Development of Lightweight Backpack Electric Fishing Gear – Phase II

Institute of Freshwater Ecology

R&D Technical Report W209

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Statement of use
This report reviews the Environment Agency Code of Practice for Electric Fishing Operations. A new Annex C is proposed to cover the use of Backpack Electric Fishing (BEF) equipment. Details of the specification for new equipment constructed under the new annex C are detailed. Results from a study evaluating the impact upon Rainbow trout of different waveforms and voltage commonly used for electric fishing operations are given.

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1. EXECUTIVE SUMMARY

Phase II of the Backpack Electric Fishing Project is reported.

Requirements for compliance with European and UK electrical legislation have been ascertained and discussions methods for compliance certification held with appropriate bodies. BEF equipment currently in use with the Agency has been examined with regard to compliance with all current regulations and legislation.

Specifically: The Low Voltage directive (LVD).
Electromagnetic Compatibility.
Provision and Use of Work Equipment Regulations (PUWER).

A list of recommendations for changes to the current CoP EFO which will enable BEF equipment to include ergonomic and safety system advances identified in phase I has been drawn up. The draft recommendations were presented to the EA Electric Fishing Working Group for consideration and discussed. Resultant from these discussions the proposed new Annex C to the Environment Agency Code of Practice for safety in Electric Fishing Operations (CoP EFO) is presented. Modifications, resulting from adoption of Annex C, required to the main document, Annex A and Annex B of the CoP EFO are listed.

A report on the visit to co-workers at Mississippi State University (MSU), USA and details of the joint MSU/IFE investigation into Power Transfer Theory is presented.

The results from the Waveform and Voltage Evaluation (WAVE) experiment are reported. This evaluation assessed three different electric fishing waveform types. The evaluation attempted to determine, with specific regard to power requirements, efficiency of capture and fish damage, whether advantages can be gained from using non standard pulse shapes. A pulse shape which had high capture efficiency, low injury rates and low power requirements was identified.

A prototype BEF unit incorporating all the EA CoP EFO amendments contained in the proposed Annex C has been built and tested. A workshop was held for EA fishery managers in order for them to evaluate and comment upon the prototype BEF unit. Whilst the use of non-ideal electronics meant some non-compliance with the CoP EFO, users found the equipment a distinct improvement over BEF equipment currently available in the UK.

KEY WORDS

BACKPACK ELECTRIC FISHING GEAR/ CODE OF PRACTICE/ VOLTAGE EVALUATION/ WAVEFORM EVALUATION

2. INTRODUCTION

Backpack electric fishing (BEF) gear is extremely useful and effective for sampling fish populations in small streams, particularly where access is limited. In addition, it reduces manpower requirements and therefore leads to more cost-effective sampling strategies. Equipment currently in use in the Environment Agency, however, is considered to have usage and ergonomic drawbacks (Beaumont 1997).

Phase I of this project assessed the current usage and needs of BEF equipment within the Agency, reviewed the current operational Health and Safety requirements and Environment Agency's Code of Practice for Safety in Electric Fishing Operations (CoP EFO) and assessed whether gear manufactured in the UK or other countries met or could be adapted to meet the CoP EFO. Recommendations were made regarding both the specifications for BEF equipment detailed in the CoP EFO and future research direction regarding the assessment of electrically efficient waveforms.

Phase II of the project seeks to address the issues raised in Phase I.

Objectives of the study are as follows:

1. To review the current equipment legislation and regulations and investigate methods whereby equipment can gain certification of compliance with current equipment legislation.

2. To make detailed recommendations regarding amendments to the CoP EFO.

3. To carry out trials to assess the merits of different electrical waveforms.

4. To build a prototype BEF unit to incorporate design and construction details determined above.

This report details the findings on the above objectives.

3. REGULATION COMPLIANCE

3.1 CE Marking

CE marking is now a legal requirement for a wide-range of equipment that is placed on the Market in Europe. The CE mark is a visible indication that the manufacturer is claiming compliance with all relevant "New Approach" directives in force. The requirements for CE marking are set out in The CE Marking Directive 93/68/EEC the details of which are incorporated into the legislation implementing the LV directive and the EMC directive. Backpack Electric Fishing Equipment falls within the scope of at least two such directives:

The Low Voltage Directive 7/23/EEC (The LV Directive)

The EMC Directive 89/336/EEC. (The EMC Directive)

These directives require that manufacturers prepare a "Declaration of Conformity" prior to affixing the CE mark. This declaration should be based upon a documentary evidence of compliance. The directives differ slightly in their implementation.

3.1.2 The Low Voltage Directive 7/23/EEC (The LV Directive)

The LV Directive defines only general requirements (safety objectives). It leaves the detail of how to achieve compliance with the manufacturer and the signatory(ies) of the Declaration of conformity. There are several routes to the CE mark but essentially there are two potential and widely different approaches, these being the "Standards Approach" and the "General Declaration Approach". The Standards Approach uses one or more relevant Harmonised Standards and demonstrates conformance on a clause by clause basis. This route tends to be favoured by the test houses and Product Safety agencies. Alternatively, the manufacturer may construct the product in accordance with the essential requirements (safety objectives) of the directive without application of standards. In such a case, the manufacturer must include a description of the solutions adopted to satisfy the safety requirements of the Directive within the technical documentation. In the case of a challenge by the authorities in charge of market surveillance (Trading Standards Authority in UK) a report drawn up by a Notified Body (i.e. an approved test house) would be considered to be an element of proof of conformity.

3.1.3 The EMC Directive 89/336/EEC (The EMC Directive)

The EMC Directive sets out certain protection requirements and defines three routes to compliance. Two of the routes may be applicable to backpack electric fishing equipment these being the "Standards Route" and the "Technical Construction File" route. The third route, the "Type Examination" route, is applicable only to radio communication equipment. The standards route uses the application of one or more relevant harmonized standards on a clause by clause basis to demonstrate compliance. This is by far the most administratively simple route, provided appropriate and relevant harmonized standard(s) are available. The technical Construction File route requires the manufacturer to construct a file of technical information about the product, to a prescribed formula, in order to justify how the protection requirements of the directive have been met. It *must* include a technical report by a "Competent Body" (i.e. an EMC approved test house).

3.2 Report of Discussions with, and Visit to, an Approved Test House

*The meeting took place at 1200 on 5 May 1998 at the **SOCIÉTÉ GÉNÉRALE DE SURVEILLANCE (SGS) LABORATORIES.**, Bowburn.*

3.2.1 Introduction

Present: Alex Dobie (SGS Consultant)
Jim Hogg (Electrical Adviser, Environment Agency)
Mike Lee (Electronics Engineer, IFE).

The meeting commenced with a brief introduction to the SGS group with particular reference to the Bowburn facilities.

The operation of Electric Fishing equipment was explained, boom boats, bankside, and backpack operation described.

The partnership between the Environment Agency and IFE was explained and an outline of the work undertaken in Phase I was described and illustrated with photographs of representative equipment. An overview of the work to be undertaken within Phase II was given, with emphasis on the production of a prototype to demonstrate the feasibility of the manufacture of “safe”, compliant (with legislation), equipment from which a tender specification will be derived.

3.2.2 Safety

Issues of safety were discussed with reference to the Environment Agency COP. AD agreed IEC335 is an appropriate standard and that, although part 2 is not yet published, it would be reasonable to design to it in the absence of any harmonised or national standard. Subsequent discussions confirmed that there is no obligation to meet standards, but that Article 6 of the Low Voltage Directive (72/23/EEC) implies that equipment, which conforms to an appropriate IEC standard will be regarded to conform to the provisions of Article 2 (i.e. that it is safe). If we wish to deviate from the standard (e.g. swap tilt switch for immersion switch, or use 24 V controls) it could be acceptable provided that we can justify it, ultimately, in a court of law. Such an argument is strengthened if it is supported by a report from a notified body (for LVD).

3.2.3 Electromagnetic Compatibility Regulations

AD enlisted support from an SGS EMC engineer to look at the equipment. He suggested that the generic standard for light industrial equipment may be appropriate, with tests for emissions, susceptibility, and ESD. Susceptibility may be a particularly safety critical test if the system can be switched on through a solid state switch. If claiming compliance by the standards route, then the equipment must fully meet all relevant standards claimed. If full compliance with all elements of the claimed standards cannot be demonstrated then the only route to conform with the requirements of the EMC Directive is the Technical Construction File route, for which a technical report or certificate issued by a competent body is mandatory. There was some concern as to how representative tests could be arranged (i.e. with a distributed electric field).

3.2.4 Conclusion

The meeting concluded with a brief tour of the facilities at SGS Bowburn site. Facilities include Electrical testing for transients, physical, environmental, EMC susceptibility, conducted emissions, and harmonics. The site contains SGSs only UK open field RF test site.

3.3 Explanation of "Notified" and "Competent" Bodies

3.3.1 Notified Bodies

The essential requirements of the Low Voltage Directive (LVD) are that the equipment is constructed in accordance with good engineering practice in safety matters and that it does not endanger the safety of persons, domestic animals or property when properly installed, maintained, and used in applications for which it was made. A report from a notified body is not a legal requirement under the Low Voltage Directive, however it would add substantial weight to any argument against compliance with the directive.

