

Electro Explosive Devices (EED)
Characterization and Testing Facility
Establishment using resistors as a
dummy load.

by
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requirements for the award of BEng
(Hons) Ordnance, Munitions and
Explosives (OME) Engineering

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Declaration of Originality

I, Jacob Ian Smith declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

Signed:*J.I.Smith*.....

Date:*15/07/2025*.....

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Abstract

Electro Explosive Devices (EEDs) are critical components in both military and civilian applications, requiring rigorous testing to ensure safety, reliability, and compliance with standards such as Defence Standard (Def Stan) 59-114. Establishing a new EED test house, such as at Defence Munitions (DM) Gosport, necessitates validation of testing equipment and processes. However, the high cost and safety risks associated with live EEDs present challenges. This study explores the use of resistors as cost-effective and safe substitutes for EEDs during the validation phase of test house establishment.

The research employed resistors as dummy loads to simulate the electrical behaviour of EEDs, focusing on three test sequences: consistency of applied stimuli, determination of failure thresholds, and repeatability of catastrophic failure. Results demonstrated consistent application of stimuli within a 6-millisecond range for duration, though recorded voltage and current levels exceeded expected values, likely due to additional resistance in the test circuit. The study highlighted the importance of oscilloscope placement and circuit design in ensuring accurate measurements. Despite these anomalies, the methodology proved effective in identifying potential issues within the test setup, underscoring the utility of resistors in pre-validating EED testing environments.

The findings suggest that resistors can serve as a viable preliminary validation tool, offering a safe, cost-effective alternative to live EEDs. However, further investigation is required to address observed discrepancies in voltage and current levels. Future research should focus on refining the test setup, incorporating inert EEDs for enhanced realism, and formalising resistor-based validation as a standard practice. This approach has the potential to improve safety, reduce costs, and streamline the establishment of EED test facilities.

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1. Introduction

1.1. Background

- 1.1.1. Electro Explosive devices (EED) are electrical items containing a small explosive component designed to convert electrical input energy into heat, to initiate a primary explosive to achieve a desired task [1]. This is typically done using an Exploding Bridge Wire (EBW) [2], Exploding Foil Initiator (EFI) [3] or Hotwire [4]. All convert the electrical energy into heat energy, which is then used to set off the primary explosive within the EED. They are a key component in many different systems as they are typically the trigger that starts that system, requiring them to be dependable, robust, and suitable for the desired application. Due to their design they not only have to be manufactured in accordance with local and international (where appropriate) standards and regulations they also must meet various electrical/electronic standards and regulations as well.
- 1.1.2. EEDs are used everywhere in military applications to initiate bombs and in the civilian world. They are not just for initiating explosive trains, they can be used to generate large volumes of gas (airbags), large flames (jet engine initiation) or even to move a piston (restraining devices). If something requires an action to be completed quickly (sub one second) an EED is the likely choice.

1.2. Problem Statement

- 1.2.1. EED testing to prove it is safe and suitable for service is vast and complicated due to the several types of standards and regulations they must be manufactured to. One of these areas is around Electrical characterization which is covered by Defence standard (Def Stan) 59-114. This standard covers the electrical circuits in systems incorporating explosive components, but most importantly electrical/electromagnetic environments [5]. This document lists the appropriate testing methods that should be used to prove an EED is safe and suitable to be used in an electrical/electromagnetic environment.
- 1.2.2. One aspect that warrants consideration when setting up a new test house is the standards that need to be met during the testing. EEDs although small, are expensive devices to procure so testing them in numbers to get an accurate statistical result can cost a significant amount. As with any test house the new site must be validated as being able to test to these standards, without this validation the testing is meaningless. Currently to do so would require great expense procuring EEDs to test, however as an EED is essentially a resistor (converting the

electrons kinetic energy into heat [6]) a reasonable approach could be to use resistors to validate a test house processes at a significantly reduced cost.

1.3. Objective

- 1.3.1. The goal of this report is to evaluate the effectiveness of resistors as a substitute to EEDs when validating a new test house. The test house in question will be Defence Munitions (DM) Gosport, who are working towards become an MoD owned EED test house. This approach will allow the MoD to have an inhouse testing facility as well as diversifying their portfolio.
- 1.3.2. With recent changes to the National Authority (NA) approved testing method, a new testing approach will be needed for any new EED being characterized. This method is called the Langlie method [7] and has been developed from previous methods and addresses issues identified with the original characterization work.
- 1.3.3. This report will employ the Langlie method and apply it to a series of resistors with identical ratings, subjecting them to the same process and stages that are to be applied to a real EED going through this testing. By subjecting the resistors to this approach and recording their reactions to the applied electrical stimulus, a comparison can be made to known response values.

1.4. Scope

- 1.4.1. The main boundary of this report is the testing of resistors to validate a test house for EED testing. The testing will be conducted by the author with Subject Matter Expert (SME) guidance at DM Gosport. DM Gosport is already set up and ready to conduct this type of testing with the equipment needed in place and in working order.
- 1.4.2. The Langlie method has been approved by the NA and has a predefined methodology. There is a step-by-step process that needs to be followed from one resistor to the next. Using the result of the previous EED to determine the stimulus level to be applied to the next one. The exact step by step approach will be covered in greater detail later in this report.
- 1.4.3. If timings allow the testing boundary will expand to include EEDs to prove the results from a live EED match that off the resistors thus confirming the theory that resistors can simulate EEDs for testing purposes. Or if it disproves the theory that resistors can be used as a substitute for establishing an EED test house.

2. Literature Review

2.1. Intro

- 2.1.1. As mentioned in section 1.1 EEDs are critical components used across defence and civilian sector due to their rapid, reliable initiation via electrical ignition. However, to be able to show an EED is safe and suitable for use in these areas they must undergo characterization, resulting in rigorous testing in controlled environments. This is to ensure safety, reliability, and regulatory compliance. Validation of this testing process is essential to avoid false positives or negatives, erroneous measurements or even catastrophic failures.
- 2.1.2. A common way to validate testing of electrical systems in industry is to use a resistive dummy load i.e., a resistor that simulates the electrical and thermal properties of a real devices while eliminating risk. These approaches have been used throughout the civilian sector for testing items such as radio antennas [8] and amplifiers [9]. These dummy loads can help identify test rig anomalies, system impedance mismatches, and data acquisition errors before a real device or signal is introduced.
- 2.1.3. This review explores the foundational literature on EED design and testing, then covers validation challenges and how resistive dummy loads provide a testing alternative. The objective is to identify gaps in the current methodologies and justify integrating resistor-based validation as a novel, safe, and effective calibration step in EED test house establishment.

2.2. Overview of EED devices

- 2.2.1. As briefly touched on in section 1.1 Electro Explosive Devices or EEDs is an electrically initiated initiator containing a primary explosive or pyrotechnic composition. The definition according to National Aeronautics and Space Administration (NASA) is an EED “contains some reaction mixture that is electrically initiated, with the output of the initiation being heat, shock or mechanical action” [10]. An EED acts as a high-speed transducer converting an electrical pulse into an explosive or pyrotechnic output. This allows for precise timing and remote initiation of detonations that would otherwise require a direct flame or impact. EEDs typically consist of a small bridge element (wire, foil, or film) in intimate contact with a primary explosive or pyrotechnic. When an electrical pulse is applied to the EED it rapidly heats and detonates the adjacent energetic material.

