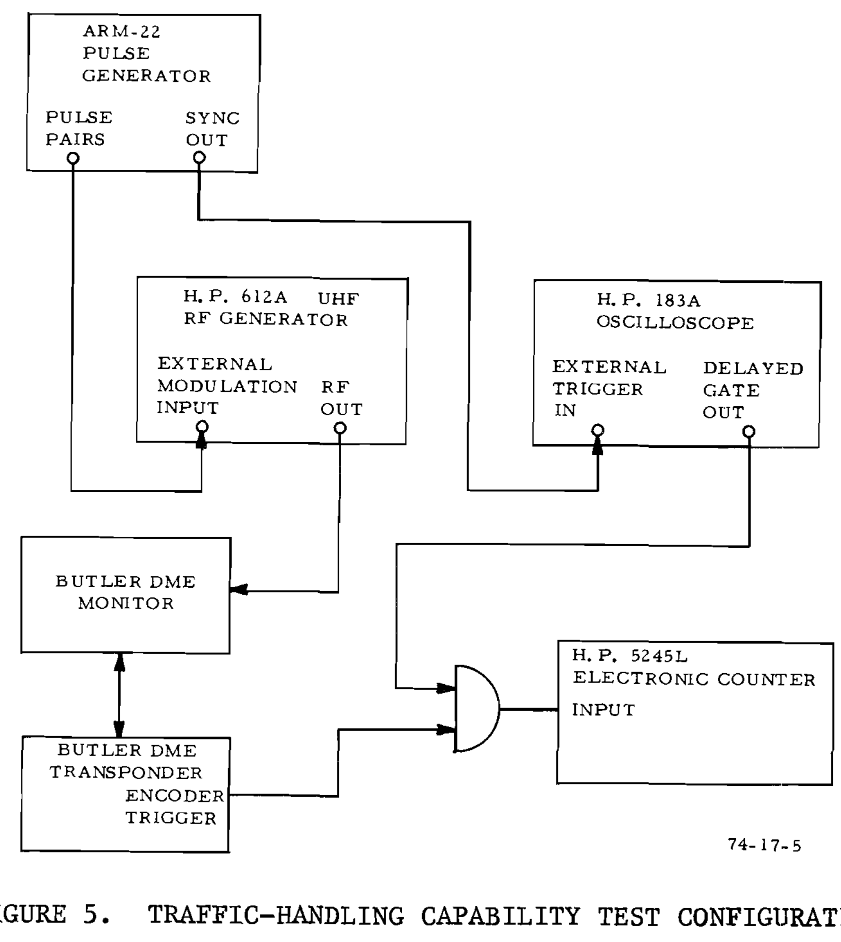


FIGURE 5. TRAFFIC-HANDLING CAPABILITY TEST CONFIGURATION

carrier was used to simulate random-period interrogation loading of the DME ground station. The monitor pulse pair generator, normally used to provide interrogations into the system for maintenance and monitoring, was disconnected, and the output of the Hewlett-Packard RF generator was applied to the DME ground station in place of the monitor pulse pair generator.

Measurements were taken of the number of interrogations, the number of replies to the interrogations, and the total number of pulse pairs transmitted from the transponder. The equipment used for these measurements consisted of a Hewlett-Packard 5245L electronic counter, Hewlett-Packard 183A oscilloscope with 1801A and 1821 plug-ins, and the Butler DME test unit. The pulse pairs out of the AN/ARM-22 pulse generator were counted by the electronic counter and represent the number of interrogations of the ground station. The total number of pulse pairs being transmitted from the Butler DME was counted on the test-unit counter with the input selector set to tranmitter. In order to count the number of replies to the interrogations, the counter must only count pulses that are not only synchronous with, but delayed from the interrogations. An AND gate was used to provide the selectivity needed for counting. One input to the AND gate was the encoder trigger from the Butler DME, which represents a decoded interrogation and was signaling the pulse pair generator of the transponder to produce a reply. The other input to the AND gate was a pulse from the delayed trigger gate of the oscilloscope which allows only those encoder triggers which occur during the delayed trigger gate pulse to be counted. The oscilloscope was externally triggered from the sync output of the AN/ARM-22 pulse generator. Once the oscilloscope was triggered, the pulse from the delayed trigger gate output could be delayed from the main sweep by controls on the scope. The delay was adjusted so that the delayed trigger pulse could be delayed the same amount from the interrogation as the encoder trigger. The width of the delayed trigger gate pulse determined how accurately the reply delay must be in order to be counted.

AUTOMATIC REPETITION RATE CONTROL TESTS. The automatic repetition rate control (ARRC) test determined the normal traffic-handling capability of the DME with respect to the ARRC's. The test configuration was the same as for the traffic-handling capability tests. With the echo-suppression circuits turned OFF, two tests were performed. The first test consisted of setting the ARRC No. 1 control to 1000 ppps, removing the ARRC No. 2 control, and with different interrogation loadings, recording the number of transmitter pulse pairs, the number of replies to the interrogations, and the number of replies due to noise. The second test recorded the same parameters and was conducted the same way, except the ARRC No. 2 control was set for 2700 ppps.

ECHO SUPPRESSION - FALSE-DME TESTS. The echo suppression - false lock-on test consisted of interrogating the ground station with an interrogation pulse pair plus a false interrogation pulse pair and recording the number of false interrogations that were replied to, with and without echo suppression. Echo suppression - false-DME test configuration is shown in figure 6.

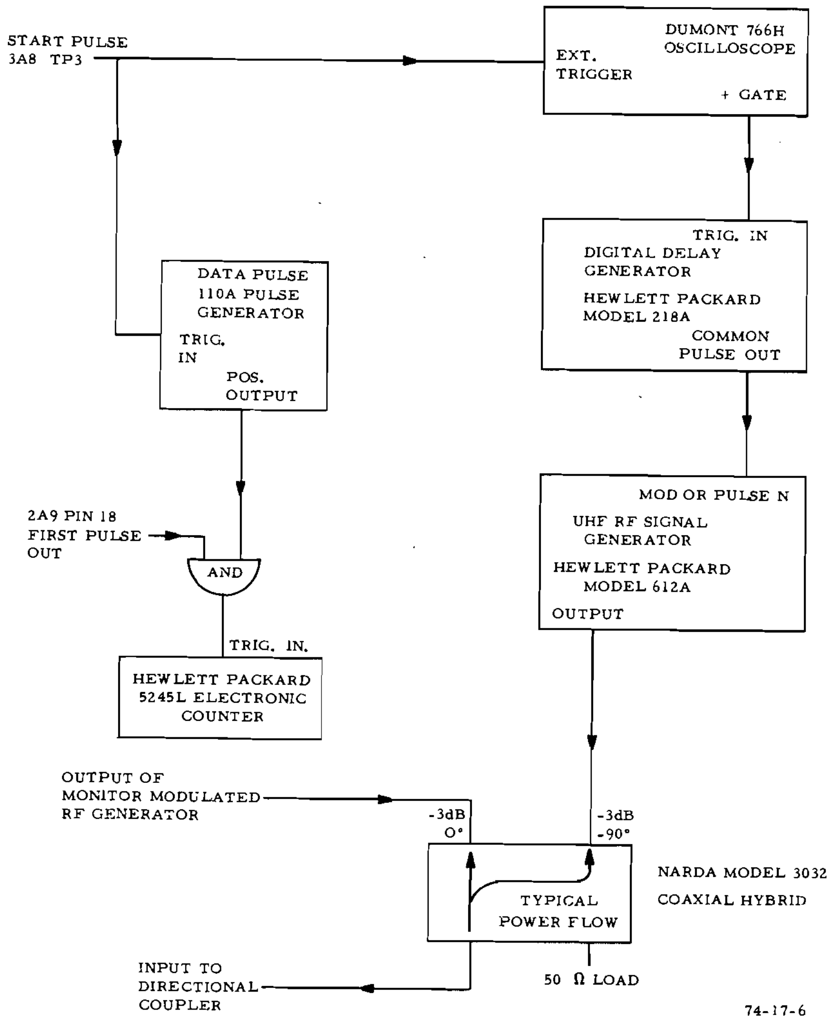


FIGURE 6. ECHO SUPPRESSION - FALSE-DME TEST CONFIGURATION

The start pulse from the Butler signal generator, which generates the normal interrogation, was delayed by an external delay generator. The output of the delay generator was a pulse pair in sync with, but delayed from the start pulse and used to modulate the UHF RF generator operating in the pulse 2 mode. The normal interrogation from the monitor RF generator and the false interrogation generated externally were routed to the coaxial hybrid whose output was applied to the normal output of the monitor RF generator. The output of the monitor RF generator fed the transponder-unit interrogations through the cabinet wiring into a directional coupler with a 30-dB insertion loss, as if an interrogation was from an airplane.