In implementing the Low Voltage Directive in the UK, the Electrical Equipment (Safety) Regulations 1994 paragraph.8 states:

> "Where the conformity of any electrical equipment with the requirements of regulation 5(1) is called into question (whether in any proceedings or otherwise) any report prepared by a body notified in accordance with the procedure set out in Article 11 of the Low Voltage Directive for the purpose of Article 8.2 of that directive may be relied upon and due regard shall be had to any such report by any person or court by whom the question of conformity falls to be determined."

3.3.2 Competent Bodies

Under the EMC Directive, a body is considered to be competent if it fulfils the criteria set out in Annex 2 of the Directive. These criteria include the availability of personnel and of the necessary means and equipment to carry out work; technical competence and professional integrity of personnel; independence in carrying out tests; preparing reports and performing verification functions provided for in the directive; maintenance of professional secrecy; and possession of civil liability insurance. A body can be recognised as competent either by an accreditation body recognised as such by the competent authority of a member state, or by a body representing the supervisory authority of a member state (DTI in UK).

If compliance with EMC is claimed by Technical construction file, the file must contain a certificate from a competent body. It is possible under the EMC legislation to claim compliance under the standards route without a report from a competent body, provided that the equipment can be demonstrated to comply fully with an appropriate harmonised standard.

3.3.3 Summary

While neither piece of legislation necessarily forces tests to be carried out, or reports to be prepared by an independent third party, it would almost certainly be in our interests to have the support of such an independent body for any design specification, which we propose. In the case of the Low Voltage Directive, for example, the only appropriate standard that we are aware of is IEC335 (2), which specifies the use of a tilt switch. If we do not wish to incorporate a tilt switch (and hence cannot claim to fully meet that standard), the support of a notified body would add great weight to an argument to justify such non-compliance. It would be expected that in order to gain such support, the third party would need to be satisfied that appropriate alternative measures had been put in place (e.g. immersion switches).

In the case of the Electromagnetic Compatibility Directive, unless we can fully meet all appropriate standards, a certificate or report from a competent body is mandatory to declare compliance by the Technical Construction File route. However even if we choose to self certify compliance to standards it may still be necessary to enlist assistance for tests such as immunity to electromagnetic radiation for which we are not equipped and which may have serious safety implications.

Although not unique, SGS are well suited to consult on this project as a notified body under low voltage directive and a competent body under EMC directive. They are within reasonable travelling distance of the Windermere Laboratory and have laboratory capacity within reasonable lead times. Before any final decision regarding the selection of a test laboratory, one or more alternative organisations will be contacted to obtain alternative opinions and, possibly, quotations.

3.4 Cost Estimates for Independent Evaluation of Production BEF Equipment to Confirm Compliance with Relevant Legislation

Following the visit to SGS labs at Bowburn Co. Durham, estimates of the anticipated cost of evaluating a sample of BEF equipment to confirm compliance with relevant legislation were sought. A second test house was also approached by telephone to discuss the requirements and obtain comparative cost estimates.

Test House	EMC Testing	Safety Testing	Total
SGS [1]	£1600	£950	£2550
TRL [2]	£1350	£2500	£3850

It should be noted that the price quoted for Safety Testing by TRL includes a £300 element for consultancy fees, which they recommend because of the unusual and potentially hazardous nature of the product.

The figures are presented as budgetary guide prices and are for “single pass” tests. Should it be necessary to implement a design review as a consequence of test results further costs may be incurred. Obviously every effort is made within the design procedure to use knowledge and experience to anticipate potential problem areas and, wherever possible, to build in appropriate safety margins. However EMC in particular is notoriously difficult to predict or model, and the pre-compliance test equipment available will only allow a subset of full compliance tests to be undertaken during development, so it is essential to “build in” some contingency for test failure.

Because of the high cost of this type of equipment testing and certification, it is proposed that formal compliance testing should only be undertaken when a prototype which is very close to a production unit is available. However there may be some merit in undertaking some limited pre-compliance testing with a test house before then, in order to gain some feeling for the magnitude of any problems, to obtain some "calibration" information for in house measurements, and to build up a relationship with a test house in order to gain from the "informal consultancy" which is undoubtedly available. This type of testing is undertaken by the same personnel and using the same equipment as formal testing, but is not certified. It is estimated that such testing may cost in the region of 30% of a full compliance test.

Because the market in equipment testing can fluctuate significantly depending upon capacity, workload, and arrival of new legislation, it is recommended that these, and possibly other, test houses are approached when hardware is available in order to establish more detailed test specifications, costs, and lead times.

3.5 Addresses

[1] Société Générale de Surveillance (SGS) South Industrial Estate Bowburn Co. Durham DH6 5AD Tel. 0191 377 2000 Fax. 0191 377 2020	[2] TRL EMC Ltd Moss View Nipe Lane Up-Holland West Lancashire WN8 9PY

4. REVIEW OF CODE OF PRACTICE FOR SAFETY IN ELECTRIC FISHING OPERATIONS (CoP EFO)

The following changes are required to the Main Document: Environment Agency Code of Practice for Safety in Electric Fishing Operations in order to comply with the specifications and requirements set out in Annex C for Backpack Electric Fishing Gear.

4.1 Main Document

P4 Control Boxes: Calls for control box fittings such as handles, control knobs, sockets to be non-conductive. This may not be possible for lightweight backpack equipment. IEC335-2 (section 6.1) calls for classification as class II or class III. Class III relates to SELV (SELV is defined in IEC335-1 section 2.5.2) and is therefore not applicable for BEF equipment. Thus Class II should be specified (Class II is defined in IEC335-1 section 2.4.8).

P4 Cables and Connectors: Specifies DIN plugs that it has been agreed are not appropriate for backpack equipment.

P5 Backpack Equipment: Calls for *"mercury tilt and float switches"*. Mercury is not necessary and reference to it should be removed.

P5 User Options: Should refer to Annex C in the case of backpack equipment.

P10 Maintenance: Refers to Annex B. It should explicitly exclude backpack electric fishing gear.

4.2 Annex A

The Electric Fishing Task Group has decided that Annex A should remain basically unchanged, except that section 4 (Backpack Equipment) should be removed and the title should be changed to exclude backpack electric fishing equipment. The title would be changed to the following: "Code of Practice for safety in Electric Fishing Operations. Annex A, Electric Fishing Equipment Specification for the Design and Construction of Fishing Machines using Hand Held Electrodes but *excluding* Backpack Electric Fishing Equipment".

4.3 Annex B

Annex B is a prescriptive maintenance schedule and is unlikely to be applicable to BEF equipment. In particular P3 section 5 'Control Box' states *"Finally, connect mains power to the input socket on the box and test all the functions to assess the correct operation of the control box including tilt and float switches on Back-Pack type control boxes."* The connection of 'mains' power to a control box is specifically forbidden elsewhere in the code of practice (main document P3 *Mains Electricity*) and is not recommended under any circumstances for backpack equipment.

Appendix 1 of Annex B gives example maintenance check-lists and equipment test certificate. It is envisaged that in the specification of new backpack electric fishing equipment some of these tests will be inappropriate or inapplicable and that the maintenance specification and schedule for backpack equipment may be better separated from other types of electric fishing equipment. It can be seen from the existing specification that it is difficult to produce a general specification for test procedures without referring to design details of specific equipment. A more satisfactory route would be for the CoP EFO to require that any BEF equipment supplied *must* include an appropriate maintenance specification and schedule within its accompanying documentation. An operational requirement within the CoP that any equipment *must* be operated in accordance with the maintenance schedule supplied with it by the equipment manufacturer (*e.g.* in the Main Volume Section 6 *Maintenance*) should ensure that this is adhered to. This would then place a responsibility on a manufacturer to specify appropriate tests and maintenance with due regard to safety, while leaving sufficient design freedom to produce equipment of differing design details.

5. ANNEX C : BATTERY POWERED BACK PACK ELECTRIC FISHING EQUIPMENT SPECIFICATION

5.1 Introduction and General Conditions

This document contains engineering specification criteria for the design and construction of Backpack Electric Fishing systems for use by or on behalf of the Environment Agency. It includes all types of electric fishing systems that are designed to be carried by the operator during use. The manufacturer of the equipment shall be responsible for the design, construction, testing and supply of equipment in accordance with this specification.

5.2 Materials and Workmanship

The design and all materials used in the construction of the system shall be of appropriate quality and suitable for the intended purpose of Backpack Electric Fishing. The system must comply with all relevant legislation including the Health and Safety at Work etc. Act 1974, Provision and Use of Work Equipment Regulations 1998, the Electrical Equipment (Safety) Regulations 1994 and the Electromagnetic Compatibility Regulations 1992 and be to the entire satisfaction of the Agency's Electrofishing Task Group.

All equipment and materials supplied shall be new and in current production. Items of equipment and components shall be selected to minimise different types and sizes in accordance with good engineering practice. Units shall carry the European "Keymark" which assures high standards of design, build and after service.