- 2.2.2. There are three types of EEDs used in engineering or defence applications, these being bridgewire devices, exploding foil initiators (also known as slappers) and semiconductor film bridge devices. In an Exploding Bridgewire (EBW) also known as a hot wire initiator, a thin resistive wire is embedded in a small amount of energetic material. Typically, a capacitor-fed pulse is discharged sending a current through the thin wire producing copious amounts of heat to detonate the explosive composition [2]. An EBW detonator is a classic military example of these devices. EBWs achieve extremely precise timing, which made them ideal for synchronizing multiple detonations and a good example of this is the symmetrical implosion of a nuclear weapons core. In the early days of its development the “fat man” nuclear bomb, consisted of a plutonium core surrounded by high explosives segments which were all initiated at the same time by an EED initiator [11]. An EBW EED will be the focus of this report going forward, although it must be pointed out the testing can still be applicable to all three types of EED.

2.3. EED testing and Characterization methods.

- 2.3.1. EED characterization aims to precisely determine EED response across operating and extreme conditions and is covered in depth by Def Stan 59-114 [12]. This document sets out how to achieve full characterization of an EED, through first principles, design recommendations and electrical/electromagnetic environments. To achieve full characterization an EED must be subjected to a series of environmental conditioning stimulus before being electrically tested.
- 2.3.2. These stimuli can include vibrations, shocks, temperature cycling and a whole host of other environmental factors [12]. These factors fall outside the scope of this report and therefore will not be covered in detail. The main focused of this report is what is known as partial characterization, which is where an EED is only tested in accordance with Def Stan 59-114 and the interim test methodology [7]. This again falls into two further subcategories with one being the statistical analysis of the data recorded from the physical testing. This data is analysed using the Langlie method which was an analysis procedure developed by H.J. Langlie for the Ford Motor company in 1965 [13].
- 2.3.3. The testing part of this process will be the main focused going forward which is derived from the Langlie method, where an EED has a known manufacture defined upper and lower firing limit. This is typically provided by the manufacture where they state these limits if they are manufacturing EEDs in accordance with MIL-DTL-23659 (this lists and details specifications EEDs should be manufactured to) [14]. Using these upper limits a medium is found for the starting point, and depending on the results of this test the following test will either start at the limit maximum

or minimum. Again, dependent on the results the next step would be to test at the minimum, maximum or medium levels [7]. To do this level of testing, a test house must be able to confidently provide the correct stimulus level and duration throughout these tests, as a typical characterization campaign can use upwards of 450 individual EEDs to get a statistically significant number at the end.

2.4. Risk of improper testing environments

- 2.4.1. Without proper test house validation, a number of faults and failures can occur from false triggers, failure to fire (inconsistent stimulus delivery), inaccurate time to fire data and many more safety issues. Recorded incidents such as misfires have been traced back to insufficient grounding, or poorly calibrated test equipment. Though not often published in peer-reviewed literature defence-industry high profile failures (such as the Trident test failure in 2024 [15]) and anecdotal accounts can attest to the frequency and severity of these failures.
- 2.4.2. Mitigations to these failures can include procedural check lists, regular equipment calibrations and redundancy. A simple yet underreported approach for electrical EED testing is the use of a “Dummy load” to pre-validate the tests. Before the introduction of a live EED, a resistor-based test can simulate its electrical behavior, revealing issues with the test equipment and process.

2.5. Using resistors (dummy loads) for test house validation

- 2.5.1. As a resistors design is similar to that of an EED (most specifically an EBW) they are a prime candidate to be used as a dummy load in a validation test. A dummy load is a resistive (can be reactive but not in this case) device that simulates the electrical characteristics of a real EED. Primarily resistance and sometimes inductance, absorbing electrical energy as heat. This response is similar to how an EED would react to the same input; by matching an appropriate resistance level to that of the intended EED to be tested, a preliminary validation test can be undertaken to ensure the test equipment is calibrated for that EED. This method is common in RF and amplifier testing, where dummy loads ensure consistent impedance and prevent stray signal emissions [16].
- 2.5.2. A dummy load is put in the place of an EED and subjected to a similar stimulus that would be expected to be applied to that of an EED. During the trial, an oscilloscope would record the voltage, current, power and duration of the stimulus, to ensure it is as expected and consistent. If any one of these parameters are different to what is expected an investigation can be undertaken to find the

cause, be it cabling faults (too much impedance), grounding problems or instrument calibration.

- 2.5.3. By using this approach, it provides a safe none-explosive validation for the test, repeatability by using identical resistors with a high tolerance percentage (<5%), costs effective as resistors are relatively cheap to purchase, and diagnostic clarity as observed anomalies point more towards equipment issues than device.

2.6. Gaps in Literature and justification for this study

- 2.6.1. Despite the broad use of dummy loads in electronics their integration into EED test validation remains underexplored in published defence or aerospace literature. The only available report found that touches on this is one dating back to 1993 titled “Proposed electrical test procedures for safety and suitability of electro-explosive devices for service”. Produced by THORN EMI electronics [17] for the Ordnance board of the Ministry of Defence. This document only briefly covers dummy loads stating that “a dummy load is then used to set up the power levels for a given sample of EED” [17]. Even the current standards defined in Def Stan 59-114, that is used to set out the principles of design, use, assessment, and test for electrical circuits incorporating electro-explosive devices, does not cover how to validate these test process. Therefore, currently EED test houses are left to their own devices to validate their test processes.

2.7. Summary and conclusion

- 2.7.1. This review has covered the characterization method of EEDs through their design and how these tests are critical to prove they are safe and suitable for service. It has shown the benefits of validating test equipment and proposed a novel and safe way to go about this. Using dummy loads to validate EED testing before incorporating a real EED into the mix provides a safe and suitable alternative that is widely used in the electronics sector already from industry to enthusiasts. Despite its wide use in RF and amplifier testing it remains a novel and unutilized in the EED world.
- 2.7.2. The gaps highlighted above underpins the need to explore this area further, to formalise dummy load testing into the validation of new test houses and continued calibration of these test houses. By proving a test house can continuously provide accurate and consistent pulse levels and duration, it validates their equipment as being suitable. Thus, adding confidence to the results gained on real EEDs when subjected to the same testing.

3. Testing Methodology

3.1. Langlie Method

- 3.1.1. As described in section 2.3 the Langlie method is comprised of a number of separate steps, with the main aim of this report being the physical testing section. Although just as important, the environmental conditioning and the statistical analysis of the results are outside the scope of this report.
- 3.1.2. The key step for the new methodology to be used for characterization as defined in the Interim test methodology [7] requires the selection of an upper and lower limit. These can sometimes be provided by the manufacture as they can typically provide a range that would trigger the device. The upper limit (μ_{Max}) will be where the devices constantly go, and the lower limit (μ_{Min}) will be result in expected no-go. A “go” is defined as the device firing or going open circuit and “no-go” is defined as the device failing to fire on application of test stimulus [7]. From the defined upper and lower limit, a mean stimulus (μ) can be determined. It is expected that the mean will be four standard deviations from the upper and lower limits as stated in AOP-43 [18]. AOP-43 is the subsection within Def Stan 59-114 that details all pertinent characterization information.
- 3.1.3. The first step in the Langlie testing method is to initiate the first test (x_1) at the mean level, the outcome (y_1) of the first test will determine what to do next¹ [7, 18]:

- a) A go ($y_1 = 1$) = second test stimulus $x_2 = \frac{(x_1 + \mu_{Min})}{2}$
b) A no-go ($y_1 = 0$) = second test stimulus $x_2 = \frac{(x_1 + \mu_{Max})}{2}$

Then after the second trial (y_2) the third stimulus (x_3) can be determined as

- c) $y_1 = 1$ and $y_2 = 0$ **OR** $y_1 = 0$ and $y_2 = 1$, then $x_3 = \frac{(x_1 + x_2)}{2}$
d) $y_1 = 1$ and $y_2 = 1$, then $x_3 = \frac{(x_2 + \mu_{Min})}{2}$
e) $y_1 = 0$ and $y_2 = 0$, then $x_3 = \frac{(x_2 + \mu_{Max})}{2}$

On completion of the third trial (y_3), test stimuli 4 (x_4) and onwards can be calculated.