To measure the effect of the echo-suppression circuit a DATA PULSE 110A pulse generator, and a Hewlett-Packard 5245L electronic counter were used. An AND gate was used to gate through only those pulses that were in sync with, but delayed from the false interrogation. One input to the AND gate was an externally delayed start pulse delayed by the DATA PULSE 110A pulse generator, and the other input was the first pulse of the encoder. The first pulse of the encoder was used by the transponder to trigger the first pulse of the reply pulse pair. The output of the AND gate was counted on the counter for 10-second intervals.

LABORATORY RESULTS.

FIRST-PULSE VERSUS SECOND-PULSE TIMING. Table 1 lists the tabulated data of the measured reply delays with various interrogation-pulse spacings for first-pulse and second-pulse timing. Figures 7 and 8 show examples of the pulses used to determine reply delay, for different interrogation pulse spacings utilized. Reply delay was measured from the half-amplitude point on the leading edge of the first interrogation pulse to the half-amplitude point on the leading edge of the first pulse of the reply pulse pair. The markers were spaced at 1-μs intervals, with the major marker at the reply delayed 50 μs from the half-amplitude point of the leading edge of the first interrogation pulse.

The data shows that with second-pulse timing, the reply delay changes in direct proportion to the interrogation-pulse spacing. First-pulse timing shows that the reply delay remained constant for the various interrogation-pulse spacings.

TABLE 1. FIRST-PULSE VERSUS SECOND-PULSE TIMING TEST RESULTS

Pulse Spacing	First-Pulse Timing Delay*	Second-Pulse Timing Delay*
10 μs	50.1 μs	47.9 μs
11 μs	50.1 μs	48.9 μs
12 μs	50.0 μs	50.0 μs
13 μs	50.0 μs	50.8 μs
14 μs	50.2 μs	51.8 μs

*Delay measured from the half amplitude of the first pulse of the interrogation pulse pair to the half amplitude of the first pulse of the reply pulse pair.

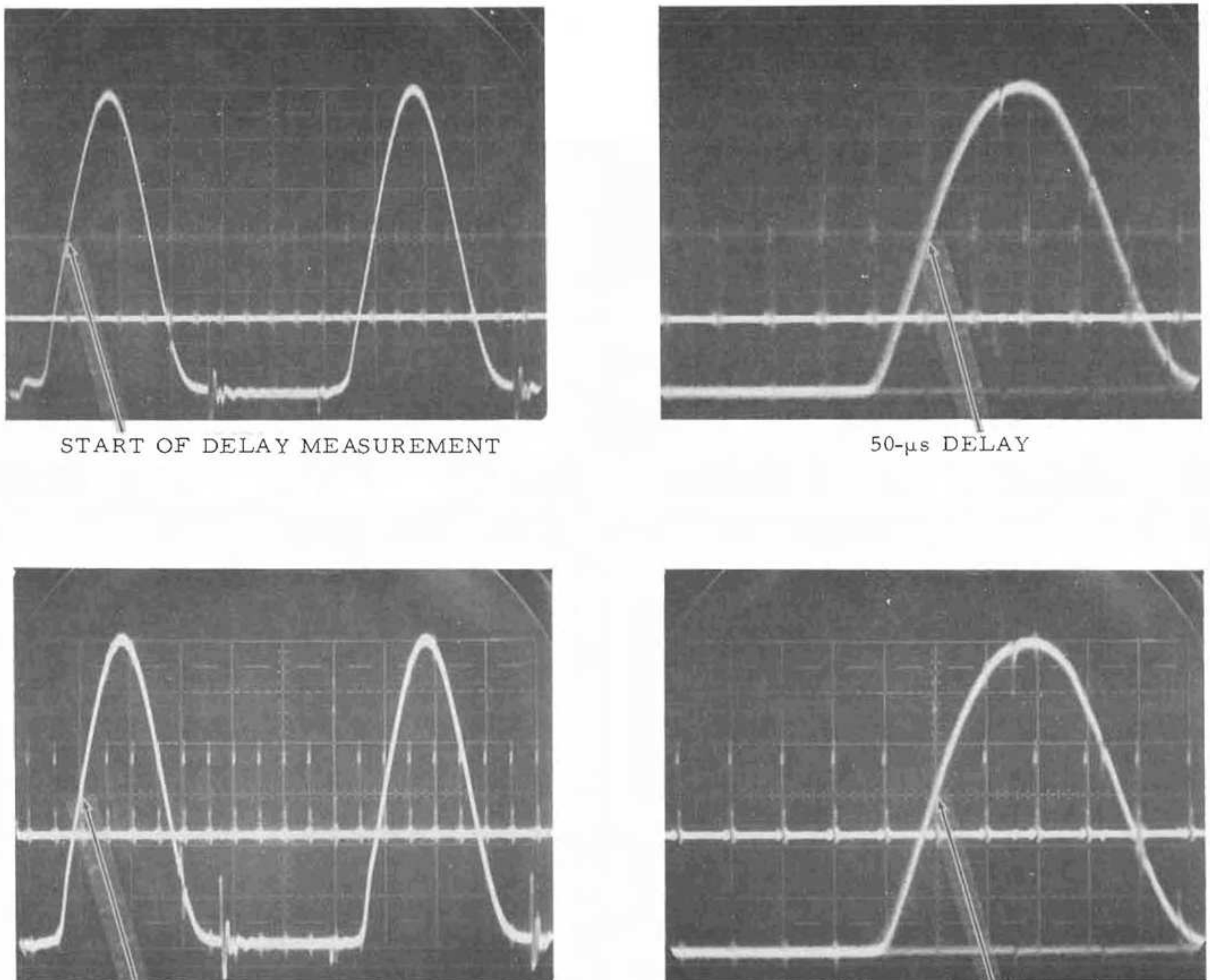
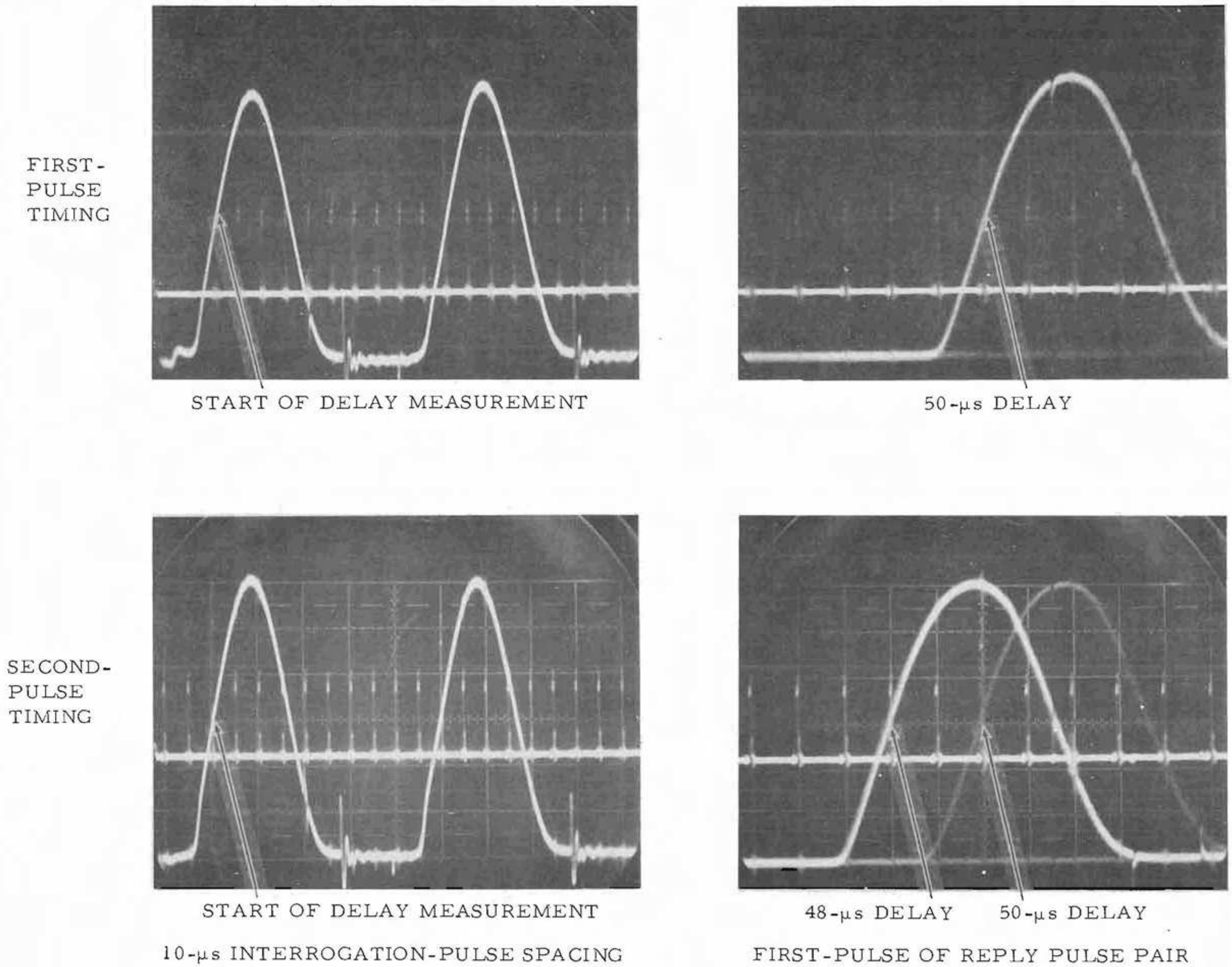