All materials, which come into contact with water, shall be resistant to corrosion and organic growth.

5.3 System Design

Backpack Electric Fishing systems must be battery powered. Engine driven generators are not permitted.

The backpack unit must be mounted on a quick release harness to enable rapid removal from the operator in an emergency. The backpack fishing system shall be ergonomically designed to minimise strain on the operator.

The system shall operate with minimum unwanted noise and vibration.

All parts of the system shall be chosen to have a minimum operational life of 3000 operational hours, and shall maintain their properties without undue deterioration due to ageing, exposure to light, or other foreseeable cause. All parts, which are subject to wear in service, shall be readily accessible and provision shall be made, where applicable, for adjustment or replacement of these parts.

Spare parts shall be available for 10 years after the date of manufacture.

The total weight of any Backpack Electric Fishing System shall be less than 15kg.

All system components shall be suitable for use within an ambient operating air temperature range of -5°C to +40°C.

5.4 Quality Assurance

The Environment Agency will require a QA system such as BS EN 9001 (Manufacture and Design) certification.

5.5 Drawings

All drawings provided by the supplier shall be of standard size (A3 or A4). Drawing practice and symbols shall be in accordance with BS 5070. The standard used shall be stated on all drawings. All dimensions shall be in ISO metric.

All drawings shall have a drawing number, title, issue number and date.

The supplier shall submit the following drawings:

1. Detailed general arrangement drawings of all the main items of equipment to a scale not smaller than 1:20. Any CAD drawings supplied shall be in '.dxf' format.
2. A detailed wiring diagram showing all connections to printed circuit board level. Printed circuit board details need not be included but all external connections to the board must be referenced.
3. Detailed schematic diagrams to enable fault finding and diagnostic operations to be carried out.

5.6 Operation and Maintenance Manual

An operation and maintenance manual shall be provided. It should be of A4 size. Prints of drawings within the manual shall be A3 or A4 size.

The manual shall have content sheets at the front and a comprehensive index at the back. A full list of all relevant drawings shall be included.

The manual shall contain the following:

- A copy of the Certificate of Conformance relating to the system
- Safety instructions and pre-start check list
- Title page giving the name and address of manufacturer, model number and type of system to which the manual relates, serial number (or range of numbers) to which the manual relates, date of issue.
- System specification is to include the following information:

1. Manufacturer's name and Address
2. Manufacturer's model and serial number (or range of serial numbers)
3. Range of rated output voltage
4. Maximum rated output current
5. Details of waveforms available
6. Maximum and minimum rated input voltage

7. Maximum rated input current
8. IP rating of component parts.

- Operational instructions including details of all available controls, instruments, and indicators included in the safety system.
- Maintenance schedule
- Fault finding and diagnostic guide.
- The part numbers and suppliers of replaceable components.

5.7 Backpack Electric Fishing Control Unit - Construction

5.7.1 General

All external components of the Backpack Electric Fishing Control Unit shall be suitable for use in a wet outdoor environment. Particular attention must be given to robustness of construction, weight, protection of components from ingress and terminations.

It shall have ingress protection meeting the requirements of IPX6. All cables entering or leaving the unit must be properly terminated so as to maintain the IP rating (*e.g.* in glands or connectors with appropriate strain relief mechanisms). The carrying frame shall be capable of securely carrying the backpack and be made of non-conductive material. The manufacturer shall state clearly in the operation and maintenance manual which parts of the frame are suitable for carrying the backpack .

Where fitted, carrying handles shall be constructed from non-conductive material and shall be secured by corrosion resistant fixings.

The frame shall be fitted with adjustable fittings to enable the backpack to be fitted to the operator.
It shall be equipped with a quick release mechanism to assist the rapid removal of the backpack from an operator in an emergency.

At least one double pole mushroom headed latching ‘Emergency Stop’ button of a design conforming to BS EN418 shall be mounted on the control box in a position easily accessible to the operator and an assistant. The button(s) shall be red in colour and mounted on a yellow escutcheon and clearly marked ‘Emergency Stop’. The function of this switch is to remove the power supply from the electrodes in an emergency. When activated, the supply shall enter a ‘tripped’ state, which must not be reliant upon the mechanical latching mechanism of the Emergency Stop switch(es). This state shall be indicated by a visible warning. Resetting the state of the system to an operational mode shall require releasing the mechanical latch and operating a separate “reset” switch or sequence of switches. It must not be possible for the operator alone to reset the system to operational mode.
All controls used for adjusting and resetting the state of the system during normal operation must be accessible from outside the control box.

5.7.2 Enclosure

The enclosure shall be manufactured from a corrosion resistant, non-conducting material. The enclosure shall be fitted with a hinged door having a minimum door opening of 135° or a lid with screw type fixings. In either case, unauthorised entry to the box shall be prevented by means of lock or security fixings that require the use of a special tool. The enclosure shall be constructed to comply with the insulation requirements for a Class II appliance (IEC335-1 Section 2.4.8).

5.7.3 Wiring

The specifications for internal wiring described in IEC335-1 (23) shall be adhered to. Power circuit conductors shall have a minimum cross sectional area of 1.5 mm^2 . All shall be adequately rated for their worst case maximum voltage and current.

5.7.4 Connectors

All external connectors shall have ingress protection meeting the requirements of IPX6 when mated and shall be rated for the worst case voltage and current that the unit is capable of sourcing. Connectors shall be supplied with sealing caps so that their ingress protection can be maintained even when they are not mated. Anode and cathode outlets shall be non-interchangeable. Where connectors contain both power and control circuits, the power pin must be shielded to a minimum of 3kV insulation.

5.7.5 Controls

All switches, push buttons and other controls shall be secured to the enclosure in such manner that they cannot turn or work loose during normal operation or maintenance. The control switches and housing shall have impact resistance to BS-EN60439-6 standard IK08.

5.7.6 Instruments

Instruments shall be flush mounted and fitted with impact resistant covers. Instruments must be clearly visible in daylight conditions. They shall be clearly and permanently labelled and shall have an accuracy to within 5% of the maximum displacement. Ammeters and their associated circuitry must be capable of withstanding fault currents without damage.

5.7.7 Indicators

Indicator systems shall be provided to indicate the following states: Power Available, Electrodes Energised,
Current limit, Unit Tripped. Their function shall be clearly labelled.
The use of Light Emitting Diodes is preferred where practicable to provide high efficiency and reliability.

Indication of the following states shall be provided

- Input power available - white
- Electrodes Energised - red
- Current limit - blue
- Unit tripped - amber
- Stopped – green

The use of flashing indicators is not precluded. The duty cycle of any indicator system must be adequate to maintain clear visibility even under daylight conditions.

An audible sounder shall be included to provide a tone (that may be pulsed) when the electrodes are energised. The sounder may have a user-adjustable volume but shall be set at a minimum level which is clearly audible above likely background noise levels.

5.7.8 Markings

Identification labels shall comprise black text on a white background.
Warning labels shall comprise black text on a yellow background.
All controls, indicators, and instruments shall bear a label to indicate their function.
All labels shall be clearly visible and permanent.

A nameplate shall be fixed to the unit giving the following minimum information:

1. Manufacturer's name and address
2. Manufacturer's model and serial number
3. Month and year of manufacture
4. Maximum rated output voltage
5. Maximum rated input voltage
6. Maximum rated input current
7. IP rating of the control unit, the battery unit and the electrodes

5.7.9 Fixings

All fixings, hinges, catches, locks and similar hardware shall be resistant to corrosion under conditions likely to be experienced during use. Where fixing screws are used they must not be readily unfastened from the outside of the unit.

5.7.10 External Cables

All external cables shall have high conductivity stranded copper conductors with a minimum cross sectional area of 1.5mm ^{2} for power conductors and 0.5 mm^2 for control conductors. Notwithstanding the previous statement, cables shall be adequately rated for the worst case voltage and current condition. All cables must be installed in continuous lengths. At their termination with the enclosure or connector, cables must be sealed to the appropriate IP standard of the component they are entering. Cables shall be suitably protected at terminations to prevent excessive bending. Brightly coloured cables shall be used that have suitable over-sheath to prevent damage due to abrasion, scuffing, or tearing. They shall be resistant to water, U-V radiation and organic growth.

5.8 Tests for compliance

A sample complete electrofishing system shall be independently type tested by an appropriate test authority to certify its ingress protection meets the specified IP rating. A sample unit shall be independently type tested and certified by an appropriate test authority to ensure that, where the equipment is claimed to meet the requirements of published standards, these standards are met. Production control procedures shall demonstrate compliance of subsequent units with all relevant legislation; alternatively, appropriate tests will be undertaken on each unit before it is supplied , as shown below.

a) Type Tests to be carried out on one example of each design or variant of a design. Tests are to be performed using a suitably rated DC supply or battery supply.

i) **Voltage waveform.** Each of the available fishing circuit output waveforms shall be tested. The resultant waveforms for each of the tests is to be recorded. The test shall be carried out on a resistive load with the fishing system providing full rated current. If the system is of the variable voltage type tests are to be carried out at 25%, 50%, 75% and 100% of rated voltage. Waveforms are to be recorded within 5 minutes of switching on from cold and then again after one hour of continuous full load operation. There should be not more than 5% difference between the cold and hot waveforms at any point on the waveform.

