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Explosive Logic Circuits

by

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ABSTRACT

This report describes a study of explosive logic circuits conducted by the Los Alamos Scientific Laboratory for Picatinny Arsenal. Parameters studied were minimum cross section of XTX 8003, matrix materials, null gate designs, corner turning ability, and spacing requirements in the selected material. A prototype circuit with two inputs and three outputs was designed, constructed, and tested. A null gate for 0.5-mm-wide by 0.5-mm-deep full radius track was developed, tested, and used in the prototype circuit.

I. SUMMARY

A full radius track, 0.5 mm wide by 0.5 mm deep, was chosen as the minimum cross section recommended for the XTX 8003 (Extex)* explosive used.

Matrix materials of polycarbonate and aluminum were tested and polycarbonate was recommended because of lower shock damage and ease of fabrication.

A null gate was designed that would give a positive, reliable interruption of the Extex tracks. A minimum time of 1.5 μs was required for the gate to close.

Corner turning ability of the Extex tracks in polycarbonate was investigated and the angle of failure was found to be between 135 and 150°, total angle.

The spacing requirement for 0.5-mm tracks was found to be greater than 7.62 mm, if no interactive shocks were encountered. Damage was seen at the maximum spacing of 11.5 mm when a track was subjected to a shock interaction wave between two 0.5-mm tracks.

A prototype logic circuit, 38 mm diam by 6.35 mm thick, with two input signals and three output signals was constructed, tested, and found to work in accordance with design objectives.

II. INTRODUCTION

The application of logic circuits to the arming sequences and initiation of munitions is a useful tool for the weapons designer. With the proper configuration, small tracks containing explosive can be designed to provide various output pulses from selected inputs. One of the basic elements that allows these circuits to be designed is the null gate, which enables one track to render another track inoperative without initiating it. The initial work in this field was done by the Naval Weapons Laboratory, Dahlgren, VA, and this work is described in two reports.[1,2] Subsequent work was

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*80 wt% PETN, 20 wt% Sylgard 182.

done by the Naval Weapons Center (NWC), China Lake, CA.[3] We describe in this report the work done on explosive logic circuits by the Los Alamos Scientific Laboratory (LASL) with funds provided by Picatinny Arsenal, Dover, NJ.

III. MATERIAL SELECTION

A. Explosive Type and Configuration

The choice of the minimum cross section of explosive for use in a logic circuit must take into consideration performance reliability as a function of storage time. Thus, the explosive should be capable of initiating and detonating reproducibly in a given configuration independent of time and temperature through the expected storage life and environment.

The detonation velocity of Extex as a function of charge diameter, with the explosive confined in polycarbonate, is shown in Fig. 1. Under these conditions of confinement, Extex failure occurs at a diameter less than 0.38 mm and greater than 0.25 mm. These data indicate that a diameter equal to or less than 0.38 mm should be avoided.

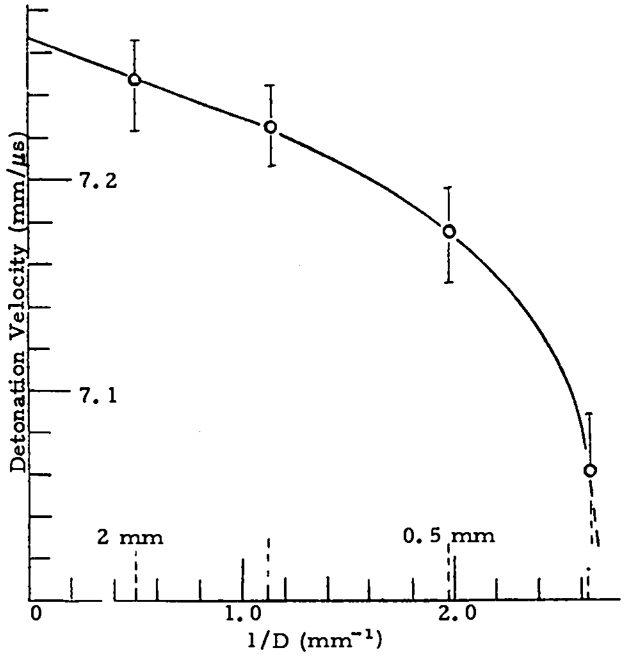


Fig. 1. Extex velocity vs diameter.