FIGURE 7. FIRST-PULSE VERSUS SECOND-PULSE TIMING, PHOTOGRAPHS WITH 12-μs INTERROGATION-PULSE SPACING



74-17-8

FIGURE 8. FIRST-PULSE VERSUS SECOND-PULSE TIMING, PHOTOGRAPHS WITH 10-μs INTERROGATION-PULSE SPACING

ARRC CONTROL TEST RESULTS. Figures 9 and 10 show the effects of ARRC control on the number of pulse pairs transmitted from the ground station, the number of interrogations replied to, and the number of transmitted pulse pairs due to squitter. The X axis represents the number of random-period pulse pairs used to interrogate the ground station.

Each figure contains three plots: No. 1 is pulse pairs out of the transmitter versus interrogations; plot No. 2 is replies to the interrogations versus interrogations; and plot No. 3 is replies due to noise versus interrogations.

The Y axis for plot No. 1 is the number of transmitter pulse pairs out of the ground station, and for plot No. 2 and No. 3, the Y axis is the number of reply pulse pairs out of the ground station.

Figure 9 shows that without ARRC No. 2, the number of transmitted pulse pairs increases as the interrogations increase (plot No. 1). Plot No. 2 shows that as the interrogation rate increases, the number of replies to the interrogations increase, and plot No. 3 shows that as the interrogation rate increases, the number of replies due to noise decreases.

In figure 10, all conditions of the test are the same as in figure 9, except the ARRC No.2 has been set to the normal value of 2700 pulse pairs. Plot No. 1 of figure 10 shows that the number of transmitted pulse pairs increases with the increase of interrogation pulse pairs, but once the number of transmitted pulse pairs reaches 2700, it maintains a maximum transmitted pulse count of 2700 pulse pairs for all increasing values of interrogations. Plot No. 2 shows the number of replies to the interrogations increasing with increasing interrogation. The number of replies increases until the number of replies reaches 2700 pulse pairs; the same value as the number of transmitted pulses. Plot No. 3 shows that the number of replies due to squitter decreases as the interrogation rate is increased. The number of replies due to squitter goes to zero when the number of transmitted pulses equals the number of replies to the interrogations.

TRAFFIC-HANDLING CAPABILITY TEST. Figure 11 shows the reply efficiency of the ground station for different interrogation rates. The X axis represents the rate of interrogations in pulse pairs. The Y axis represents the reply efficiency in percent. Reply efficiency was determined by dividing the number of replies to the interrogations by the number of interrogations times 100 percent. Several plots are presented on this one figure. Plot No. 1 shows the reply efficiency of the ground station with no ARRC No. 2 and no echo suppression. The reply efficiency remained above 85 percent for all interrogation rates. Plot No. 2 shows the reply efficiency of the ground station with ARRC No. 2 adjusted for 2700 ppps, but with no echo suppression. The reply efficiency remained above 85 percent until an interrogation rate of 3000 ppps was reached. After this point, as the interrogation rate increased the reply efficiency decreased until, at 5000 ppps, the reply efficiency was down to 52 percent. Plot No. 3 shows the effects of adding a 50-μs-wide