Where the waveform is pulsed DC e.g., quarter waveform, then the first 50% of the voltage rise to its peak value should be near-instantaneous.

ii) **Current waveform.** Each of the current waveforms available from the electric fishing system is to be tested. The resultant wave form is to be measured by a suitably rated resistive shunt. The resultant wave form for each test is to be recorded. The tests for each available waveform are to be carried out at 25%, 50%, 75% and 100% of rated output current.

iii) **Full load heat test.** A heat test shall be performed on the system at 110% of rated current. The test load shall be resistive. A separate heat test shall be carried out for each waveform that the system is designed to provide. Temperature measurements at a selection of points on the outside of the control unit enclosure shall be taken at appropriate intervals of time.

These temperature measurements shall be plotted and the test continued until equilibrium is reached. No part of the outside of the enclosure shall exceed the temperatures stated in IEC335 and the system shall continue to provide the design voltage and waveform throughout the test.

iv) **Semi conductor protective device effectiveness.** The Control Box shall be set up for a load test using a resistive load. Provision shall be made for fitting a short across the resistive load. This should give a maximum resistance of one quarter of an ohm between the Hand-held Electrode anode and the cathode sockets. The control box is to be set up on the resistive load as if for fishing. Power is to be switched off and the short applied to the load. Power is to be switched on as if for fishing. The protective device must operate immediately the power is applied to the fishing circuit. The protective device is to be reset / replaced and the short circuit removed. On re-energisation of the fishing circuit the control box and other components are to perform as the design specification. The test is to be repeated for each waveform the control box is designed to provide.

b) Production Tests to be performed on each unit manufactured

i) **Insulation Resistance.** The insulation as measured with a 500 volt DC insulation tester between the output side of the power circuit and any exposed conductive part external to the control box shall not be less than 100 meg ohms

ii) **Functional test of safety control circuit devices.** The function of each of the protective safety control circuit devices specified is to be satisfactorily demonstrated.

iii) **Voltage and frequency adjustment.** The control box is to be shown to be capable of providing the full specified voltage range and waveforms into a resistive load.

iv) **General Safety feature: Check list.** The following features shall be confirmed as provided on each manufactured unit by means of a formal check list.

CONTROL BOX

Waterproof glanding on operator controls	YES/NO
Electrofishing Equipment Labels	YES/NO
Components firmly secured to chassis plate	YES/NO
Adjustment and reset controls only accessible from outside	YES/NO
Robust, high visibility cable properly glanded	YES/NO
Label detailing type of supply required	YES/NO
Double pole latching 'STOP' button	YES/NO
Hand-held electrode & cathode sockets non-interchangeable	YES/NO
Electro-mechanical extra low voltage switching system	YES/NO
All power switching double pole	YES/NO
Bleed resistors on capacitor discharge unit	YES/NO
Indicator lamps to show operational state	YES/NO
Audible sounder operates when electrodes energised	YES/NO
Voltage control adjustment smoothly and fully variable	YES/NO
Output current indication	YES/NO
Output voltage indication	YES/NO
Battery status indication	YES/NO

HAND-HELD ELECTRODES

Waterproof and strain resistant cable entry	YES/NO
Robust, high visibility cable	YES/NO
Conductivity between plug power pins and hand-held electrode head less than 3Ω	YES/NO
Insulation between fishing output circuit and control circuit greater than 100MΩ	YES/NO

CATHODE

Strain relief cord for trailing cathodes	YES/NO

5.9 Circuit Requirements

5.9.1 General

All components shall be selected to operate within their specified operating parameters under all conditions of operation. The unit shall not be damaged in any way as a result of any value of resistive load placed across the electrodes with any combination of control settings. Wherever possible, circuits and components thereof shall be designed not to fail to danger.

5.9.2 Batteries

Batteries must be housed in a separate enclosure to the Control Unit. The battery enclosure shall have ingress protection meeting the requirements of IPX5. Batteries shall be non-spillable and rechargeable and shall be of the “sealed for life” type construction.

5.9.3 Power Input

Interconnecting cables between the battery enclosure and the Control Unit shall pass through appropriate glands or be terminated in connectors with ingress protection equal to that of the enclosures they enter.

5.9.4 Charging System

A separate charging system shall be supplied as part of the overall system and shall be appropriate for the type of battery used.

Any charging system must be designed so that the access door has to be open during the charging process.

5.9.5 Control Circuit

The control circuit shall operate as an SELV (Safety Extra Low Voltage) system (defined in BS 7671) at a nominal voltage of 12 V AC rms or DC.

The control circuitry shall be suitably protected by fuses or circuit breakers on both poles.

5.9.6 Power Conversion Circuit

The manufacturer shall specify the maximum output voltage, output current and output power for the unit.

A two-pole switch or two-pole contactor shall be fitted, which isolates both poles of the output circuit from the power source. If the switch/contactor is placed on the input side of the converter rather than the output side, an additional single pole switch or contactor must be installed on the output side of the converter to isolate the anode output.

All capacitors shall be discharged to less than 12 V within 2 minutes of the power supply being removed.

5.9.7 Safety Circuitry

The safety circuit shall include :

1. a manually operated safety control switch (Dead Man Switch) on the hand held electrode
2. one or more immersion switches on the control unit
3. a tilt switch that operates when the unit is tilted beyond 45° from its operational vertical axis
4. one or more emergency stop switches.

The manually operated safety control switch must have impact resistance to BS-EN60439-6 standard IK08, the switch shall be constructed of non - conducting material, and must be shrouded so that it can only be actuated manually by the operator, and capable of withstanding 10^6 switching operations.

The manually operated safety control switch shall comprise two series connected single pole switches. Both of these switches must be closed to enable the output to be energised. To ensure that the either of the switches has not failed to a short circuit condition the two switches are to be independently and continuously monitored. If either of the switches fails to open within 100ms of the other, the power supply shall enter a 'Tripped' state.
The safety circuit shall ensure that the electrodes cannot be energised until the following conditions have been met:

1. The emergency stop switch(es) is (are) in a Reset state.
2. The 'trip' circuit (comprising 3,4 and 5 below) is in a Reset state.
3. Immersion switches are not activated.
4. Any other safety device fitted to the system is in a Reset state.
5. The tilt switch is not activated.

The safety circuit shall be designed as far as is reasonably practical to ensure that in the event of any single component failure the electrodes cannot be energised.

Nothing in the above precludes the development of novel and additional techniques for operating the safety circuit subject to full compliance with fail safe and monitoring techniques described above.

5.9.8 Voltage Control

The system shall maintain its output voltage within 5% of its set value for any value of resistive load placed across the output electrodes, unless the supply enters a 'current limit' state, in which case a clear warning shall be available to the operator.

5.9.9 Pulsed output control

Where the output is pulsed the unit shall maintain the pulse duration and repetition rate to within 5% of its set value. This shall be irrespective of any value of resistive load placed across the output electrodes, unless the supply enters a 'current limit' state, in which case a clear warning shall be available to the operators such as an audible sounder.

5.9.10 Audible Indicators

An audible sounder shall be included to provide a tone (that may be pulsed) when the electrodes are energised. The sounder may have a user adjustable volume, but shall not be capable of being switched off.

5.10 Electrodes

5.10.1 General

Backpack Electric Fishing system utilises two electrodes. The anode is generally held in the water by the operator by means of a long insulated pole that is connected to the control unit by means of a flexible cable of type described in 7.10. The assembly comprising the metallic electrode, the insulated handle and the associated cable is referred to as the hand-held electrode.

No part of the electrode assemblies may be constructed of wood or any material that could absorb moisture or become conductive during / after submersion.

The cathode is trailed in the water behind or alongside the operator. It comprises a length of insulated cable connected to an un-insulated section, which may itself be flexible cable or braid.

5.10.2 Hand-Held Electrode

The flexible cable must enter the hand held electrode tubular handle at the opposite end to the anode head. The cable should be as short as possible without compromising operator use. The anode head shall be removable.

The hand-held electrode handle shall be equipped with a control switch assembly as described in 9.7 having a single manually operated safety control switch.
The minimum distance from the manually operated safety control switch to any part of the un-insulated anode head shall be 1 metre.

A means of fixing the anode head to the handle that prevents any movement or rotation of the head shall be provided.

The hand-held electrode assembly, excluding its connector when mated to the appropriate socket outlet, must have ingress protection meeting the requirements of IPX7.

The hand-held electrode shall be designed so that it can be used for extended periods without undue fatigue to the operator.

5.10.3 Cathode

The cathode cable must include a sufficiently-long insulated portion such that the un-insulated length is at least 1m behind the operator during use.

An appropriate strain relief mechanism shall be provided to ensure that any strain caused by pulling on the trailing end of the cathode is not transmitted to the connector.