As part of another program, the detonation velocity of 0.5-mm-diam Extex, confined in polycarbonate, as a function of storage time at 60°C was determined. Results of this work are shown in Fig. 2. The detonation velocity was found to be time dependent under these conditions of storage. Storage at room temperature (~20°C) for similar periods of time indicates that the velocity is time independent. Additional work has been done by Golopol and Hetherington, Lawrence Livermore Laboratory (LLL),[4] and these data support the results reported here.

On the basis of these data, a full radius track, 0.5 mm wide by 0.5 mm deep, was chosen.

B. Selection of Matrix Material

Polycarbonate and aluminum were selected as possible matrix materials. A device, illustrated in Fig. 3, was fabricated from each material, loaded with Extex, and initiated with a small PETN-loaded detonator. The devices were then recovered and the performance was evaluated by examination. With both materials, the detonation in the Extex turned the right angle corners, and the mechanical damage to the matrix was minimal. The 0.5-mm explosive-filled tracks in polycarbonate were enlarged to about 1.0-mm diam after detonation; in the aluminum, the same size tracks were enlarged to about 1.5-mm diam. Polycarbonate was selected as the matrix material because

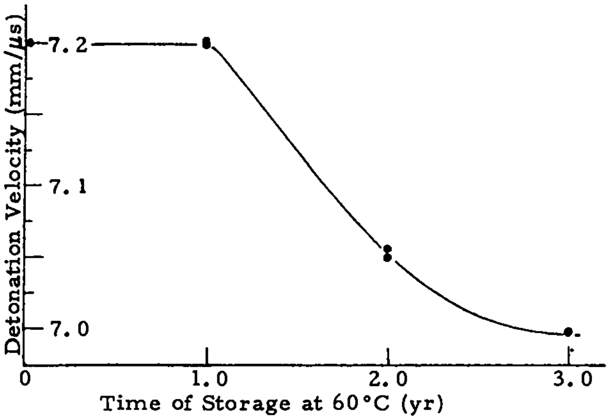


Fig. 2. Extex velocity after storage.

of the lower damage level and the ease of fabrication and inspection.

IV. DESIGN CIRCUIT PARAMETERS

A. Null Gate Design

Two null gate designs were considered. Schematics of the two designs are shown in Fig. 4. In the first, the detonation wave comes from point A and presumably fails to turn the acute angle to point C. In the second, a previous detonation from point C disrupts the track between point A and point B, causing it to fail when detonated.

A schematic of the first null gate device tested is shown in Fig. 5. The detonation wave starts at the detonator counterbore and proceeds down the center track and out to the null gates. At the same time, it travels around the outer track and, because the path is longer, arrives at the null gate point after the gate has been actuated by the center track. The passing tracks in the top half of the device are fed from a path that is routed across the left side of the device to provide a longer and varied actuation time for these null gates. This device had 16 null gates. There were four gate widths (0.12, 0.25, 0.5, and 0.76 mm) and four gates were made in each width. The track cross section was maintained at 0.5 by 0.5 mm. Results of this test indicated that gaps between 0.5 and 0.76 mm would disrupt the channel.

An unexpected result noted in this test was the failure of the Extex to turn some of the right-angle corners. Inspection of the track depths at the failure locations indicated that because of a machining error, the track depth was 0.38 mm instead of 0.50 mm. Failures were attributed to the reduced track depth.