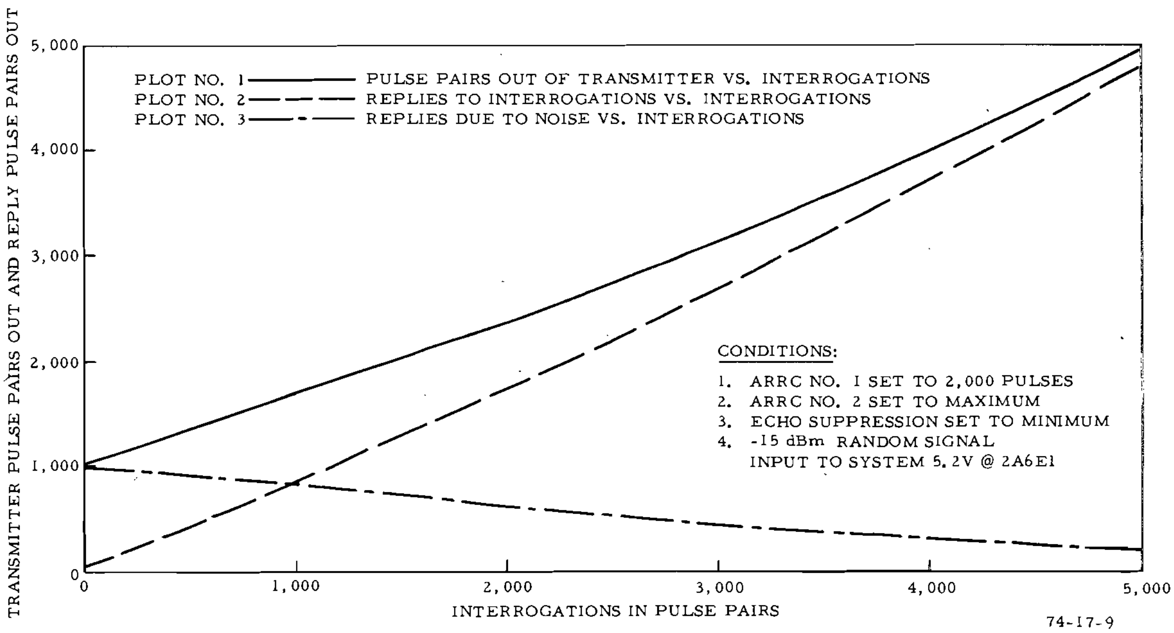


FIGURE 9. ARRC CONTROL, TEST RESULTS WITH NO ARRC NO. 2

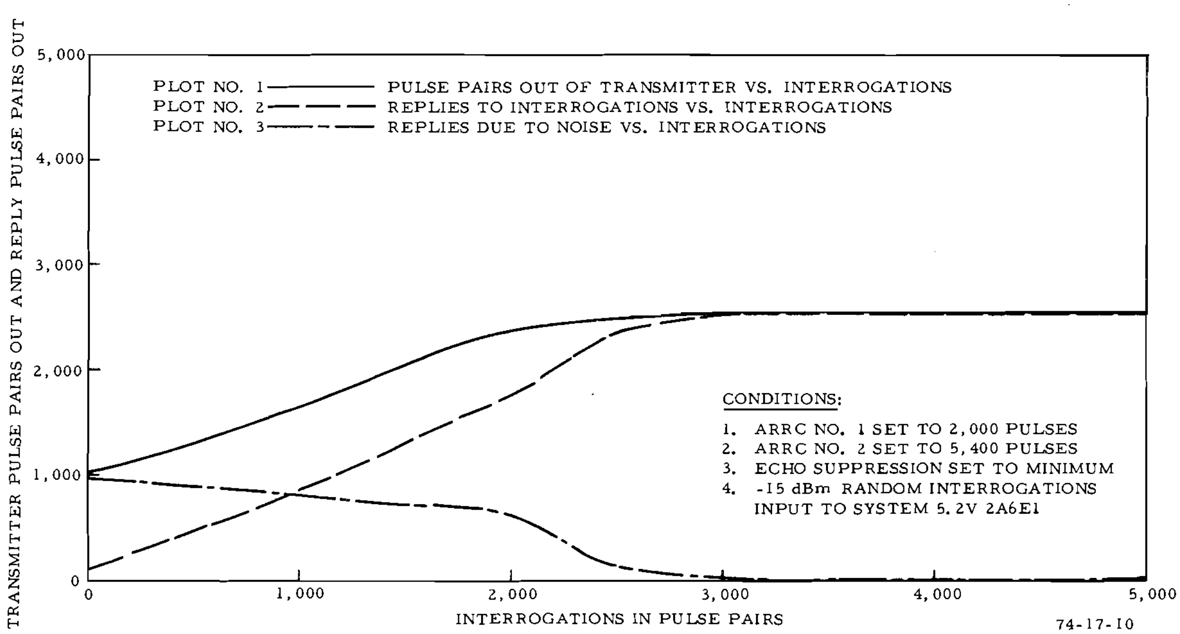
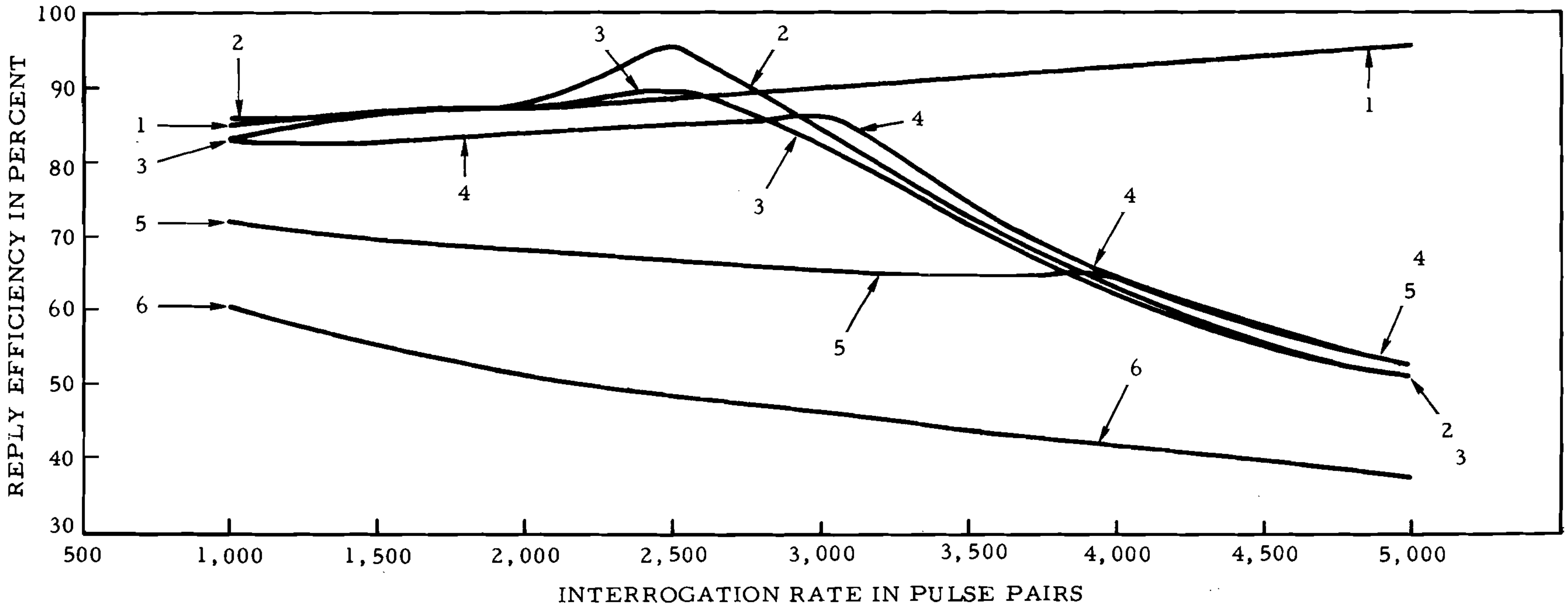


FIGURE 10. ARRC CONTROL, TEST RESULTS WITH ARRC NORMAL



CONDITIONS OF TEST

PLOT NO.	ARRC NO. 1 PPPS	ARRC NO. 2 PPPS	ECHO-SUPPRESSION GATE WIDTH μs
1	1,000	NONE	0
2	1,000	2,700	0
3	1,000	2,700	50
4	1,000	2,700	100
5	1,000	2,700	200
6	1,000	2,700	400

74-17-11

FIGURE 11. REPLY EFFICIENCY VERSUS INTERROGATION RATE

echo-suppression gate. The results were similiar to thoses in plot No. 2. Plot No. 4 shows the effects of increasing the echo-suppression pulse to 100 μs. The reply efficiency was 82 percent at an interrogation rate of 1000 ppps, increasing to 87 percent at an interrogation rate of 3000 ppps, at which point the reply efficiency decreased to a value of 52 percent at an interrogation rate of 5000 ppps. Plot No. 5 shows the effects of a 200-μs-wide echo-suppression pulse. The reply efficiency at an interrogation rate of 1000 ppps was 72 percent and decreased to 52 percent at an interrogation rate of 5000 ppps. Plot No. 6 shows the effects of a 400-μs-wide echo-suppression gate. The reply efficiency was 60 percent at an interrogation rate of 1000 ppps, decreasing to 38 percent at an interrogation rate of 5000 ppps.

ECHO SUPPRESSION - FALSE LOCK-ON TESTS. Figure 12 shows the reply efficiency of the echo versus the interrogation rate with various echo-suppression gate widths. The X axis represents the interrogation rate of the false interrogation (echo). The Y axis of the figure represents the reply efficiency of the echo. The echo was delayed 100 μs from the true interrogation. Plot No. 1 shows the reply efficiency of the echo was approximately 91 percent for an interrogation rate of 100 ppps to 1500 ppps, with no echo suppression. Plot No. 2 shows that with an echo-suppression gate width of 50 μs, the echo reply efficiency remained approximately 91 percent. Plot No. 3 had an echo-suppression gate width of 100 μs and plot No. 4, 150 μs. These two plots show the reply efficiency of the echo as 11 percent for an interrogation rate from 100 ppps to 1500 ppps.

Figure 13 shows the effect on echo reply efficiency while holding the width of the echo-suppression gate fixed and changing the delay of the false interrogation with respect to the true interrogation. The X axis represents the delay of the false interrogation from the true interrogation. The Y axis represents the reply efficiency of the false interrogation. The echo-suppression gate width was held constant at 100 μs for the 4 plots. Plots No. 1 and 2 had a pulse repetition rate of 500 ppps and plots No. 3 and 4, 1000 ppps. Plot No. 1 and 3 use an initial adjustment of the echo-suppression gate width of 100 μs. In plot 2 and 4, the RC decay time of the echo-suppression circuit was changed, and then the reference voltage was adjusted to obtain an echo-suppression gate width of 100 μs. Plots No. 1 and 2 show a reply efficiency for the echo of 11 percent with the false interrogation delayed 50 μs to 90 μs; at 100 μs, the efficiency goes to 85 percent and, with a delay of 110 μs to 140 μs, a reply efficiency of 91 percent. Plot No. 3 is similiar to plot No. 1 and 2, but, with a delay of 100 μs, the reply efficiency is up to 90 percent. Plot No. 4 is similiar to plot No. 3, except that at a delay of 90 μs, the reply efficiency is up to 55 percent.