- 3.1.4. This is the standard procedure that should be followed for testing EEDs and to do this a test house must have confidence that the test equipment can deliver an

¹ All steps are covered in detail in the Interim test methodology and AOP-43 [7] [18]

accurate and consistent stimulus to the EEDs. Without the confidence the result will not be accurate or reliable to use for the statistical analysis aspect of the Langlie methodology.

- 3.1.5. When testing the resistors for the accuracy, the methodology used will be different and will be conducted in three parts.
- 3.1.6. The first test will consist of one resistor being exposed to ten stimuli of the same magnitude and duration. This will be used to measure how consistent the Voltage, Duration, Amps, and Watts that are applied as part of the testing. A good result will show a small deviation between four measuring points.
- 3.1.7. The second test will be to ramp up the applied stimuli (magnitude and the duration) until a point where a resistor will fail continuously. This is to assist with the third step of the process.
- 3.1.8. The third step will be to subject ten of resistors to a catastrophic stimulus. This step is intended to simulate an EED being initiated and also to prove the test equipment can operate at a higher level. Along with proving the process of replacing an EED between tests is suitable and achievable.

3.2. Role of Resistors in Testing

- 3.2.1. The basic role of the resistor in these tests to act as a dummy load, to mimic the stimulus-response behavior of an EED. The stimuli flowing through resistor wire would generate a resistive force plus heat, which as covered in section 2.2 is how an EED would initiate the energetic material. The critical consideration when using a resistor as a dummy load is to match resistors Ohm's rating with that of a particular EED (That is if you are pretesting for a certain EED). For the instance of the validation effort covered in this report, any resistance level of a resistor will suffice providing it is kept constants for all tests, and a suitable tolerance level is chosen (sub 5%) [16]. Some variation in the resistor is useful for the third test as this will draw out any weaknesses in the test set up.
- 3.2.2. The sole purpose of the resistor in this validation testing is to provide a dummy load to simulate an EED. As described in section 2.5, it is a simple and cost-effective way to safety test for inconsistencies within test equipment. It should be employed in the same fashion of an EED and subjected to the same stimuli. For test one in this series, the resistor was subjected to a representative stimulus that a typical EED could be subjected to of 250mV and for 500mS.

- 3.2.3. The resistor used in this testing will be a singular resistor placed in series with the test house circuitry, to accurately replicate how an EED would be tested. Figures 1 and 2 below show how the resistor was employed for the testing. It must be pointed out that the double crocodile clips are not a desirable way to hold the resistor in the test, this was an ad hoc fix as the larger clips could not suitably grip the smaller wire on the resistor.



Figure 1: Resistor in test position



Figure 2: Resistor in test configuration close up.

3.3. Test Equipment and Setup

- 3.3.1. All test equipment that should be used with EED characterization is detailed within Def Stan 59-114 [12]. Figure 3 below shows all the test equipment used for EED characterization (excluding the firing box and test room which will be covered in a separate section). From top to bottom of the figure 3 the following components can be seen, Oscilloscope, inline multimeter, safety ohm meter (yellow box), pulse width generator, Isolator switch/firing device (black box), and constant power module and capacitance discharge (including the master and slave units in blue).



Figure 3: Test equipment cabinet.

4. Design and Establishment of the Testing Facility

4.1. Facility Layout and Design

- 4.1.1. As with all new test house facilities, they need to be designed and built, fortunately DM Gosport have been proactive with establishing their testing area in one of their operation rooms. Below is a graphic representation of the test house layout.

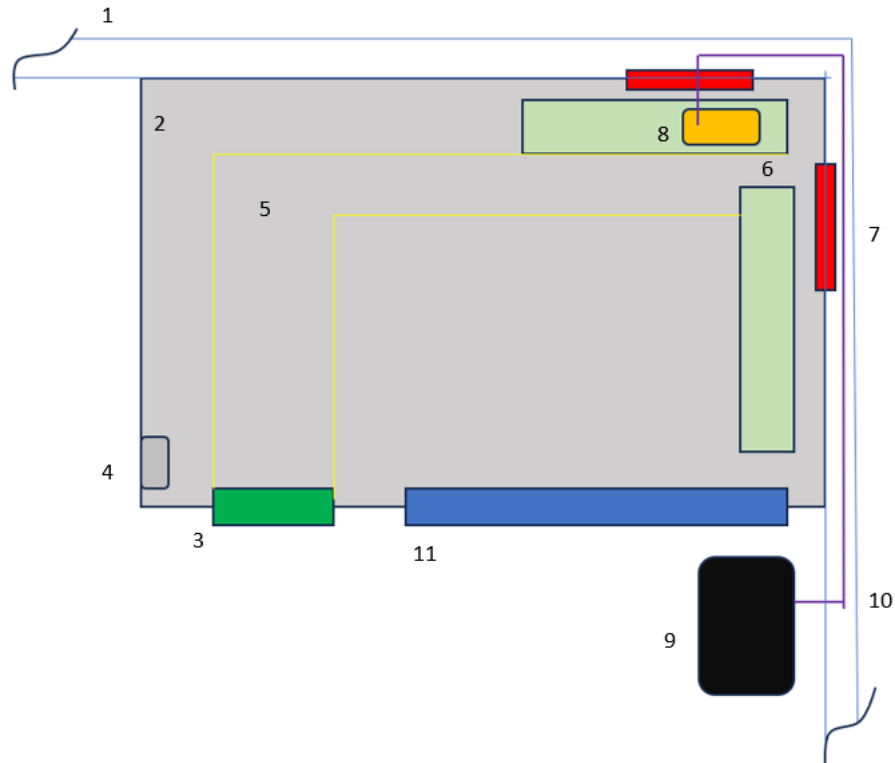


Figure 4: Test house layout.

1. Thin blue lines = interior and exterior walls of the processing building
2. Large grey box = EED characterization room (including walls)
3. Dark green rectangle = Entrance
4. Small grey box = Human static discharge point
5. Yellow lines = safe walking lane
6. Light green rectangles = test bench
7. Red rectangles = blow out panels
8. Orange box = explosives firing box
9. Black box = Testing equipment cabinet
10. Purple line = Cable routing between testing equipment and firing box.
11. Blue rectangle = Safety glass window

- 4.1.2. This testing room is typical of what would be seen within an EED test house, the door consists of a safety lock which only accepts the interlock key. Inside the door is the static discharge device used to ensure any personnel within the test room is free of any static charge (appropriate PPE should be worn as well such as insulated boots and anti static overcoat). There are predefined walking lanes that must be always kept clear. There are dedicated work benches, one for holding the next set of devices to be tested and one holding the firing box and a place for the already tested devices to go.
- 4.1.3. In the walls of the test room there are blow out panels which are designed weak points in the wall that will allow an overpressure to escape in a safe manner, if an unintended explosive event were to happen inside the room. There are reinforced viewing windows along the one wall allowing an operator to view inside the test room ensuring it is safe to enter. Finally, there is the test cabinet consisting of all the electrical equipment detailed in the previous section and a cable linking it to the firing box. One element that is not shown in Figure 4 above is the extractor fans installed within the room, there is one for the room itself and one attached to the firing box. This is to ensure all harmful products of explosion are constantly being extracted.
- 4.1.4. Although the exact quantities are not available to share, the testing room will have a maximum Net Explosive Quantity (NEQ) that can be placed within the room at one time. This NEQ is a defined maximum that can be stored in there and this quantity will be suitable to conduct a number of tests without posing a significant danger to the operators or the building itself.