Measures must be taken to ensure that moisture does not migrate within the insulated section of the cathode cable due to immersion.

The cathode cable shall be terminated in a connector with ingress protection meeting the requirements of IPX6.

5.10.4 Connector Specifications and Pin-Outs

The manufacturer shall define pin configuration and connection details in the operation and maintenance document. Additional or replacement electrodes must be wired as the originals.

5.11 Technical specification

In addition to meeting the requirements outlined above, the electric fishing system shall be manufactured so as to comply with the specification detailed below.

5.11.1 Battery performance

The battery shall be capable of providing one hour of operation under maximum output conditions.

5.11.2 Control box output

The output waveform shall be a short square wave of 0.5ms duration and be available via a selector switch at both 50 Hz or 100 Hz frequency.
The output voltage shall be smoothly variable between 100 volts minimum and 300 volts maximum.
The output current shall be a maximum of 2 amps.

5.11.3 Instruments

The control box shall be provided with the following instruments:

Battery state-of-charge indicator
Output voltmeter indicating peak voltage
Output ammeter.

5.11.4 Electrode heads

The standard anode head shall be 250mm diameter with an optional larger head of 400mm diameter being made available.
The cathode head shall comprise a 1m length of 26 mm wide braided copper earthing strip.

6 WAVEFORM AND VOLTAGE EVALUATION (WAVE): PROGRESS REPORT

6.1 A Comparison between the USA and UK Studies

Prior to the commencement of the UK project, a visit was made to Mississippi State University (MSU), USA to meet with workers carrying out a similar research project. The UK and USA projects differ enough in their aims and methodology that they are complementary rather than duplicate each other.

The purpose of the USA study is to document the extent of electric fishing injuries to warm-water fish and factors associated with injury. Evaluation species do not include any that are present in the UK.

In the USA study experimentation is being conducted under controlled artificial conditions in a polyethylene plastic tank. The electric field within the tank is homogeneous, with the current flowing parallel to the sides of the tank, providing a constant voltage gradient (E, V cm^{-1}). Thus, the field strength encountered by a fish will be the same throughout the field. Fish will not be free swimming but will be held in a nylon mesh bag to keep them away from the electrodes, tank walls and bottom.

The frequencies, waveforms, and voltages being evaluated in the USA study are those produced by commercially available electric fishing equipment. Frequencies will include the lower frequencies favoured by USA researchers for capturing certain species (7.5, 15, 30 Hz) as well as the frequencies similar to those more commonly used in the UK (60 and 120 Hz). Waveforms will include square and exponential pulse shapes. Again in a departure from the voltages commonly used in the UK the USA study will evaluate voltages of up to 1000 V. Pulse duration will be 1-5 ms per pulse. A gated pulse type (Coffelt's Complex Pulse System - CPS™) will also be evaluated.

In contrast, the UK study will identify which of three voltage waveforms commonly used for electric fishing is the most power and capture efficient waveform for use in BEF equipment, while not causing unacceptable injury or mortality rates to the fish.

The three waveforms to be assessed are square wave, exponential decay and gated burst. An assessment will be made of capture efficiencies of these waveforms both at constant voltage and constant power level (based upon the power usage of the square wave pattern). The research will note factors associated with injury and help identify electric fishing procedures that will optimise electrical efficiency of BEF equipment while minimising injury to fish.

The UK investigation will focus on salmonid species as these are often targeted with backpack electric fishing. Due to their availability rainbow trout (*Oncorhynchus mykiss* Walbaum) will be used for the evaluation.

In total contrast to the USA study the UK WAVE experiment will use a semi-natural channel and free swimming fish. In addition to the present USA study, many of the studies on waveform and voltage evaluation described in the literature have used very artificial systems (plastic tanks, *etc.*). The results obtained from these studies therefore may be not applicable to, or difficult to extrapolate to, natural streams (Snyder 1992). The UK WAVE design will have the advantage of being carried out in earth channels that will have the electrical characteristics of a natural stream yet can still give controlled, repeatable experimental conditions. Results are therefore likely to be directly applicable and valid for actual field equipment use.

6.2 Joint UK/USA Research

While in the USA, the opportunity was taken to collaborate in the research being undertaken by Dr S Miranda of the Mississippi Co-operative Fish and Wildlife Research Unit based at MSU.

With the increased interest being shown by researchers (*e.g.* Jesien and Horcutt, 1990; Burkhardt and Gutreuter, 1995) in the concept of constant power output for different water conditions, a further evaluation of Power Transfer Theory, as postulated by Kolz (1989), was undertaken.

Initially a series of experiments were carried out in order to determine whether the orientation of the fish within a direct current (dc) field would affect its observed response to the field. If the principles of Power Transfer Theory were correct, it was postulated that in a homogeneous dc electric field the orientation of the fish should not affect the observed response of the fish to the field. Individual channel catfish (*Ictalurus punctatus* (Rafinesque)) were constrained by nylon mesh bags to be in a particular orientation relative to a fixed dc electric field (sideways on or long-ways on). It was observed that the orientation of the fish did not affect its observed response to a dc electric field.

Further work was then carried out to enable a required voltage level for specific behavioural responses to be predicted for different conductivity waters.

Equation 26 in Kolz (1989) states:

$$\frac{P_t}{P_a} = \frac{4 \cdot q}{(1+q)^2}$$ *Equation 6.1*

Where P_a is the Power applied,
P_t is the Power transferred (into the fish),
q is the Resistance mismatch ratio (R_2/R_1).

Now, consider a unit volume in a homogeneous electric field. From Kolz (1989), the following can be derived:

$$P_t = P_a \cdot \frac{4 \cdot \frac{c_w}{c_f}}{\left(1 + \frac{c_w}{c_f}\right)^2}$$ *Equation 6.2*

Where c_f is the conductivity of the fish,
c_w is the conductivity of the water.

If therefore

$$P_a = c_w \cdot \left(\frac{V}{D}\right)^2 \qquad \textit{Equation 6.3}$$

Where V is the applied voltage
D is the distance over which the voltage measured.

Then

$$P_t = c_w \cdot \left(\frac{V}{D}\right)^2 \cdot \frac{4 \cdot \frac{c_f}{c_w}}{\left(1 + \frac{c_f}{c_w}\right)^2} \qquad \textit{Equation 6.4}$$

Where P_t is the power transferred
c_w is the conductivity of the water
c_f is the conductivity of the fish, assumed to be 150 ΦS.cm^{-1} (from Kolz and Reynolds, 1989)

Equation 6.4 can then be transformed to obtain V thus

$$V = \sqrt{\frac{P_t}{c_w \cdot Z}} \cdot D \qquad \textit{Equation 6.5}$$

Where

$$Z = \frac{4 \cdot \frac{c_f}{c_w}}{\left(1 + \frac{c_f}{c_w}\right)^2}$$

Using Equation 6.4, empirical evidence can be obtained for the power transfer (into a fish) that is required to elicit a specific response in the fish (galvano-taxis, narcosis, *etc.*). Thereafter Equation 6.5 can be used to determine the voltage required to obtain those same responses for differing conductivities of water.

A small series of experiments were run in order to test the validity of Equation 6.5 and its ability to calculate the voltage required to elicit a specific behavioural response in the fish. Channel catfish were placed in the experimental tank and the dc voltage gradient increased in stepped increments until the fish showed signs of firstly galvano-taxis and then tetany. The water conductivity and dc voltage gradient were then measured for each of the two responses (no assessment of the fish conductivity was made). The conductivity of the water in the test tank was altered by adding salt and the voltage required to elicit the same responses calculated from Equation 5. The calculated dc voltage gradient was established in the tank, a fish placed in the tank and the system energised.

The response of the fish was found to be as predicted.

Settings used in the experiments were as detailed in Table 6.1.

Table 6.1 Power transfer required to obtain specific behavioural responses in water of differing conductivities

Conductivity (ΦS.cm^{-1})	**Voltage Gradient (V.cm^{-1})**	**Behavioural Response**	**Power transfer (mW.cm^{-3})**
190	0.32	Galvano-taxis	1.92×10^{3}
190	0.97	Tetany	1.76×10^{4}
700	0.22	Galvano-taxis	1.97×10^{3}
700	0.66	Tetany	1.77×10^{4}

A similar trial was carried out, but substituting Pulsed Direct Current (PDC). As the applied voltage was pulsed, peak voltage values were not used, instead voltage values measured by Root Mean Square (rms) were substituted (see Appendix 2 for full explanation of methods used to measure voltage). According to Power Transfer Theory, if fish response is due solely to power transfer, then PDC (measured in Volts rms) should be equally predictable from Equation 6.5 as for using steady dc.