Another test was conducted where a false interrogation was generated to fall within a 70-μs-wide echo-suppression gate. The amplitude of the false interrogation was increased to -35 dBm (-5 dBm from generator and 30-dB loss in directional coupler) to determine if the echo-suppression gate could be broken. With an amplitude of -35 dBm, the gate could not be broken.

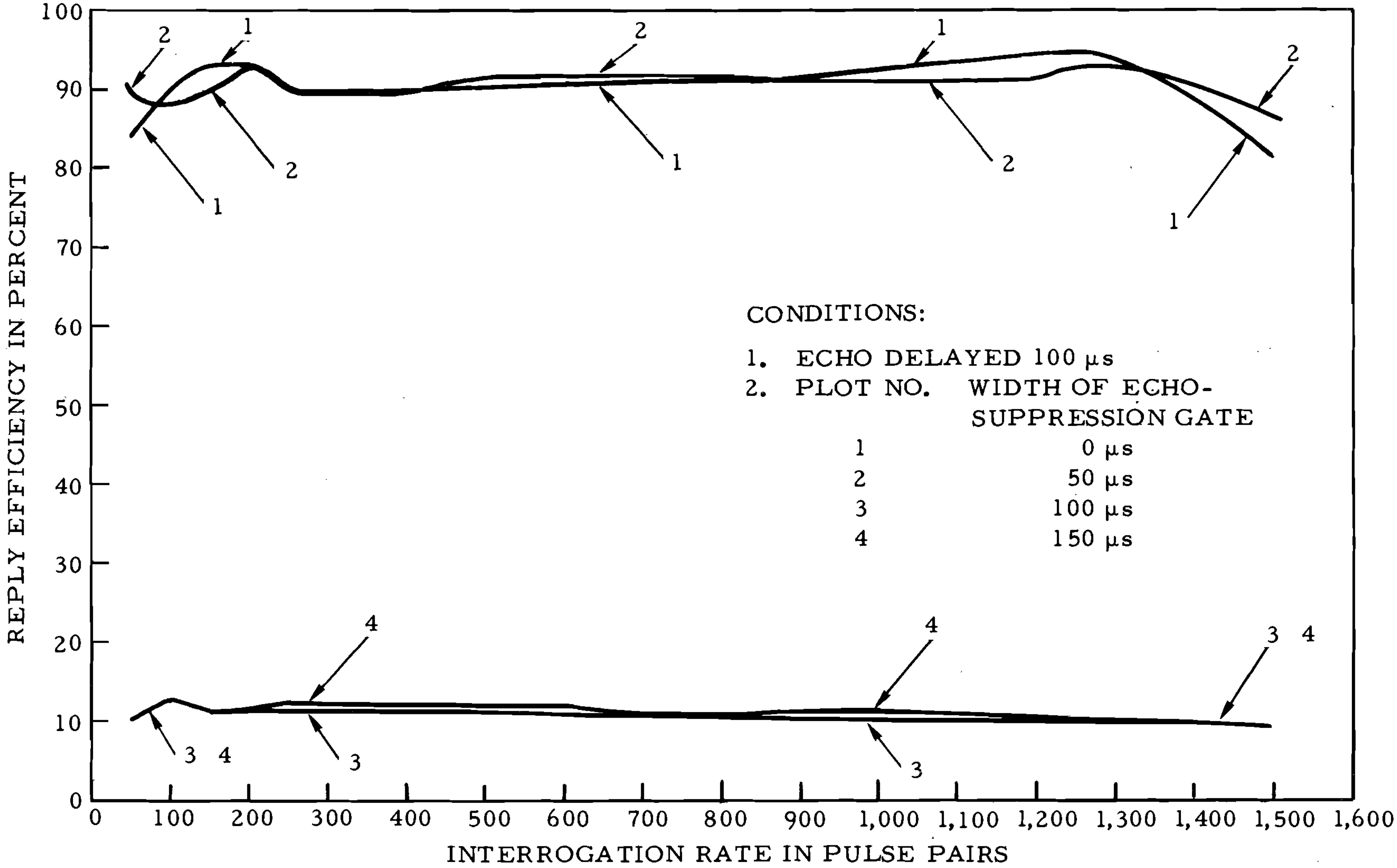


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FIGURE 12. INTERROGATION RATE VERSUS REPLY EFFICIENCY OF ECHO WITH DIFFERENT ECHO-SUPPRESSION GATE WIDTHS

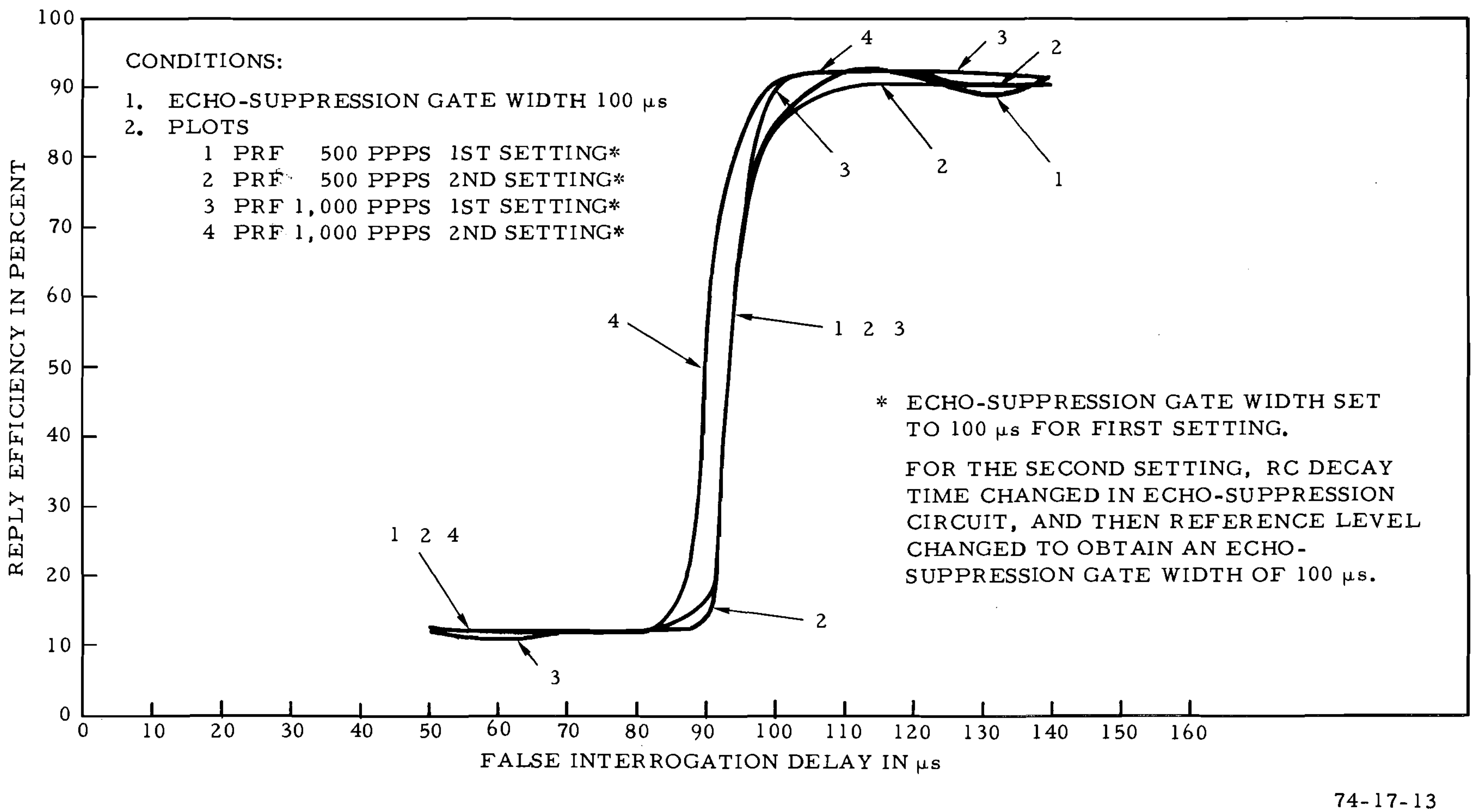

FIGURE 13. REPLY EFFICIENCY OF THE ECHO VERSUS FALSE-INTERROGATION DELAY

ANALYSIS

FIRST-PULSE VERSUS SECOND-PULSE TIMING.