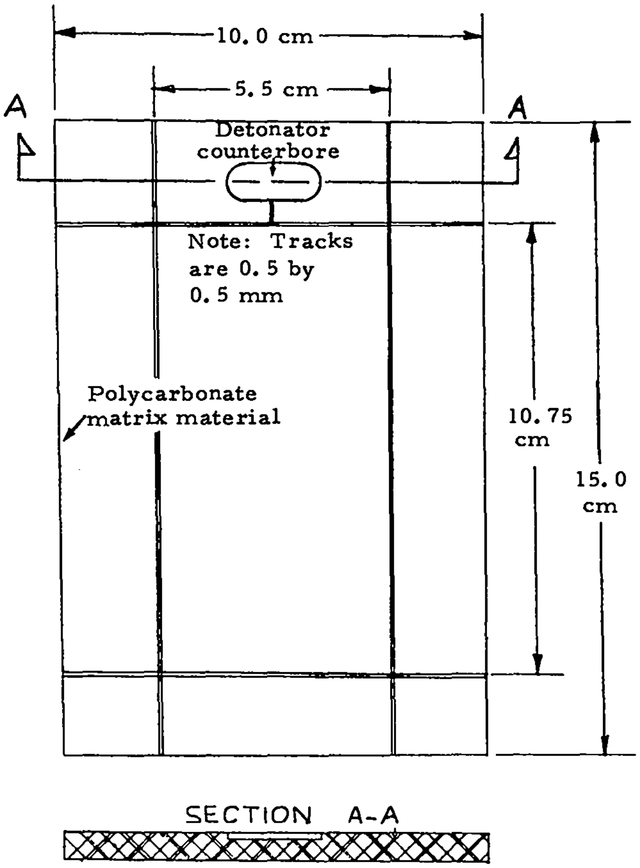


Fig. 3. Material selection device.

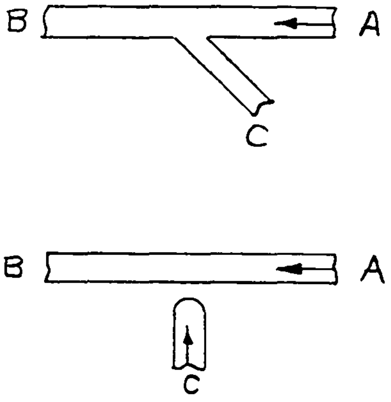


Fig. 4. Null gate and corner turning device designs.

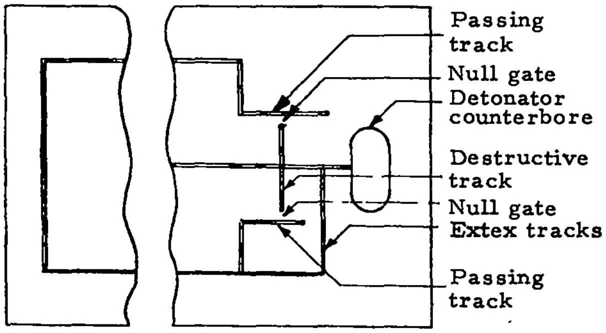


Fig. 5. Schematic of null gate device.

After analysis of the results of this test, a second test was made in which the null gate gap in all 16 gates was fixed at 0.62 mm. A radiograph of this device before firing is shown in Fig. 6. To test the effect of a confining cover plate, one of the test devices was left uncovered and the other was covered with a 0.25-mm polycarbonate cover. Approximately 75% of the gates functioned in both devices. The gate failure in the other 25% was attributed to the inability of the shock coming from the destructive track to reliably disrupt the Extex in the passing track.

After this test, a third design was tested. This design provided a null gate gap of 0.62 mm, like the second test, but a hole of the same diameter as the track and 0.75 mm deep was added to provide additional energy at that point. Also, a relief was provided opposite the gate to provide space for the displaced Extex. A schematic drawing of this gate is shown in Fig. 7.

A counterbore for a second detonator was added to allow the destructive track to be fired and the device to be inspected before the track disruptions were tested by firing. Fig. 8 displays two radiographs of this device, one before and one after the firing of the null gates. Note that in this design the breaks in the track were adequate in every case. This design was tested with and without a 25-mm cover as in previous tests. In the covered model, the cover was blown off and it pulled the Extex out of portions of the remaining tracks. This deficiency must be overcome in the final design if a cover on the device is required.

B. Corner Turning and Element Spacing

A test device, shown in Fig. 9, was designed to determine the maximum included angle that could be turned and the minimum lateral and vertical spacing that can be used for the selected Extex track size in a polycarbonate device. Each device had four tracks to be initiated by detonator A with an included angle of 120, 135, 150, and 165° on each track. A second set of four tracks, initiated by detonator B, was placed at an angle to the first tracks to provide a lateral spacing between them that varied continuously from 3.17 to 11.5 mm. An air gap 1.27 mm deep was provided in the space between the tracks. In addition, a tapered slot containing an Extex track was cut into the bottom surface of the device perpendicular to the four tracks initiated by detonator A. This provided a vertical spacing test in which the distances between the tracks were 1.3, 4.37, 7.05, and 10.6 mm.