4.2. Regulations and legislation

- 4.2.1. As with any explosive storage or processing facility there is a number of legislation and standards that must be adhered to when dealing with anything explosives related. Below is an overview of the key considerations and regulations that apply to explosive processing buildings in the UK:

4.2.2. Key Legislation

- **Health and Safety at Work etc. Act 1974 (HSWA) [19]:** This is the overarching legislation that requires employers to ensure the health, safety, and welfare of employees and others who may be affected by their activities.

- **Explosives Regulations 2014 (ER 2014)** [20]: These regulations govern the manufacture, storage, and handling of explosives in the UK. They require duty holders to assess risks, implement control measures, and obtain appropriate licences for explosive activities.
- **Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)** [21]: DSEAR applies to workplaces where explosive atmospheres may occur. It requires employers to assess risks, classify hazardous areas, and implement measures to prevent or mitigate explosions.
- **Building Regulations 2010** [22]: These regulations set out requirements for the design and construction of buildings, including those used for explosive processing. Specific provisions may apply to fire safety, structural integrity, and ventilation.

4.2.3. **Design and Construction Requirements** [23].

Explosive processing buildings must be designed to minimise risks associated with explosions. Key considerations include:

- **Separation Distances:** Buildings must be located at safe distances from other structures, public areas, and personnel to reduce the impact of an explosion.
- **Blast-Resistant Design:** Walls, roofs, and doors may need to be designed to withstand or direct the force of an explosion away from critical areas.
- **Ventilation:** Adequate ventilation is required to prevent the accumulation of explosive gases or dust.
- **Fire Safety:** Fire-resistant materials and systems must be used to prevent the spread of fire. Automatic fire suppression systems may also be required.
- **Electrical Systems:** Electrical equipment must be designed to prevent ignition of explosive atmospheres (e.g., using ATEX-certified equipment).
- **Grounding and Bonding:** Measures must be in place to prevent static electricity, which could ignite explosive materials.

4.2.4. **Operational Requirements** [23].

- **Risk Assessments:** Employers must conduct detailed risk assessments to identify hazards and implement control measures.
- **Licensing:** A licence from the Health and Safety Executive (HSE) or local authority is required for the manufacture or storage of explosives.
- **Training:** Personnel must be trained in the safe handling of explosives and emergency procedures.
- **Security:** Explosive processing buildings must have robust security measures to prevent unauthorised access.
- **Emergency Planning:** Emergency response plans must be in place, including evacuation procedures and coordination with emergency services.

4.2.5. **Guidance and Standards**

The following documents provide additional guidance on the design and operation of explosive processing buildings:

- **HSE Guidance** [20]:
 - HSE publishes guidance documents such as "Explosives Regulations 2014: Safety Provisions" and "Reducing Risks of Explosions in Explosives Manufacturing."
- **MoD Standards:** [23] If the building is for Ministry of Defence (MoD) use, additional standards such as DSA 03 OME Part 2: In-Service and Operational Safety Management of OME.
- **British Standards:**
 - BS EN 60079 series (for explosive atmospheres) [24]
 - BS 5306 (fire extinguishing installations and equipment) [25]
- **International Standards:**
 - ISO 45001 (occupational health and safety management systems) [26]
 - NFPA 495 (explosive materials code, though this is a US standard, it may provide useful insights) [27]

4.3. Enforcement and Inspections

- 4.3.1. The HSE is the primary enforcement authority for explosive safety in the UK [28]. Inspectors may visit facilities to ensure compliance with regulations and may take enforcement action if necessary. MoD facilities will also be visited and enforced by the inspector of explosives [29].
- 4.3.2. The above list is a comprehensive, but not exhaustive list, of all relevant legislations and regulations. It provides guidance on considerations that must be made when establishing an explosive test house. It must be pointed out that EEDs are comprised of small quantities of explosives, with the largest quantities in one device typically being measured in grams and the majority being measured in milligrams. Therefore, certain criteria listed above do not always apply, for instance having a building separation distance or blast resistance design. That said, they must be considered on a smaller scale as demonstrated so with the room pictured above. The room is in a separate corner of a larger processing room (nonexplosive components) away from any significant electrical devices. It also has the blow out panels installed designed to blow out into a disused space between the wall of the test room and the outer wall of the main building it is housed within. With that in mind, only EEDs can be tested within this room and the maximum NEQ will reflect this.

5. Experimental Validation

5.1. Practical Framework

- 5.1.1. To simulate the use of an EED in a characterization environment, the resistor was employed in the same manner as a real EED. With one exception being that a specialist jig to hold the resistors was not used, unlike on an EED. When an EED is used a bespoke jig will be developed to hold the EED. This will allow for a secure connection between the incoming wires and the electrical pins on the EED, this will also prevent any possible short circuits with the incoming wires touching the bare surface of the firing box. For this test, the resistors were secured in crocodile clips as shown in figure 5 below.



Figure 5: Resistor held in crocodile clips.

- 5.1.2. One issue that was identified was the possibility of shorting the connections out of the crocodile clips due to the firing box being of a metal construction. To mitigate this the clips were placed in such a way to ensure they “floated” above the metal surface and any contact was made by an insulated part. Figure 6 below shows the resistor in its test configuration.



Figure 6: Resistor placed in the firing box.

- 5.1.3. As part of the test a resistor of a 1Ω resistor was used. There is no definitive reason for this level of resistance being used, any resistance value would have sufficed. This resistor was provided by DM Gosport as part of this validation experiment. The resistor also had a tolerance percentage of 5%, Appendix A contains a verification of the values obtained from an online resistor calculator.
- 5.1.4. When conducting a change of the resistor (such as once it has been tested to failure) the procedure that followed to replace it, was a similar one to that used to replace an EED. No standard protocol was in place; therefore, the process was guided information through verbal instructions from the local facilities manager. The process was to ensure the constant power sources were turned to off, followed by the removal of the interlock key. This key was then used to access the testing room, once inside the room the tester could then disconnect the supply cable (this cable had to be disconnected to open the firing box). The firing box was then opened, and the resistor could be replaced. Great care had to be taken to ensure that no metal from the crocodile clips touched the metal firing box when placing the resistor back into the firing box. The procedure was then followed in reverse by connecting the cable to the firing box, locking the room door, and removing the safety interlock key. The key was then placed back into the firing

control panel and the constant power switched back to RMT (Remote) ready to continue testing.

5.2. Physical Testing Procedure

- 5.2.1. The first procedure to be tested was for reliable and repeatable stimuli delivery. This was set up to mimic the typical stimuli that would be delivered to a 1 Watt 1 Amp EED². A voltage of 250mV would be applied to the resistor for 500mS. The results would then be recorded off the oscilloscope, where the values were measured for Duration, Voltage, Amps and Watts. The resistance of the resistor was also recorded, first on a handheld multimeter (reference photo can be found in Appendix B), once installed in the test configuration the resistance was recorded on the safety Ohm meter and then after the stimuli the resistance was recorded again. The two pre-test values were used as a confirmation of the resistors value before being subjected to the stimuli. The post-test of the resistance was conducted to ensure the resistors values had not been changed as part of the test. The resistor was allowed a minimum of a one-minute cool down window between stimuli³, this was done to ensure a buildup of heat did not alter the resistors value. This resistor was subjected to a total of ten stimuli pulses.
- 5.2.2. The second procedure was to find the failure point at which the 1Ω resistor would fail from a stimulus, to do this a resistor was placed in the test configuration as described above. It was then subjected to a number of stimuli of increasing the voltage and/or duration that was applied to the resistor. The first test started at 400mV for 2.5 Seconds, the failure point was identified at 600mV and 5.3 seconds. A further three resistors were then subjected to the same input to ensure the stimuli would reliably fail a resistor ready for the third suit of tests. Table 1 below shows the progression of the applied voltage and the duration this was applied for. Test 1 to 4 were applied to the same resistor and then tests 6, 7 and 8 were all different resistors.