Presently, second-pulse timing is used in the DME ground station. First-pulse timing is a proposed method to increase the accuracy of the DME system. Airborne DME's measure the time it takes for it's transmitted signal to reach a ground station, trigger the ground station to produce a reply pulse pair, and be received at the airborne DME to determine the slant distance to the ground station. The ground station must delay all interrogations by a fixed amount (50 μs). This delay of the reply from the interrogation is called the reply delay.

With the present second-pulse timing, the reply delay of the ground station will remain constant from the second pulse of the interrogation to the second pulse of the reply. Airborne units assuming reply delay from second pulse of interrogation to second pulse of the reply will have the reply delay remain constant for all decodeable interrogation-pulse spacing. Many airborne units measure delay from the first pulse of the interrogation to the first or second pulse of the reply. The reply-pulse spacing from the ground station is 12 μs, regardless of the interrogation-pulse spacing. If second-pulse timing is used and the airborne unit measures from the first pulse of the interrogation, the pulse spacing of the airborne unit is included in the delay. The decoder tolerance on the ground station is such that interrogation pulse spacings of other than 12 μs will be decoded. Therefore, reply delay will be dependent upon interrogation-pulse spacing.

With the proposed first-pulse timing, the reply delay between the first pulse of the interrogator and the first pulse of the reply will remain constant for all decodable interrogation-pulse spacings.

Delay between the first pulse of the interrogation and the second pulse of the reply will also remain constant for all decodable interrogation-spacings. This is true because the delay between the first pulse of interrogation and the first pulse of the reply (reply delay) remains constant, and the delay between the first pulse of the reply and the second pulse of the reply (pulse spacing) also remains constant for all decodable interrogation-pulse spacings.

If the interrogation-pulse spacing is exactly 12 μs, both methods are equally as accurate. If the interrogaion-pulse spacing is other than 12 μs, and within the decoder tolerance, second-pulse timing will maintain a constant reply delay from second pulse of the interrogation to the second pulse of the reply. First-pulse timing will maintain a constant reply delay for the many airborne units that measure delay from the first pulse of the interrogation to the first or second pulse of the reply.

ARRC CONTROL TEST.

The results of the ARRC control test analysis without ARRC No. 2 control (shown in figure 9) illustrates that as the interrogation rate increased, the total number of transmitted replies increased, and the number of replies to the interrogations increased. In figure 10, with ARRC control set to normal, the total number of transmitted replies was limited to 2700 ppps, and the number of replies to the interrogations was limited to 2700 ppps. With normal ARRC, when the interrogation rate reaches approximately 2700 ppps, the number of replies to these interrogations will be limited to 2700 ppps and will cause the reply efficiency to decrease if more interrogations are added to the system. This effect on the reply efficiency is due to limiting the output of the Butler DME to 2700 ppps regardless of how many interrogations are received, and must be considered when comparing how the echo-suppression circuits affect the traffic-handling capability as measured by reply efficiency.

TRAFFIC-HANDLING CAPABILITY TEST.

The traffic-handling capability of the Butler DME was decreased when the echo-suppression circuits were used.

The monitor signal generator was not used to load the ground station because its output is periodically spaced interrogations, and a point was reached during the test where the period of the interrogation was less than the width of the echo-suppression pulse. In the "real-world", the ground station would have randomly spaced interrogations and, therefore, not every other interrrogation would fall in the echo-suppression pulse as would periodically spaced interrogations. Live interrogations would have random amplitudes also, and because echo-suppression pulse widths are dependent upon the amplitude of the interrogations, many different results would be obtained depending upon the amplitude of the interrogations.

The echo suppression versus traffic-handling capability test was conducted using randomly spaced and fixed-amplitude interrogations. This method was chosen so the maximum effect of any echo-suppression pulse width could be measured. The data shows the worst effect that echo suppression can have on the traffic-handling capability for a specific echo-suppression width. If an echo-suppression pulse of 200 μs is used, the traffic-handling capability will be effected. In the real world, because not all the interrogations will have the same amplitude, an echo-suppression pulse width of 200 μs would have less effect on the traffic-handling capability than indicated by this test.

ECHO SUPPRESSION - FALSE LOCK-ON TEST.

The operation of the echo-suppression circuits are such that any echo-suppression pulse that is generated by an interrogation cannot be broken by a pulse with a large amplitude. This method will not allow false interrogations to be processed in the Butler DME if it falls in the echo-suppression pulse. The echo-suppression pulse is a true dead-time pulse and will allow no pulses to be processed as long as the echo-suppression pulse is present.

The echo-suppression circuits were effective in reducing the number of false interrogations that were replied to, but they did not stop every false interrogation. This may present problems to the airborne unit, but, because the number of replies to false interrogations are so few, it will be more difficult for the airborne unit to lock-on to a false interrogation.

SUMMARY OF RESULTS

FIRST-PULSE VERSUS SECOND-PULSE TIMING.

1. Second-pulse timing tests showed that the reply delay between the first pulse of the interrogation to the first pulse of the reply did not remain constant for different interrogation-pulse spacings.

2. First-pulse timing tests showed that the reply delay between the first pulse of the interrogation to the first pulse of the reply remained constant for different interrogation-pulse spacings.

ARRC CONTROL TEST RESULTS.

1. If the ground station is interrogated at a rate higher than 2700 ppps, and the ARRC control is set to the nominal value of 2700 pps, the total number of transmitted replies will be limited to approximately 2700 ppps.

TRAFFIC-HANDLING CAPABILITY TEST.

1. Without ARRC No. 2 control the reply efficiency remained above 85 percent for an interrogation rate between 1000 ppps and 5000 ppps.

2. With normal ARRC control, the reply efficiency increased from 85 percent at 1000 ppps to a peak of 95 percent at 2500 ppps and then decreased to 51 percent at 5000 ppps.

3. As the echo-suppression gate width was increased, the reply efficiency decreased while testing with randomly spaced but fixed-amplitude interrogations.

ECHO SUPPRESSION - FALSE LOCK-ON TESTS.

1. The echo-suppression circuits were effective in reducing the replies to false interrogations to 11 percent.

2. All interrogations falling within the width of the echo-suppression gate had their reply efficiency reduced.

3. The echo-suppression circuits generate a true dead-time gate. Any pulse occurring during the echo-suppression pulse did not trigger a reply.

CONCLUSIONS

The following conclusions were based on tests conducted on the Butler Model 1020 in a laboratory environment:

1. With interrogation-pulse spacings of other than exactly 12 μs, first-pulse timing is effective in maintaining the reply delay between the first pulse of the interrogation to the first or second pulse of the reply constant.

2. The echo-suppression circuits were effective in reducing the number of replies to false interrogations.

APPENDIX

EFFECTS OF ECHO SUPPRESSION ON TRAFFIC-HANDLING CAPABILITY

Figures A-1 and A-2 show the effect of the ARRC on the traffic handling capablity. Figure A-1 shows that as the number of interrogation increases, the total number of transmitted replies and the number of replies to the interrogation increase, but the number of replies due to noise decreases. No ARRC No. 2 was present to limit the output.

In figure A-2 the ARRC control is set to normal. As the interrogation rate increases, the number of transmitted replies and the number of replies to interrogations increase to 2700 ppps where it is limited by the ARRC No. 2 control. Once the system reaches 2700 ppps of replies, any additional interrogations will not increase the number of interrogations replied to.

Figures A-3 through A-6 shows the effects of the echo suppression circuits with the ARRC controls set to normal. Figure A-3 has an echo-suppression gate width of 50 μs, and figure A-4 has an echo-suppression gate width of 100 μs. The results from both figures vary very little from that obtained in figure A-2. This indicates that echo-suppression gate widths of up to 100 μs have little effect on the traffic-handling capability.