The predictive ability of Equation 6.5 was, however, found to be totally undermined by the use of pulsed dc. Fish response occurred at much lower voltage gradients than were predicted by Equation 6.5. Kolz and Reynolds (1989) found a similar finding where peak voltage values were found to correlate better than rms voltage for PDC. Kolz and Reynolds (1989) do not however discuss the implications for Power Transfer Theory of these findings. Kolz and Reynolds (1990) however do discuss a comparison of P_t between dc and ac fields. They state that similar levels of transferred power were required to elicit the same behavioural response for both for dc and ac signals. Data presented for these values however would appear to contradict that assertion. Whilst it is accepted that the small number of replicates (in Kolz and Rynolds 1990) gave wide confidence limits (thereby making differences less likely to be significant) values of power transfer required to elicit a narcosis response using dc field were approximately 70% greater than for an ac field. Effective conductivity of the fish (γ_F) also seemed to alter depending on whether ac or dc fields were applied to the fish. Lamarque (1990) quoting Lamarque (1976) also noted that tetany occurs at considerably lower threshold voltages with pulsed dc compared with steady dc Sharber *et al.* (1995) in their response to comments on Sharber *et al.* (1994) by Reynolds and Kolz (1995) discuss physiological mechanisms which could account for the differences in effect between steady and pulsed dc waveforms, stating that pulsed current passes more easily through animal tissue than steady dc.

While the above series of experiments are of an extremely preliminary nature, they have indicated several areas where more research is required. Fundamental aspects, such as the measurement of different fish's conductivity, are paramount if a better understanding of the principles behind electric fishing is to be obtained. Published values for fish conductivity range from 65 µS.cm^{-1} (Kolz and Reynolds, 1989) to 3571 µS.cm^{-1} (Sternin *et al.,* 1972); although different methods used to calculate fish conductivity may be the reason for some of the variation in results. Further research on Power Transfer Theory also needs to be carried out, while the theory seems sound for steady dc voltage, there are obviously problems in applying the theory to pulsed waveforms. Results from such research should allow a more rigorous approach to the determination of system settings required to fish water of different conductivities for different fish species and enable a move away from the 'black-box' guess approach presently used by the majority of fisheries scientists.

6.3 UK WAVE Experiment

Prior to commencement of the experiment all appropriate licences required under the Animals (Scientific Procedures) Act 1986 were obtained. The project was covered by Home Office licence PPL 40/1927 and the principal investigator by Home Office licence PIL 40/5681.

The experiment began on 30th November with the setting up, testing and calibration of the electrical systems. Square wave and gated burst pulses were produced by a Smith-Root Model 12b POW electrofisher, exponential pulse waveforms were produced using IFE adapted, Deka equipment.

6.3.1 Introduction

Although electric fishing is an extremely useful technique for sampling fish populations in small streams, papers were being published as early as 1949 claiming or detailing the harmful effects of electric fishing (Hauck 1949). Subsequently, fish biologists (mainly in the USA) have conducted several research projects studying the effect of electric fishing on injury rates to fish. Research has shown that fish exposed to electric fields can suffer a wide range of short and long-term changes and damage ranging from minor behavioural modification to death (Snyder 1992). Many evaluations have, however, suffered from poorly designed experimental procedure and uncertainty over the actual electrical waveform delivered as opposed to waveform claimed to be produced by the equipment manufacturer. Few have provided accurate diagrammatic representations of the waveforms being evaluated.

The type of pulse shape used has particular bearing upon Backpack Electric Fishing (BEF) equipment (where power from the batteries is finite and limited) as different pulse shapes and frequencies will result in significantly different power requirements.

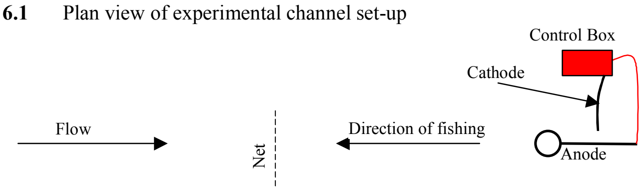
The purpose of this study is to identify which of the three voltage waveforms commonly used for electric fishing is the most power and capture efficient waveform for use in BEF equipment, without causing unacceptable injury or mortality rates to the fish.

6.3.2 Methods

The WAVE investigation focused on salmonid species as these are the species most often targeted with backpack electric fishing (Beaumont *et al.,* 1997) and are generally thought to be the most susceptible to injury by electric fishing (Snyder, 1995). Due both to their availability and the amount of previously published literature on them, rainbow trout (*Oncorhynchus mykiss* Walbaum) were used for the evaluation.

The size of fish used throughout the experiment was approximately 200 mm long and 100 g weight. A sample of 52 fish measured at the termination of the experiment had a mean length 199 mm (Standard Deviation 13mm) and a mean weight 96.8g (Standard Deviation 18.2 g). A total of 50 fish were stocked into the experimental channel prior to each evaluation. A schematic diagram of the channel design is shown in Figure 6.1 and a photograph of the actual set-up in Figure 6.2.

Figure 6.1 Plan view of experimental channel set-up



Channel dimensions were:

Overall length:	25 m
Length of stocked area:	10.5 m
Width:	4 m
Depth:	0.5 m

Cross section shape – shallow 'U'
Substratum: Clay/mud

Figure 6.2 Experimental set-up

Voltage can be measured in a number of ways (discussed in Appendix 2). Peak voltage (V_{pk}) and Root Mean Square voltage (V_{rms}) are the most useful here. For steady dc, the method used is immaterial, as both methods will give the same reading. For pulsed voltages, however, each of the two methods will give a different answer. Peak voltage will measure the maximum voltage attained by the pulse, while the rms value quantifies the equivalent steady dc voltage that would transfer the same power into the water.

Each of the waveforms were tested at both the same peak (V_{pk}) and the same rms voltages (V_{rms}). Peak voltage of the standard square waveform was set to a nominal 200 V. Mean electrical power (P_{mean}, in Watts) is a function of the rms voltage (V_{rms}):

$$P_{mean} = \frac{V_{rms}^2}{R} \qquad \textit{Equation 1}$$

Where, P_{mean} is the mean power dissipated by the load,
V_{rms} is the rms voltage applied to the load,
R is the resistance of the load.

By adjusting the voltage of the waveforms until the same V_{rms} as used for the standard square waveform was attained, an equivalent power setting for each of the three waveforms could be achieved. At experiment termination the water resistance was derived by measuring the electrical current flow when 100 V dc was applied between the electrodes. Results from this enabled the power for each of the waveforms tested to be calculated Table 6.2.

Problems with the exponential pulse set up soon became apparent. The lowest peak voltage setting on the equipment was 300 V (actual measurement 344 V_{pk}), which was higher than the standard chosen for the peak voltages of the other waveforms (200 V_{pk}). Furthermore, at 60 Hz this gave an rms voltage of only 29.1 V_{rms}. When it was tried to increase the peak voltage of the exponential pulse waveform shape in order to achieve the same rms as the square wave, it was found that the equipment could not supply the required peak voltage (>850 V_{pk}). Therefore neither comparable peak nor rms voltage levels could be achieved with the exponential pulse equipment. In order to overcome this problem it was decided not to use an exponential waveform but to substitute it with a square voltage waveform of short duration (0.5 ms). This waveform was considered an acceptable compromise between the standard square wave and the short duration pulse that the exponential pulse would have provided. The Smith-Root equipment was able to produce both suitable peak and rms voltages for this “short” square waveform. Results from the two experiments using the exponential waveform have however been included in the analysis of results. Final waveform shape, frequencies, peak and rms voltages used are tabulated in Table 6.2.

Table 6.2 Measured output of different waveforms evaluated. All measurements taken in-water using Fluke digital oscilloscope. Water conductivity 600 µS.cm^{-1} (measured at 6.5°C compensated to 25°C). Resistance 84.7 ohms

Machine setting	Pulse shape	Pulse width	Freq.(Hz)	V_{rms}	V_p	Power
IFE adapted, Deka, 300 V	Exponential	n/a	60	29.1	344	10.0
I-5 @ 200 V	Square	6 ms	60	93.2	181	102.5
I-1 @ 200 V	Short square	500 µs	60	28.8	188	9.8
P-10 @ 200 V	Gated burst	900 µs	30	53.6	192	33.9
I-1 @ 700 V	Short square – high voltage.	500 µs	60	90.8	610	97.3
P-10 @ 400 V	Gated burst – high voltage	900 µs	30	87.8	349	91.0

Note: Gated burst consisted of trains of 3 pulses of 900 µs duration with 900 µs pulse interval each train repeated at 30 Hz frequency. Oscillographs of the different waveforms evaluated are shown in Appendix 1.

The order in which the different waveforms were evaluated was randomised in order that no bias over time would affect the results.

The voltage gradient around the anode/cathode array was measured by using a three-dimensional voltage gradient measuring device of IFE design and construction. The field was measured with the anode energised at 100 V dc (water conductivity 600 µS.cm^{-1}) in the anterior, posterior and lateral axis relative to the anode. Voltage gradients, together with field magnitude values, are shown in Table 6.3 and Figure 6.3.