² In the absence of standardised reference values, the stimulus level was informed by anecdotal evidence and professional judgment provided by a subject matter expert (SME). This SME is from the MoD national authority on initiator systems and provides guidance and support to the MoD on anything EED related. He was in attendance of these experiments in a supporting role.

³ This often resulted in a window of 2 minutes between stimuli due to the time taken to record the previous tests data.

Test No	Input mV	Duration S
1	400	2.5
2	450	2.5
3	500	2.5
4	600	2.5
5	600	5.3
6	600	5.3
7	600	5.3
8	600	5.3

Table 1: Failure point stimuli

5.2.3. The third and final procedure was to repeatedly fail a resistor to see if the test equipment could reliably failure a resistor, simulating an EED initiation. The second purpose of this was to test the procedure of replacing a test item in between each test. The stimulus that was applied to the resistor was the same as tests 6, 7 and 8 in the previous procedure, 600mV for 5.3 seconds, the time it took for these resistors to fail was recorded. The resistance of each resistor pre-test was recorded both by the Ohm safety meter and the handheld multimeter. The Ohm safety meter was also used to measure the resistor post stimuli to confirm it had failed.

5.2.4. For all three procedures the following steps were taken in the order they are described in, the only difference being the changes to the applied stimuli as described above.

1. Switch on all test equipment.
2. Program all test equipment to provide the desired stimuli.
3. Ensure constant power is set to "off."
4. Remove interlock key from firing panel.
5. Use the interlock key to unlock test chamber door.
6. Unscrew the supply cable from the firing box.
7. Open the firing box
8. Insert resistor into the firing box and ensure no metal-to-metal contact of the clips to the box.
9. Close the firing box.
10. Reattach cable.
11. Lock the test chamber door and remove interlock key.
12. Place interlock key into firing panel.
13. Set constant power to RMT.
14. Double check applied stimulus is correct.
15. Turn interlock key to arm.

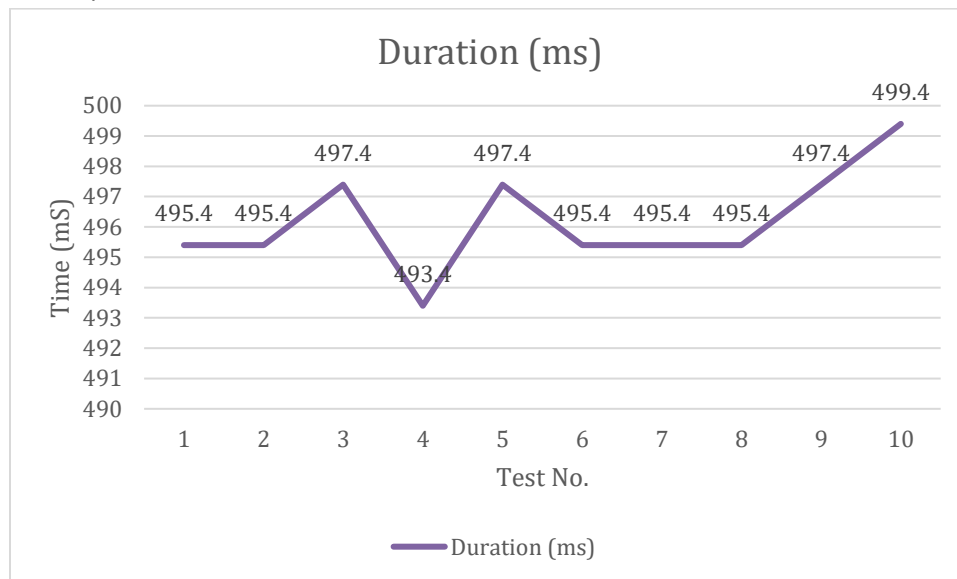
16. Ensure oscilloscope is recording.
17. Press the “fire” button to allow the stimuli to be applied to the resistor.
18. Wait for the results to appear on the oscilloscope.
19. Turn interlock key to safe.
20. Record data.

- 5.2.5. Steps 1 to 2 are to be conducted on the first startup of the test procedure.
- 5.2.6. Steps 3 to 20 are to be repeated between each test.
- 5.2.7. The results from the test were recorded within an Excel spreadsheet all of which can be seen in Appendix C, all the resistors tested were also retained and labeled appropriately, these have been photographed and can be seen in Appendix D.

6. Results and Discussion

6.1. Results, analysis, and implications

- 6.1.1. The Results from the experiment were varied, where some aspects of the testing had the predicted results whilst others did not. For example, during test sequence 1 the duration that the stimuli were applied for were within a 6-millisecond range. This range could have been smaller, as due to the type of oscilloscope used, it was exceedingly difficult to finely tune the measuring window without it jumping too far in one direction or the other. This could explain why between tests 3 and 5 there was some variation between the recorded durations. Although there was no defined “success” value for this test the fact the results were within 6 Milliseconds of each other, can be considered a good result as the point of this test was to see if the stimuli were consistent and within the 500mS stimuli target. With some finer turning on the impulse generator it can be assumed the impulse duration can be adjusted to meet the 500mS duration exactly. The reason this was not possible was due to the analog approach to adjusting the duration (manual dial), therefore it was limited to resolution of the dial to fine tune. The use of a better digital impulse generator is recommended in instances where greater accuracy is required.



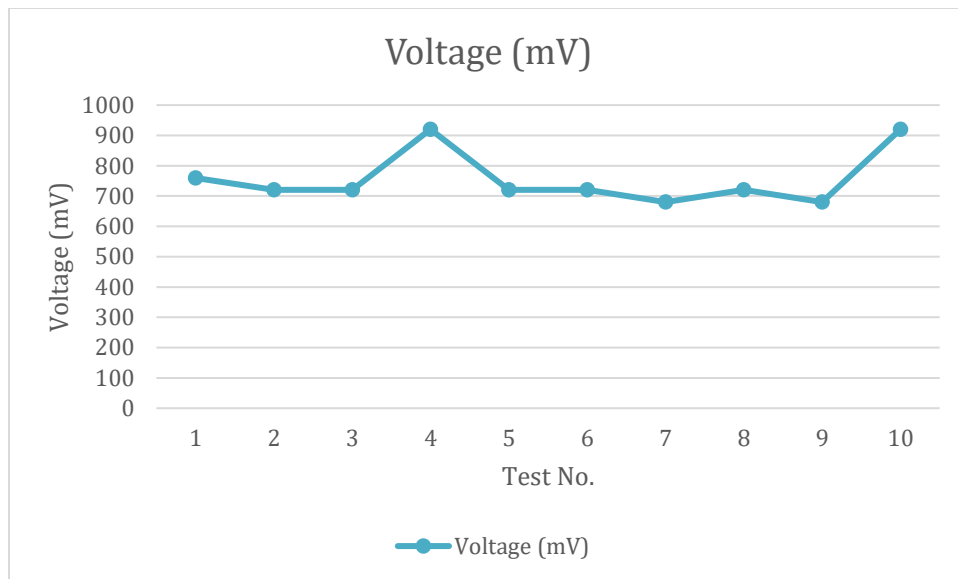
Graph 1: Test sequence 1 duration results.

- 6.1.2. The results from the Voltage recorded on the day is where the issue lies, with a stimulus of 250mV. The results that were recorded had a range of 240mV and were all above the stimuli 250mV level. Table 2 below shows the higher-than-expected voltage levels recorded on the oscilloscope. The results, although consistent as shown below in Graph 2, raises some questions as to why there was

a higher-than-expected recording of voltage. Unfortunately, this issue was not identified at the time of conducting the experiment.