The test plan was to fire the track issuing from detonator A, examine the device for damage, and then fire the track issuing from detonator B.

Fig. 6. Radiograph of second null gate device.

The detonators used were a LASL type that contained a minimal amount of PETN. Two devices were tested. The first was uncovered and the second had a 0.25-mm-thick polycarbonate cover glued over the tracks. The cover was slit between the A and B tracks to eliminate damage caused by the cover blowing off and pulling out the track material.

Fig. 10 is a print of a radiograph of one device after detonator A was fired. The second device was essentially the same. Detonator B was not fired because we felt that the objectives of the test could be met by an examination of the radiograph. Note in Fig. 10 that in all cases, the wave turned 120 and 135° included angles but failed to turn any

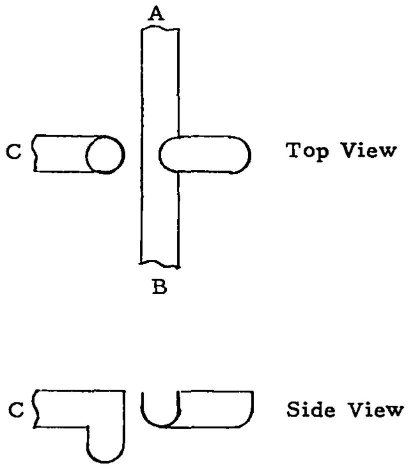
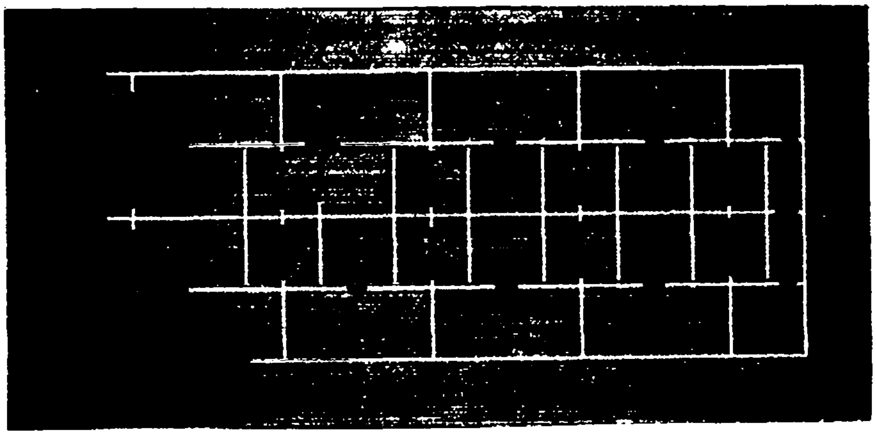


Fig. 7. Null gate device with relief.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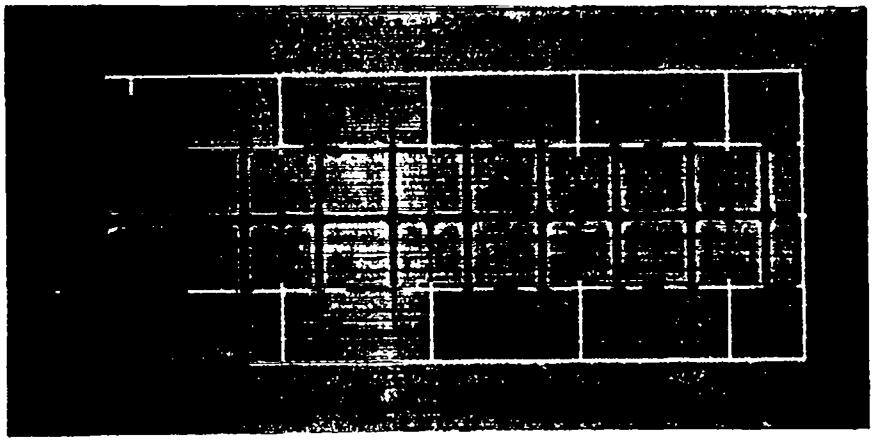
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Fig. 8. Radiographs of third null gate device before and after first firing.