Table 6.3 Voltage gradient around electrodes

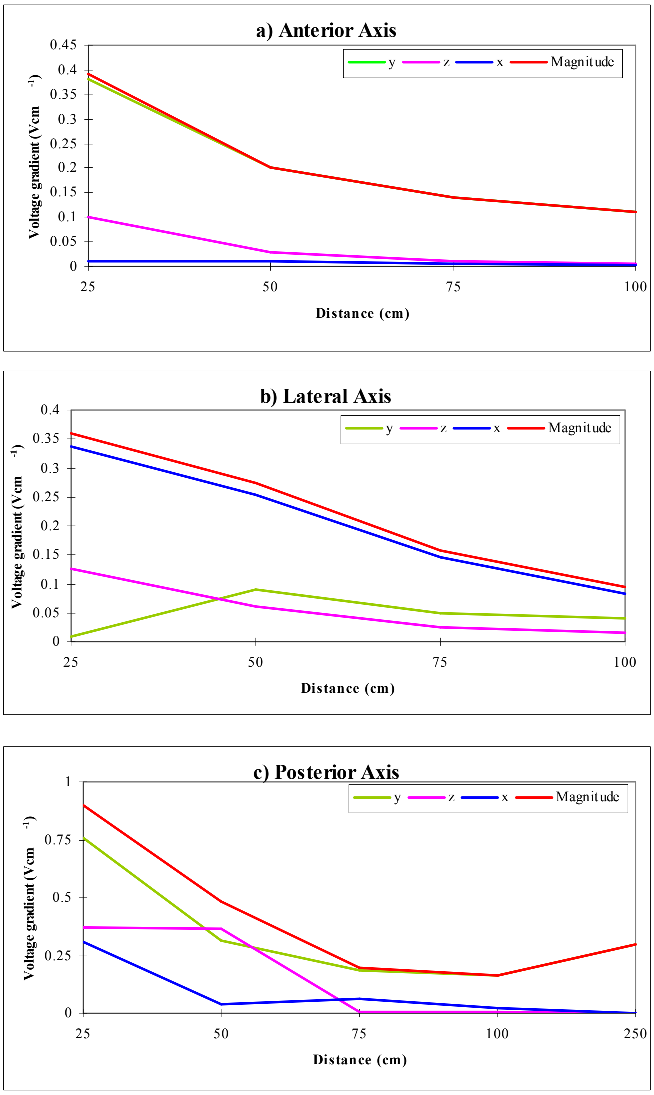
	Distance from centre of anode (cm)	y ($V.cm^{-1}$)	z ($V.cm^{-1}$)	x ($V.cm^{-1}$)	Magnitude ($V.cm^{-1}$)
Anterior	25	0.38	0.1	0.01	0.39
	50	0.2	0.03	0.01	0.20
	75	0.14	0.01	0.005	0.14
	100	0.11	0.006	0.002	0.11
Lateral	25	0.009	0.125	0.337	0.36
	50	0.09	0.06	0.253	0.28
	75	0.05	0.025	0.146	0.16
	100	0.04	0.015	0.084	0.09
Posterior	25	0.76	0.37	0.31	0.90
	50	0.316	0.365	0.042	0.48
	75	0.185	0.007	0.062	0.20
	100	0.163	0.005	0.02	0.16
	250	0.295	0.002	0.002	0.30

Measured with energising voltage of 100 V dc (water conductivity of $600\mu S.cm^{-1}$).

y is the voltage gradient in the longitudinal axis, x is the voltage gradient in the transverse axis: z in the vertical axis. The magnitude of the voltage gradient (per cm) is $(x^2+y^2+z^2)$.

Figure 6.3 Voltage gradient around anode measured in the a) anterior, b) lateral and c) posterior directions from the anode, together with the field magnitude values

Note: Measured with energising voltage of 100 V DC (water conductivity 600 ΦS^{-1}). Magnitude of voltage gradient (per cm) = sqrt(x^2+y^2+z^2)
Y = longitudinal axis: X = transverse axis: Z = vertical axis



Analysis was carried out of blood plasma cortisol levels. Plasma cortisol levels have been shown to be good indicators of stress in fish (Barton and Iwama, 1991; Schreck *et al.,* 1976) and a comparison of the different levels produced within the fish following exposure to the different waveforms could highlight effects not apparent from the catch or mortality results. Samples were restricted to those fish captured by the first pass of the electric fishing gear, as other studies show that cortisol increase is cumulative with successive electric fishing (Mesa and Schreck, 1989). Fish were allowed to recover for approximately 35 minutes post capture (range 35 - 40 minutes) whereupon a 0.5 ml blood sample was taken from a random sample of between 5 and 9 fish. The time interval between fishing and blood sampling allowed time for the cortisol response to manifest itself, but should not have been enough time for the levels to return to baseline levels (Bouck and Ball, 1966; Woodward and Strange, 1987; Mesa and Schreck, 1989; Barton and Grosh, 1996; Barton and Dwyer, 1997). Although the blood samples were designed primarily to determine inter-waveform differences, baseline samples were also taken from fish prior to any shocking and handling to determine the increase caused by the electric fishing. No control samples were taken where comparable handling, *etc.* was ensured. Although the majority of fish used were likely to be female, no attempt was made to discriminate between sexes as previous studies have showed no difference between cortisol response between sexes (Schreck *et al.,* 1976). Prior to blood sampling the fish were anaesthetised using 2-phenoxy-ethanol. Blood samples (0.5 ml) were taken from the Cuvarian sinus of the fish using heparinised syringes and 20 x 1½ gauge needles. The blood was stored on ice for approximately 1-2 hours before centrifuging at 4 °C. A 0.2ml sample of clear plasma was taken and stored frozen for analysis. Plasma cortisol levels were determined using a fully validated radioimmunoassay (Pickering *et al.*, 1987). The values of cortisol are absolute amounts in the plasma, as $ng.ml^{-1}$.

Anode and cathode were rigged, as they would be in real backpack electric fishing, with the cathode trailing *c.* 1 metre behind the anode. Alignment of the anode was also as it would be in real use, with the 280 mm diameter ring being held parallel to the water surface about 150 to 300 mm below the surface. During fishing the equipment was energised and moved at a constant rate from the downstream end of the channel towards the upstream end. Constant speed of travel was achieved by using an electrical winch system to propel the equipment. Average time to completely travel the experimental section was *c.* 40 seconds. Water depth in the channel was kept at approximately 450 mm. Water conductivity and temperature readings were taken approximately twice daily and are shown in Figure 6.4.

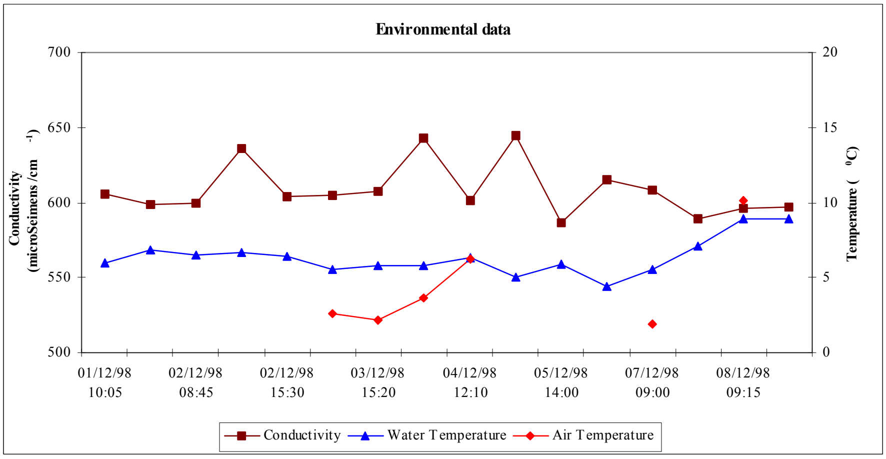


Figure 6.4: Water conductivity (corrected to 25°C), water temperature and air temperature readings recorded during the WAVE experiment

Mortality records were kept and any fish that died during the evaluation were examined for obvious tissue and skeletal damage. Any mortality of either electric fished or post experiment netted fish after they had been transferred to the holding channel was also recorded. The duration of this monitoring ranged from a maximum of 11 days (for fish at the beginning of the experiment) to a minimum of 3 days (for the last fish to be used).

At the experiment termination a sample of *c.* 25 fish from each of the waveform type batches were necropsied. The necropsy consisted of filleting one side of the fish to expose the spinal column. Any sign of gross spinal injury, haemorrhaging or other tissue damage potentially caused by the electric fishing process was recorded. In addition a sample of 5 fish from each of the waveform batches plus 5 fish not used in the electrical evaluations were X-rayed to assess skeletal damage.

6.3.3 Evaluation Protocol

For each waveform type evaluated the following protocol was carried out:

A sample of 50 fish was removed from the channel holding the stock-fish. The fish were batch marked according to the waveform/voltage evaluation being performed by fin clipping either one or a combination of pectoral, pelvic or anal fins.

After a period for acclimatisation (30 minutes) the electric fishing equipment was energised and moved through the channel.

During the electrode travel one operator wading on each side of the channel netted any immobilised fish.

When the anode reached the upstream retaining net the power was shut off and the evaluation terminated.

All netted fish were counted and retained in an oxygenated container.