Test No.	Voltage (mV)
1	760
2	720
3	720
4	920
5	720
6	720
7	680
8	720
9	680
10	920

Table 2: Recorded Millivolts



Graph 2: Recorded Millivolts

- 6.1.3. On a consistency approach it can be argued that this experiment proves that the test equipment can consistently apply a voltage within a small window, the issue is the level provided was higher than expected.
- 6.1.4. Another issue presents itself when you start analysing the current and power results from these tests. The voltage and current were both recorded from the oscilloscope which measured these during the testing. The power was then

calculated by the oscilloscope using the two recorded voltages and current. Table 3 shows the results for all three parameters as well as the duration.

Test No.	Duration (ms)	Voltage (mV)	Current (mA)	Power (mW)
1	495.4	760	920	446.4
2	495.4	720	660	475.2
3	497.4	720	460	723.2
4	493.4	920	500	460
5	497.4	720	660	475.2
6	495.4	720	660	475.2
7	495.4	680	780	530.4
8	495.4	720	620	446.4
9	497.4	680	620	421.6
10	499.4	920	500	460

Table 3: Test sequence one results.

- 6.1.5. It must be pointed out that the values for mV, mA and mW are all the maximum recorded. So as can be seen below in figure 7 the voltage tails up at the end and the amps tail down. It is believed that this could be the test equipment trying to apply a constant power, as $\text{Power} = \text{Volts} \times \text{Amps}$ [30], so by the voltage increasing the system compensated by reducing the current to try and maintain a consistence amp output.

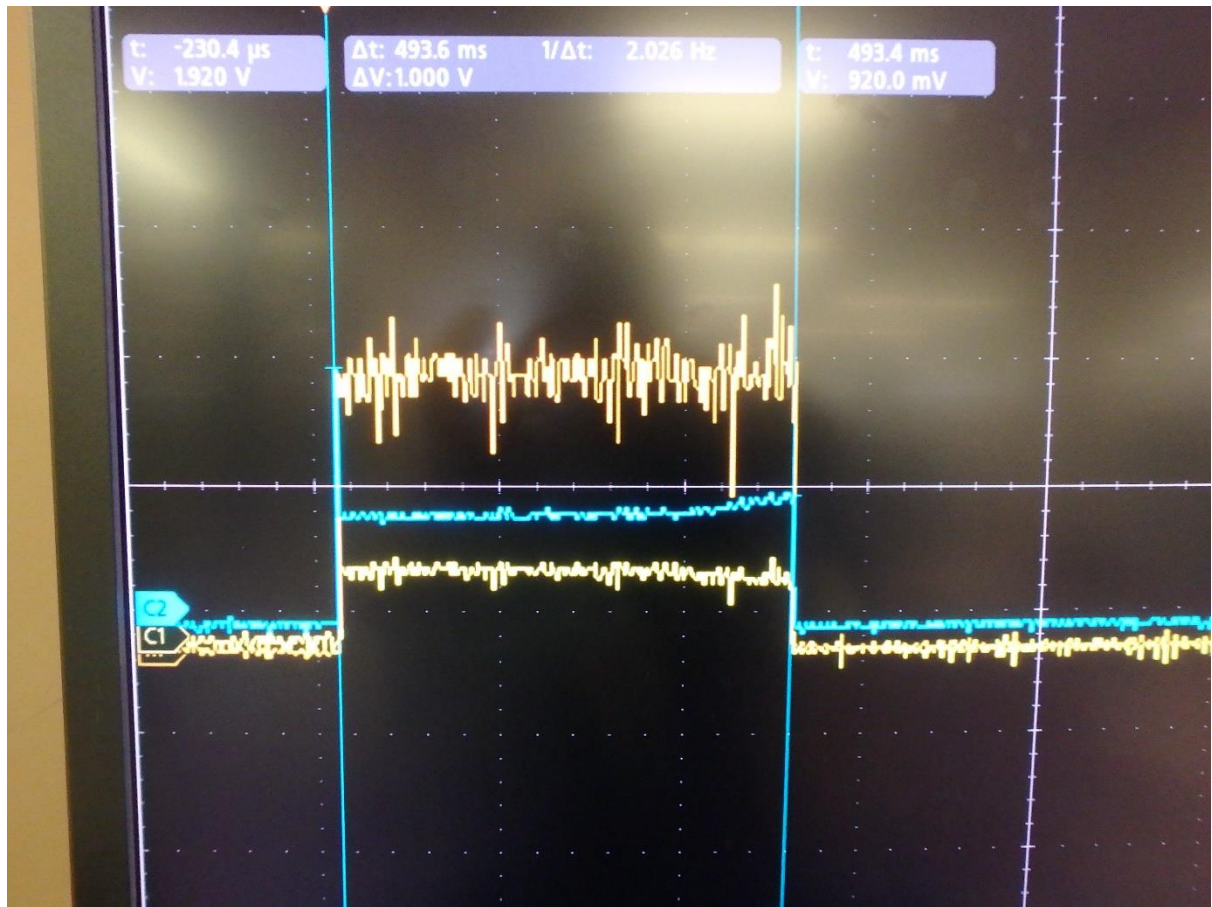


Figure 7: Test sequence 1 oscilloscope recording.

- 6.1.6. The results from the other two sequences of tests are not as important to the overall conclusion to test the suitability of using resistors as a dummy load. Test sequence two found the stimuli point where a 1 Ohm resistor would fail and test sequence three proved that the system could destroy a resistor consistently. It also validated the process needed to conduct a trial on a real EED and because of this test sequence two and three are considered successful. All the results to these two tests can be found in appendix D. To further validate this the next step would be to conduct the same process on a real EED.

6.2. Analysis

- 6.2.1. During testing, ten stimuli pulses of 250 mV were applied for 500 mS via a capacitor discharge method across a 1 Ω test resistor. The recorded voltages ranged from 680 mV to 920 mV, while corresponding currents varied between 460 mA and 920 mA. Oscilloscope-calculated power values ranged from 421.6 mW to 723.2 mW. According to Ohm's Law ($V = IR$), voltage across a 1 Ω resistor should align closely with current in mA. However, several trials deviated from this, e.g., Trial 3 recorded 460 mA and 720 mV (suggesting 1.57 Ω), while Trial 4 measured 500 mA and 920 mV (1.84 Ω), implying additional resistance was present in the circuit.
- 6.2.2. The wire connecting the measurement system to the test resistor was measured at 0.52 Ω , which, along with internal resistance in the test modules (e.g., firing control unit, pulse generator), likely contributed to the observed discrepancies. Due to the oscilloscope being connected upstream of the resistor, it captured voltage drops across both the test resistor and these additional elements. This conclusion is reinforced by the calculated total loop resistance values (from V/I) across trials, ranging from 0.83 Ω to 1.84 Ω (Table can be found in Appendix E).
- 6.2.3. Average values across all trials were 756 mV (voltage), 638 mA (current), and 491.4 mW (power). The average power calculated from $V \times I$ was 477.4 mW, showing good consistency with the measured average, despite trial-level anomalies. Trial 1 and 3 both had these anomalies, in the results for the power calculation. Both show power results that do not match with the calculated power (as shown in table 7 appendix E). Some discrepancies in power may have resulted from oscilloscope measurement techniques, such as misaligned voltage/current time bases or averaging methods. This could be resolved by placing the oscilloscope at the resistor end of the trial to ensure voltage is measured directly across the load. It also emphasises the importance of understanding oscilloscope internal computation methods for power during pulse testing [31] [32]. Results table and formulas used for the figures above can be seen in Appendix E.