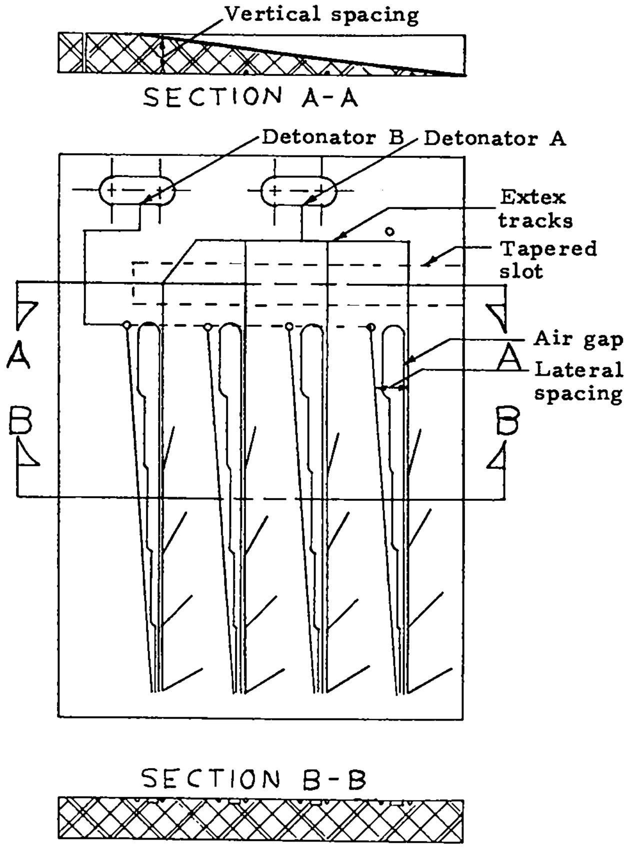

Fig. 9. Sketch of corner turning device.

of the 150 or 165° angles. The vertical spacing of 10.6 mm survived, but all tracks with vertical spacing less than that were destroyed.

In the lateral spacing tests, with the exception of the central track, damage apparently began when the center-to-center track spacing decreased to 7.62 mm. In the center track, however, damage was done to the tracks at the maximum center-to-center track spacing of 11.5 mm. The more extensive damage in this area was caused by the shock intensification resulting from an interaction between the shock waves emanating almost simultaneously from the tracks on each side as they detonated at about the same time. The location of shock interactions is an important consideration in the design of these devices.

V. PROTOTYPE DEVELOPMENT

A. Circuit Design

As a final part of this study, a prototype logic circuit device was designed. A sketch of the track layout for the first design is shown in Fig. 11a.