Figure A-5 shows the effect of a 200-μs-wide echo-suppression gate. The number of replies being transmitted and the number of replies to the interrogations are reduced as compared to a echo-suppression pulse width of up to 100 μs wide. Because of this reduction the number of interrogations required to cause the number of replies to be limited was increased. With an echo-suppression pulse of 400 μs, as shown in figure A-6, the number of replies transmitted and the number of replies to the interrogations is reduced so much that the system may be interrogated with 5000 ppps, and the ARRC No. 2 will not limit the system.

As the echo-suppression gate width is increased the total number of replies and the number of replies to interrogation are decreased, as shown in the test results. Thus the reply efficiency is also decreasing. If the reply efficiency is too low, the airborne DME will unlock.

The test results show the worst effect of echo suppression on traffic-handling capability. In the "real world," the interrogations would have random spacing between interrogations and also random amplitudes. Because the echo-suppression circuits generate a pulse width dependent upon the amplitude of the signal, the test was conducted using randomly spaced interrogations, but fixed-amplitude interrogations. This was done so a correlation between echo-suppression pulse width and traffic-handling capability could be made.

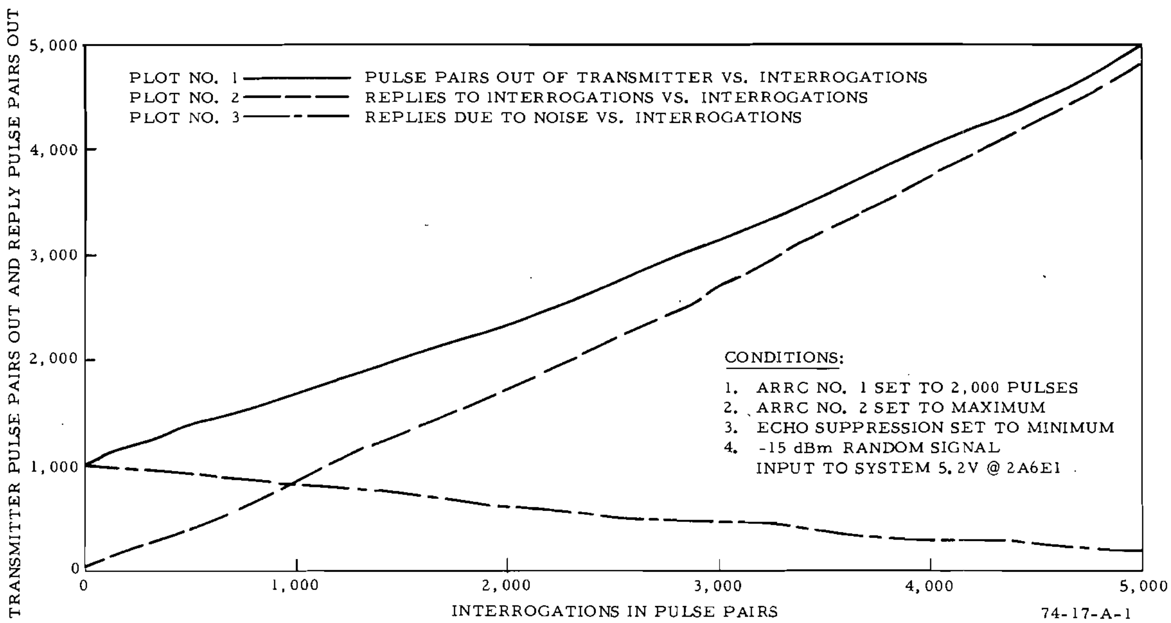

FIGURE A-1. ARRC CONTROL TEST RESULTS WITH NO ARRC NO. 2

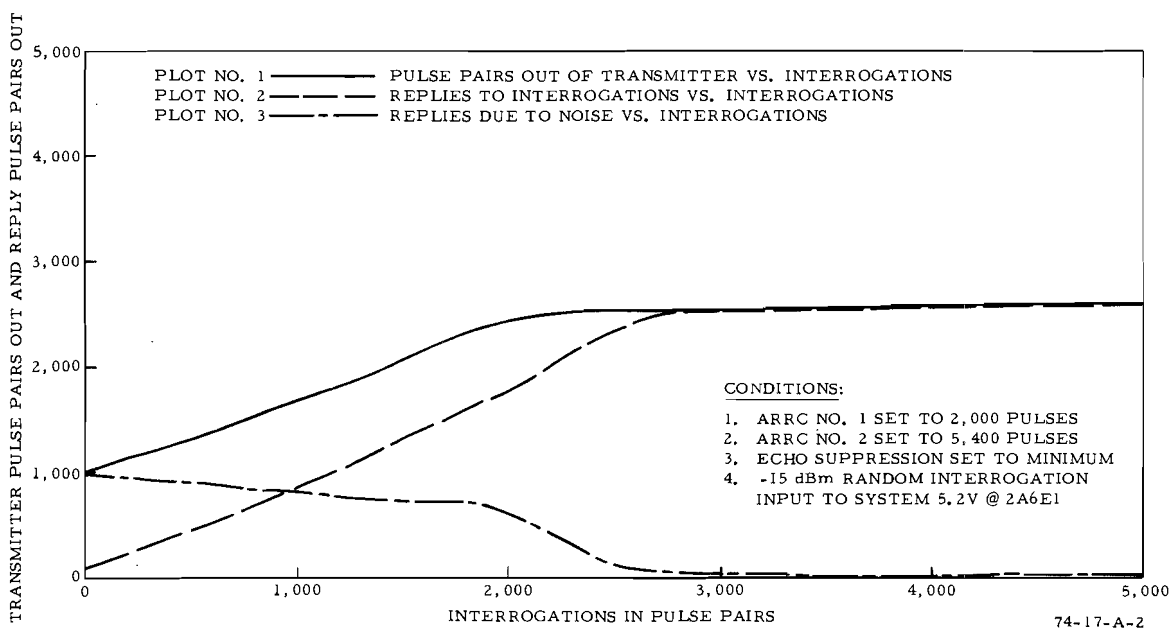

FIGURE A-2. ARRC CONTROL TEST RESULTS WITH ARRC NORMAL

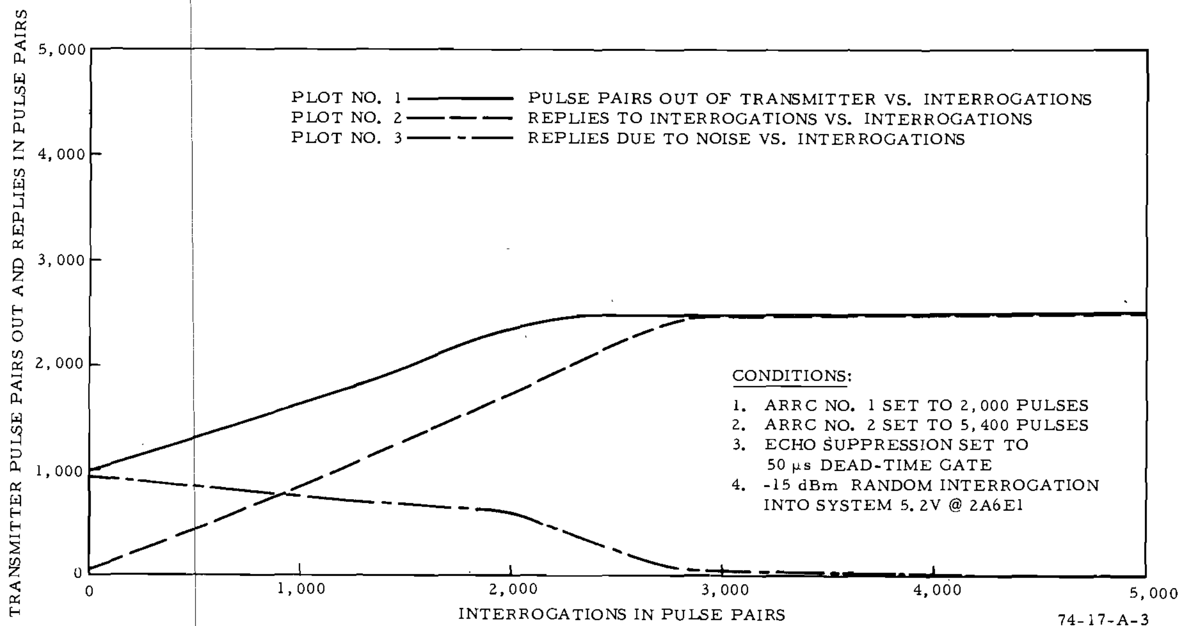

FIGURE A-3. TRAFFIC-HANDLING CAPABILITY WITH 50-μs ECHO-SUPPRESSION PULSE

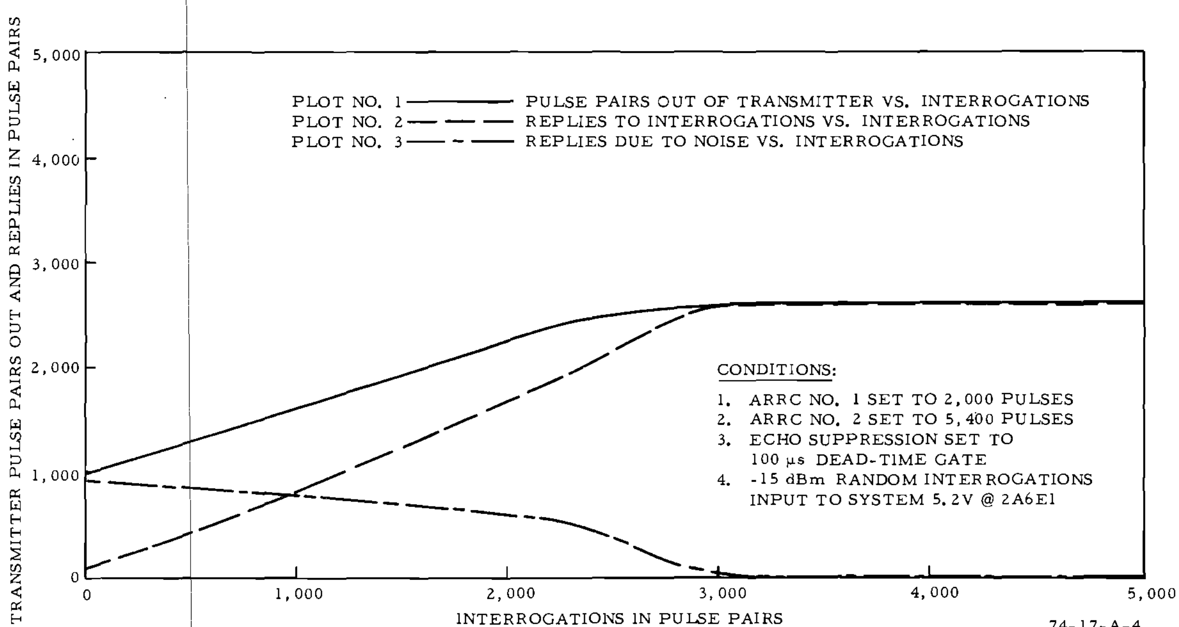

FIGURE A-4. TRAFFIC-HANDLING CAPABILITY WITH 100-μs ECHO-SUPPRESSION PULSE

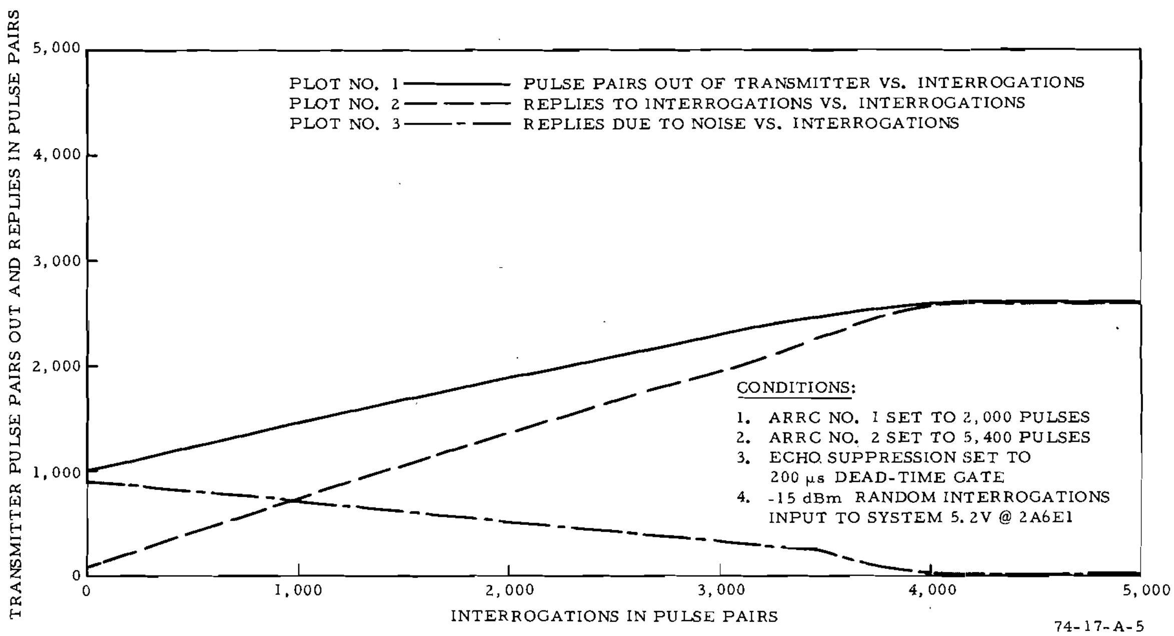

FIGURE A-5. TRAFFIC-HANDLING CAPABILITY WITH 200-μs ECHO-SUPPRESSION PULSE

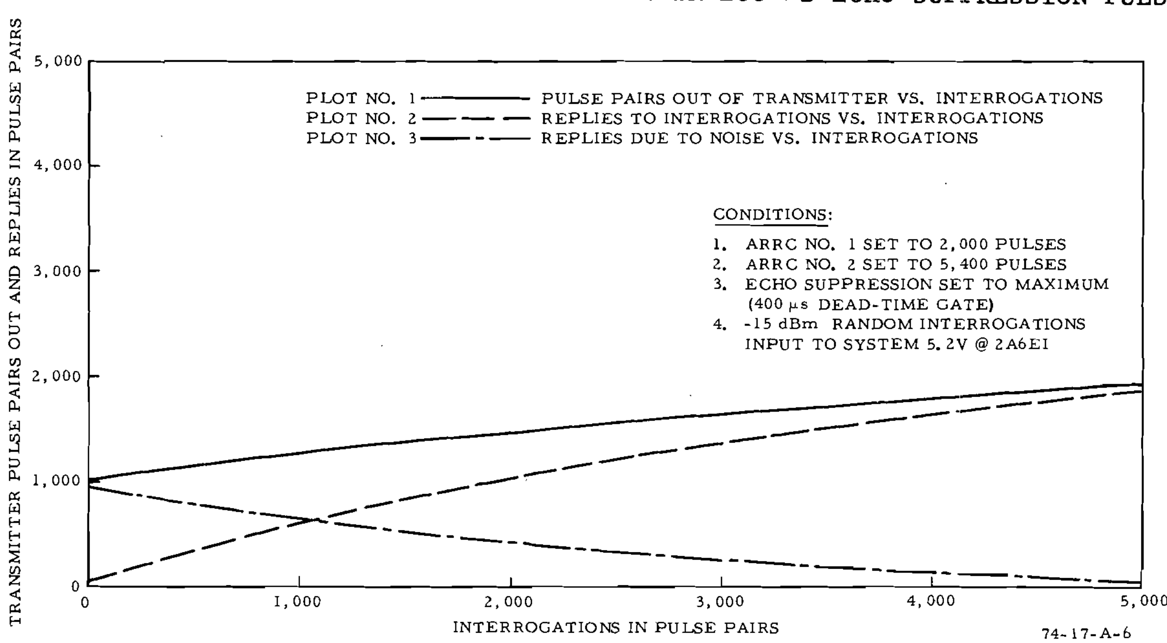

FIGURE A-6. TRAFFIC-HANDLING CAPABILITY WITH 400-μs ECHO-SUPPRESSION PULSE