6.3. Implications

- 6.3.1. As the results show that there is promise to the method due to the consistency in the levels and duration provided. Further work is needed to definitively determine why the recorded stimuli was more than anticipated. If these issues are resolved and optimised, then using resistors as a dummy load can be a valid methodology moving forward. These experiments have highlighted a floor in the test set up and this will be something the DM Gosport will need to investigate to determine where this erroneous voltage, current and resistance are coming from. Without fully understanding this, the testing levels could be considered invalid despite the consistency in the application stimuli. This demonstrates that using a resistor as a dummy load are a promising way to find potential issues and mitigate them before testing expensive EEDs. It is also worth pointing out that if the testing process was more tailored towards RF pickup testing instead of direct electrical testing, then considerations would need to be taken around the impedance difference between the resistor and an EED. Internal wire sizes of an EED could have difference impedance to a resistor so therefor is affected differently to a resistor.

7. Conclusion

7.1. Summary of Findings

- 7.1.1. The main aim of this report was to explore the use of resistors as a dummy load in an EED testing environment. The intention was to demonstrate that the resistor could simulate the resistance forces an EED would have during characterization testing. Although not successful in fully proving that DM Gosport is ready to conduct EED testing, it did highlight the benefit of using resistors to validate a new set up. Looking at the results, it was found that some of the stimuli levels were not observed to the level that was expected. The consistency was there, and in that respect, it is considered a success. It can also be deemed a success with the accuracy of the duration of the stimuli being within a 6-millisecond range across the ten tests. The issue lies with the voltage, current and power levels being recorded on the oscilloscope. DM Gosport will need to investigate why this was the case and it was proposed that this could be down to the location of the oscilloscope in the test equipment chain. By moving the oscilloscope recording points to the resistor end of the supply cable this could help mitigate the issues seen during these tests.
- 7.1.2. On a processing aspect of the validation effort, this was a success. It followed and proved the testing procedure is correct and accurate with the appropriate safety procedures in place to safely test an EED.

7.2. Limitations

- 7.2.1. As with any sort of validation effort there are limitations to using a dummy load instead of the real device. It will never be a 100% representative test, as mentioned in section 6.3.1, if the testing was for RF pickup, then a resistor could present wildly different results to that of a real EED.
- 7.2.2. Another limitation with this approach is the change in resistance of a resistor as it can increase with temperature increases [33]. Therefore, great care must be taken not to overload a resistor by subjecting it to multiple stimuli events in a short duration. In the testing of the resistor ten times for test sequence one adequate time was left (minimum of 1 minute) between shocks to help dissipate heat soak from changing the resistance of the resistor.

7.3. Future Research recommendations

- 7.3.1. Future research on this subject would be to revisit DM Gosport test facility and identify where the increase stimuli levels are coming from. By finding the cause of this increase, an adjustment to the test equipment set up can be made. This should be followed by repeating the first test sequence, looking at the same parameters and stimuli to ensure this time the oscilloscope is reading the results correctly. With the completion of this reanalysis, it can be proven the system is fully functional and ready to be tested on a live EED.
- 7.3.2. Another area of future research could be to test a series of inert EEDs. An inert EED is an EED where there is no explosive composition contained within its construction, but it is made in the same way to a live EED. This way an EED with no energetics will have the same resistance, impedance, and characteristics of a live EED just without the explosive element. This could prove the test house/equipment is correct set up and calibrated for the live EED.

8. Reflection

8.1. Challenges Encountered

- 8.1.1. During the testing phase, several challenges arose, those highlighted areas for improvement in both preparation and execution. One significant issue was the lack of a clear and structured plan for the testing format. This absence of foresight led to difficulties in interpreting results, as some output values did not align with the expected input values, which was not identified on the day. Furthermore, additional issues were not identified on the day of testing, which could have been mitigated with a more thorough understanding of the test equipment's functions. For instance, there was uncertainty regarding how and where the oscilloscope recorded data, which introduced additional complexity to the analysis. These challenges underscore the importance of entering future testing phases with a more comprehensive and detailed plan.

8.2. Positive Outcomes

- 8.2.1. Despite the challenges, several aspects of the testing process were successful. The duration of the stimuli recorded was well-aligned with the duration of the stimuli pulse, demonstrating the equipment can provide the desired stimuli duration. Additionally, the use of resistors proved valuable in identifying a potential issue with the test equipment stimuli levels as mentioned in section 8.1.1. Which may have otherwise gone unnoticed on an EED. The process of replacing resistors within the test chamber was also efficient and functioned as intended, contributing to the overall workflow. These successes provide a solid foundation to build upon in future testing scenarios.

8.3. Areas for Improvement

- 8.3.1. Reflecting on the experience, there are several key areas that could be improved in subsequent testing phases. Primarily, developing a more robust and detailed plan prior to testing is essential to ensure a smoother process and more reliable results. Incorporating a wider range and a greater number of resistors with varying ratings would also enhance the scope and accuracy of the testing. Additionally, adjusting the oscilloscope's recording points and gaining a deeper understanding of the resistance and impedance of all interconnected equipment would help to minimise uncertainties and improve the reliability of the data collected. Addressing these areas will contribute to a more effective and efficient testing process in the future.

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10. Appendices

A.

$1\ \Omega \pm 5\% (J)$



Number of Bands: 4 Band

1st Band Color:

☐ black ☒ brown ☐ red ☐ orange

☐ yellow ☐ green ☐ blue ☐ violet

☐ grey ☐ white

2nd Band Color:

☒ black ☐ brown ☐ red ☐ orange

☐ yellow ☐ green ☐ blue ☐ violet

☐ grey ☐ white

Multiplier Color:

☐ black ☐ brown ☐ red ☐ orange

☐ yellow ☐ green ☐ blue ☐ violet

☐ grey ☐ white ☒ gold ☐ silver

Tolerance Color:

☐ brown ☐ red ☐ orange ☐ yellow

☐ green ☐ blue ☐ violet ☐ grey

☒ gold ☐ silver

Figure 8: Resistor colour band index [34]

B.

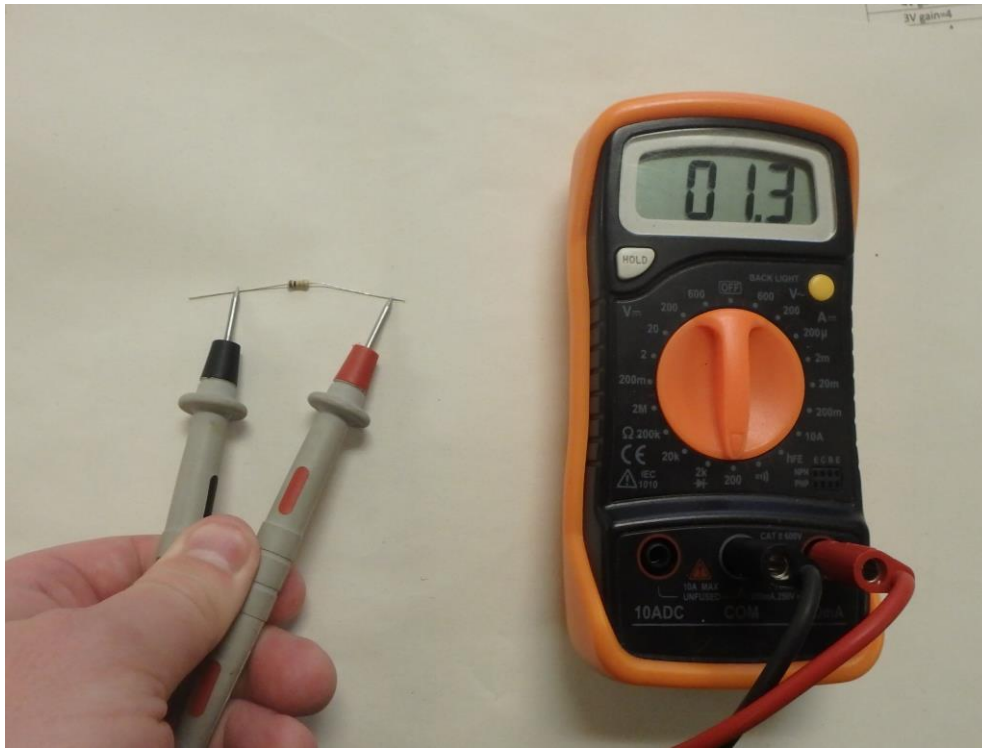


Figure 9: Measuring resistance with handheld multimeter.