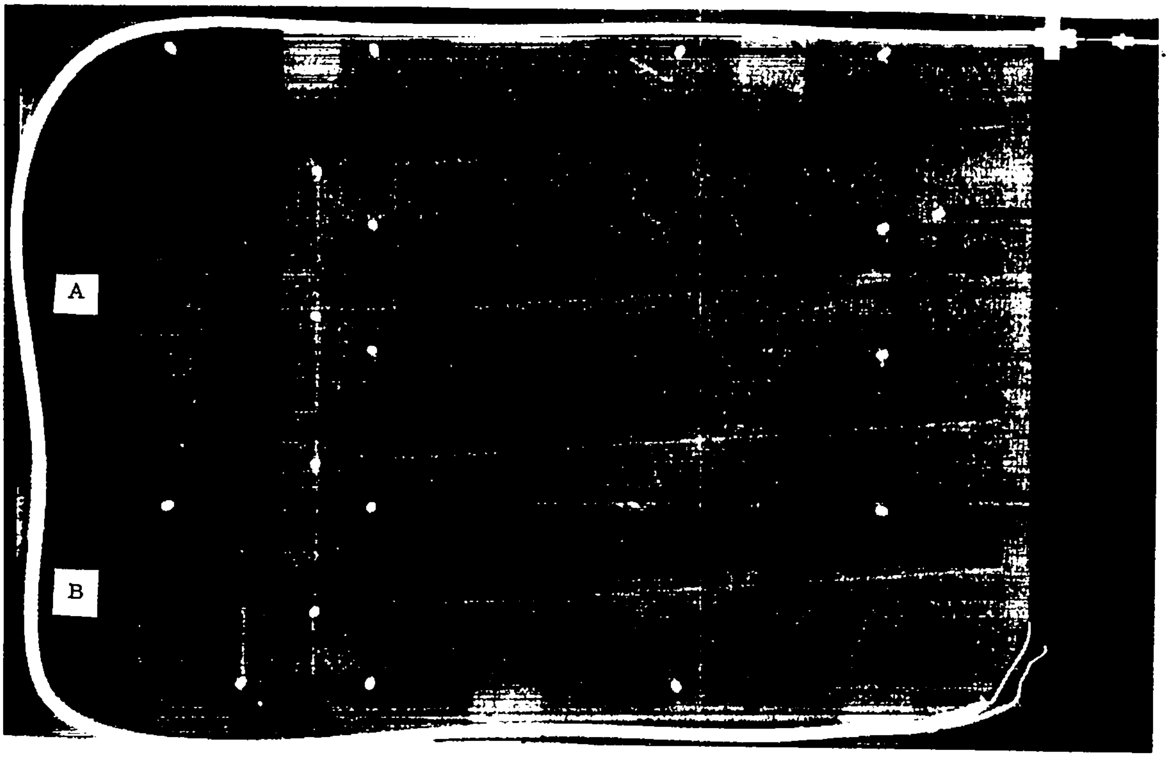

Fig. 10. Radiograph of corner turning device after firing Detonator A.

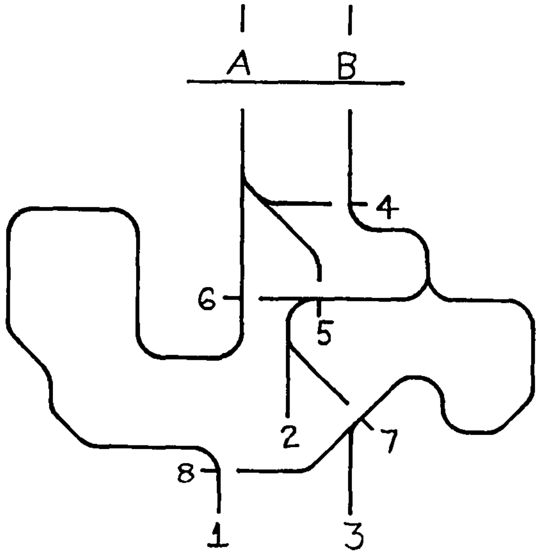

Fig. 11a. Track layout of first prototype.

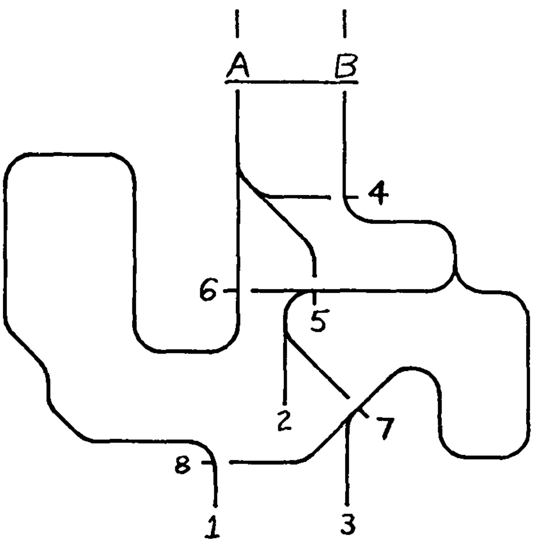

Fig. 11b. Track layout of second prototype.

The track configuration is the same as that used in the corner turning device. The objective of this design was a logic circuit that would have inputs at A, at B, or at A and B simultaneously and corresponding outputs at 1, at 2, or at 3. The null gate design used at 4, 5, 6, 7, and 8 is identical with that developed earlier in the program. The device was 38 mm in diameter and 6.34 mm thick. The material used for the matrix was Lucite plastic because it was more economical to make in the desired configuration and we felt that it would be a suitable substitute for polycarbonate in this application. The tracks were hand loaded with Extex and radiographed to assure good track quality before firing. A different type of detonator was used because of a limited supply of those used previously. The replacement detonator was considerably more energetic.

B. Test Results

Three devices were tested on one shot. One device had a detonator at point A, one device had a detonator at point B, and the other had a detonator at both points A and B. All four detonators were fired simultaneously. The devices were recovered and examined for performance after the shot.

The device that was initiated at point A gave an output at point 1 and apparently the null gates at points 4 and 5 functioned properly.

The device that was initiated at point B gave outputs at both points 2 and 3. The null gates at points 6 and 8 appeared to function properly, but the one at point 7 obviously failed.

The device that was initiated at both points A and B also gave outputs at both points 2 and 3. The null gate at point 8 functioned, but the ones at points 5 and 7 failed. The geometry of the device was examined for an explanation of these failures. The null gate geometry was identical in all places. However, the time allowed for the null gates to function was different in each case. The null gate that worked at point 8 had an actuation time of 1.4 µs. The actuation time at point 7 was 1.25 µs, and the actuation time at point 5 was 1.0 µs. We concluded that the cause of the gate failures was insufficient time allowed for the gate actuation. The detonators used in this shot caused considerable damage to the Lucite matrix but we were able to gather the required data from the pieces.

In a redesign of the device, the track pattern shown in Fig. 11a was expanded to increase the actuation times for the null gates at points 5 and 7, and a second prototype device was made according to the new design. Figure 11b shows a track layout of the second model and Fig. 12 shows a radiograph of it in the loaded condition. The basic

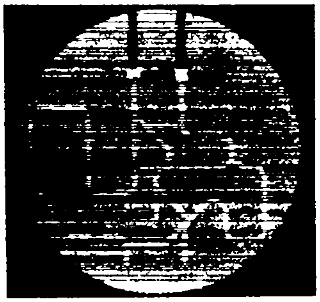

Fig. 12. Radiograph of second prototype device in loaded condition (full size).

pattern was not changed, but the actuation time at point 5 was increased to 1.57 μs, at point 7 to 1.65 μs, and at point 8 to 1.76 μs. The detonator slot was also redesigned to accommodate the end of a 150-mm length of mild detonating fuze (MDF) attached to an SE-1 detonator. Otherwise, the test setup was identical with that used on the first prototype.

Three units were fired; one initiated at A, one at B, and one at A and B simultaneously. An examination of the pieces after firing revealed that each input produced the desired output. The devices still sustained a significant amount of damage from the detonators even though the MDF train separated them by 150 mm. This damage could be reduced if only one unit were fired at a time, but for further tests, we recommend that a smaller detonator be used.

VI. RECOMMENDATIONS

Extex or its equivalent is recommended for the explosive in logic circuits because of its reliability in small tracks and its stability during extended storage periods. We feel that the use of less energetic materials would require an increase in the cross-sectional area of the track to achieve the desired reliability. This would result in an increase in the size of the device.

Of the two matrix materials tested in this study, the polycarbonate showed a significant advantage over the aluminum. Work done by NWC,[3] indicates that a lower density matrix material might allow the track spacing to be less than the present studies indicate. Future designs must compensate for the significantly higher level of damage that is sustained in areas of shock interaction between simultaneous detonation waves.

The null gate designed for the prototype circuit appears to be reliable and functional. However, the results of the corner turning experiments indicate that sharp corners, greater than or equal to 150°, could be used in the track to achieve the same results, if the corner turning method was better suited to a particular design.

We had no success in our attempts to enclose the track matrix under a polycarbonate cover.

In order to weaponize a circuit of the type successfully tested, we recommend that additional studies be undertaken in the following areas:

- There is experimental evidence[3] that with a matrix of lower density, the damage to the matrix can be substantially reduced. This reduced shock damage and the reduction in shock velocity because of the lower density of the matrix provides the possibility of reducing the space requirements. Additional work to verify this possibility is warranted.
- Our attempts to provide the prototype circuit with a protective polycarbonate cover were not successful. We feel that additional work should be done in this area.

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