C.

Test No.	Duration (ms)	Voltage (mV)	Current (mA)	Power (mW)	Resistance of test resistor after each impulse
1	495.4	760	920	446.4	1.13
2	495.4	720	660	475.2	1.125
3	497.4	720	460	723.2	1.126
4	493.4	920	500	460	1.126
5	497.4	720	660	475.2	1.126
6	495.4	720	660	475.2	1.13
7	495.4	680	780	530.4	1.123
8	495.4	720	620	446.4	1.125
9	497.4	680	620	421.6	1.136
10	499.4	920	500	460	1.13

Table 4: Test one full results

Test No	Input mV	Duration S	Ohms before	Ohms after
1	400	2.5	1.16	1.12
2	450	2.5		1.06
3	500	2.5		0.95
4	600	2.5		0.84
5	600	5.3		0
6	600	5.3	1.14	0
7	600	5.3	1.2	0
8	600	5.3	1.16	0

Table 5: Test two full results

Test no	Time to failure (S)	Resistor Ohms before test	
		Handheld multimeter Ohms	Safety Ohm meter
1	2.5	1.2	1.16
2	1.3	1.2	1.16
3	1.3	1.2	1.16
4	1.2	1.2	1.16
5	3.4	1.2	1.12
6	0	1.2	1.15
7	3.5	1.2	1.11
8	1.3	1.2	1.18
9	3.4	1.2	1.11
10	0	1.2	1.17

Table 6: Test three full results

D.

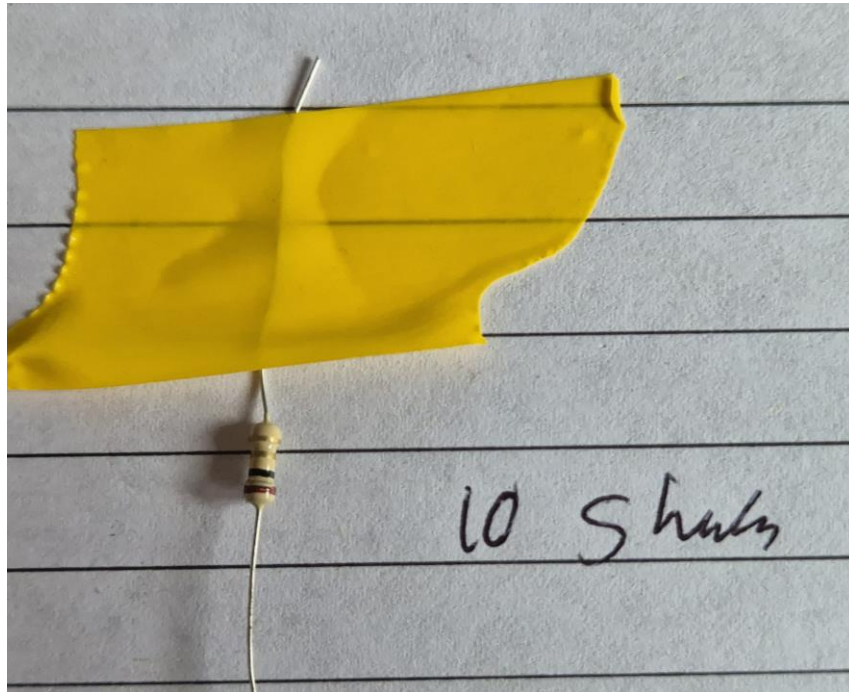


Figure 10: Test one resistor after 10 repeated stimuli applications.

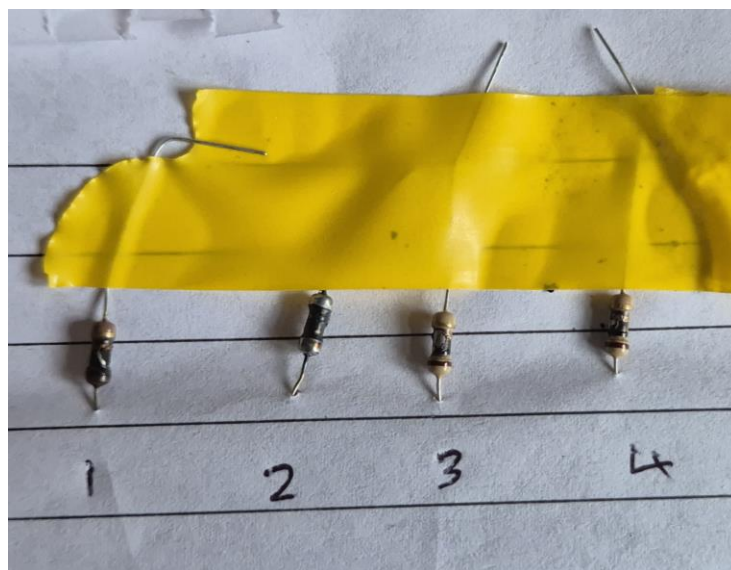


Figure 11: Test two resistors after testing.



Figure 12: Test three resistors after testing.

E.

Test	Voltage (mV)	Current (mA)	Measured Power (mW)	Calc Resistance (Ω)	V $\times$ I Power (mW)
1	760	920	446.4	0.83	699.2
2	720	660	475.2	1.09	475.2
3	720	460	723.2	1.57	331.2
4	920	500	460.0	1.84	460.0
5	720	660	475.2	1.09	475.2
6	720	660	475.2	1.09	475.2
7	680	780	530.4	0.87	530.4
8	720	620	446.4	1.16	446.4
9	680	620	421.6	1.10	421.6
10	920	500	460.0	1.84	460.0

Table 7: Test one calculation results

Summary Statistics

Average Voltage: 756.0 mV

Average Current: 638.0 mA

Average Measured Power: 491.36 mW

Average V $\times$ I Power: 477.44 mW

Ohm's Law

To calculate the **resistance** (Ω) based on measured voltage and current:

$$R = \frac{V}{I}$$

- **V** is voltage in volts (V)
- **I** is current in amperes (A)
- Result: **R** in ohms (Ω)

In the analysis, since data was provided in millivolts and milliamps, it was first converted:

$$V = \frac{\text{Voltage (mV)}}{1000}, I = \frac{\text{Current (mA)}}{1000}$$

Then,

$$R = \frac{V}{I}$$

Power from Oscilloscope (Given)

Power values (in milliwatts, mW) were directly recorded by the oscilloscope for each test. No formula was applied here — these are empirical values.

Calculated Power ($V \times I$)

To validate power, it was also **manually calculated** from voltage and current:

$$P = V \times I$$

Then converted to milliwatts:

$$P_{mW} = V \times I \times 1000$$

Where:

- **V** in volts
- **I** in amperes
- P_{mW} is power in milliwatts (mW)

Averaging

To compute the **mean** value across 10 trials for voltage, current, and power:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n x_i$$

Where:

- $\bar{X}$ is the average.
- x_i are the individual measurements.
- $n=10$ (number of trials)

Applied separately for:

- Voltage (mV)
- Current (mA)
- Measured Power (mW)
- Calculated Power (mW)