After a 30-minute recovery period, the fish remaining in the experimental channel were again electrofished. Fish from the second fishing were kept separate from those caught in the first fishing.

At the end of both fishings all fish remaining in the channel were netted out and put in a recovery channel.

After approximately 35 minutes post capture a blood sample was taken from a sample of fish caught in the first fishing.

All fish were transferred to a large holding channel and were monitored for any post-experimental mortality.

6.3.4 Results

All waveforms evaluated caught a high proportion of the fish in the experimental channel. As a high proportion of fish were caught in catch 1, catch 2 efficiencies were unduly influenced by the capture, or not, of individual fish. For this reason analysis of efficiency rates has been confined to catch 1 numbers only (where this potential bias was far less). Minimum catch efficiency (averaged over the number of replicates performed) was 48% (exponential pulse) and maximum 86.7% (Short-square - high voltage). A comparison of the catch efficiency of the different waveforms was made. The proportion of fish caught in catch 1 by the short-square and gated burst waveforms (both standard and high voltage) was compared (t-test) against the first catch for the standard square waveform. Only the exponential waveform showed any significant difference between capture rates ($p=>0.01$), being lower than the other waveforms evaluated. Full details of catch numbers (both catch one and catch two) and efficiencies of each waveform are shown in Table 6.4 and Figure 6.5, results from the t-test are shown in Table 6.5.

Table 6.4 The catch efficiencies of each waveform. C1 = catch 1, C2 = catch 2

SQUARE WAVE					SHORT SQUARE PULSE				
	C1	% effic	C2	% effic		C1	% effic	C2	% effic
Rep 1	31	62	13	68	Rep 1	27	54	11	48
Rep 2	44	88	5	83	Rep 2	40	80	9	90
Rep 3	36	72	13	93	Rep 3	43	86	4	57
Rep 4	44	86	6	86	Rep 4	43	86	7	100
Rep 5	44	88	6	100	Rep 5	40	80	8	80
Mean	39.8	79.3	8.6	86.1	Mean	38.6	77.2	7.8	75.0
StDev	6.0	11.8	4.0	11.8	StDev	6.7	13.3	2.6	22.0
95% CI	5.3	10.3	3.5	10.4	95% CI	5.8	11.7	2.3	19.3
EXPONENTIAL PULSE					**GATED BURST - HIGH VOLTAGE**				
	C1	% effic	C2	% effic		C1	% effic	C2	% effic
Rep 1	25	50	12	48	Rep 1	32	64	12	67
Rep 2	23	46	6	22	Rep 2	38	76	9	75
Rep 3					Rep 3	38	75	13	100
Rep 4					Rep 4	43	84	8	100
Rep 5					Rep 5	44	88	5	83
Mean	24.0	48.0	9.0	35.1	Mean	39.0	77.4	9.4	85.0
StDev	1.4	2.8	4.2	18.2	StDev	4.8	9.4	3.2	14.9
95% CI	2.0	3.9	5.9	25.3	95% CI	4.2	8.2	2.8	13.1
GATED BURST					**SHORT PULSE - HIGH VOLTAGE**				
	C1	% effic	C2	% effic		C1	% effic	C2	% effic
Rep 1	30	60	12	60	Rep 1	44	86	6	86
Rep 2	40	80	6	60	Rep 2	44	88	6	100
Rep 3	38	76	8	67	Rep 3	43	84	8	100
Rep 4	29	58	5	24	Rep 4	47	89	6	100
Rep 5	36	72	11	79	Rep 5	43	86	2	29
Mean	34.6	69.2	8.4	57.8	Mean	44.2	86.7	5.6	82.9
StDev	4.9	9.8	3.0	20.5	StDev	1.6	1.7	2.2	31.0
95% CI	4.3	8.6	2.7	17.9	95% CI	1.4	1.5	1.9	27.1

Table 6.5 Significance tests for differences between square and other waveforms

	Square	*Exponential*	*Square*	*Gated Burst*	*Square*	*Short Square*	*Square*	*Gated Burst - High Voltage*	*Square*	*Short Square - High Voltage*
Mean	79.255	48.000	79.255	69.200	79.255	77.200	79.255	77.365	79.255	86.653
Variance	138.148	8	138.148	95.200	138.148	177.200	138.148	87.507	138.148	2.990
Observations	5	2	5	5	5	5	5	5	5	5
Pooled Variance	112.119		116.674		157.674		112.828		70.569	
Hypothesised Mean Difference	0		0		0		0		0	
df	5		8		8		8		8	
t Stat	3.528	SIG p>0.01	1.472	NS	0.259	NS	0.281	NS	-1.393	NS
P(T<=t) two-tail	0.017		0.179		0.802		0.786		0.201	
t Critical two-tail	2.571		2.306		2.306		2.306		2.306	

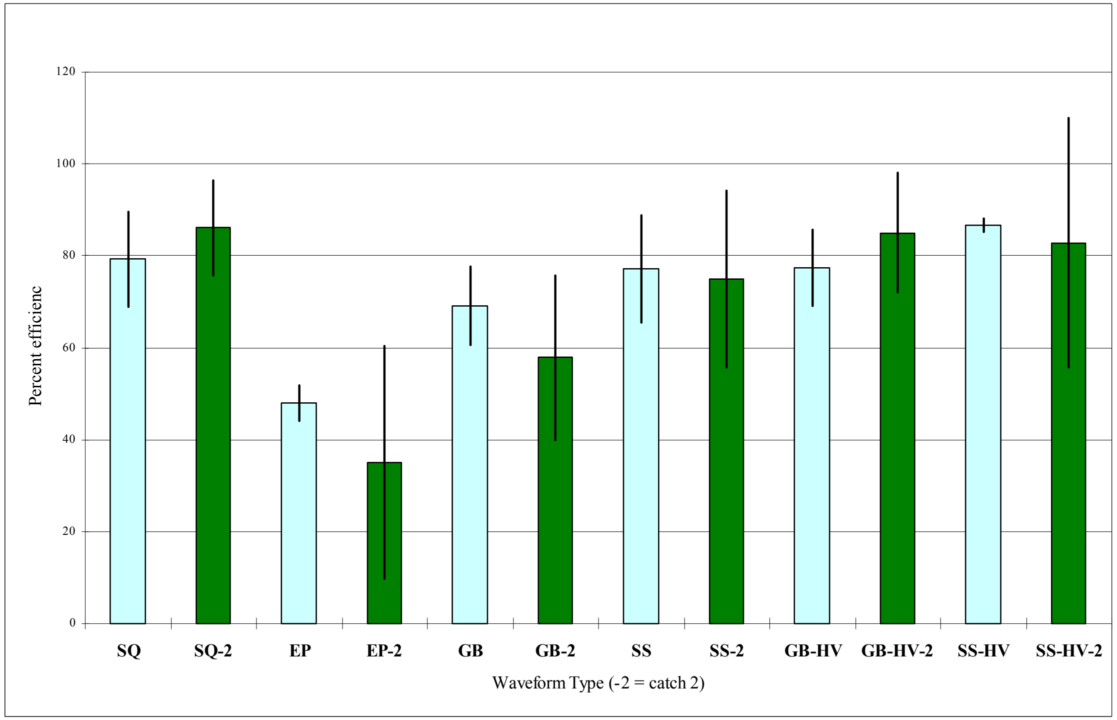
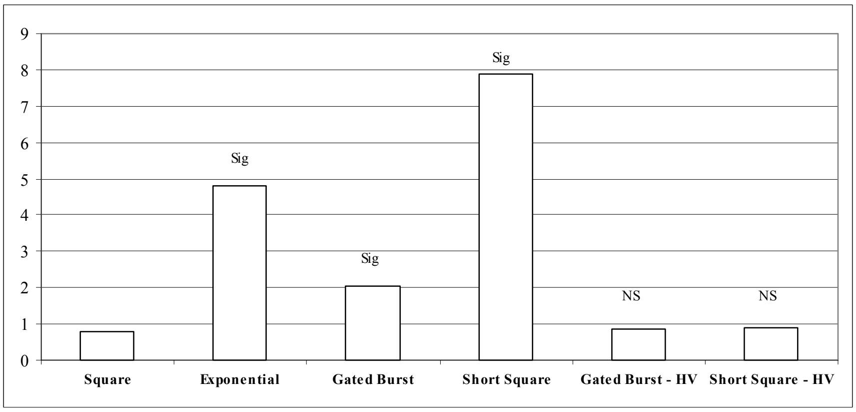


Figure 6.5 Mean (+/- 95% CL) catch efficiencies for different waveforms (-2 = second catch)

In addition to basic catch statistics presented above, estimates were made for catch-per-unit-power (CPUP) for each of the waveforms evaluated, shown in Figure 6.6. With a peak voltage of 200 V, significantly higher values (p = <0.05) of CPUP were found for the exponential, short square and gated burst waveforms, when compared with the CPUP for the standard square waveform. No significant difference between the high-voltage short square and gated burst waveforms and the standard square waveforms were found.

Figure 6.6: Catch per unit power. Catch 1 only, significance of difference from square wave noted, Resistance = 84.7 Ω

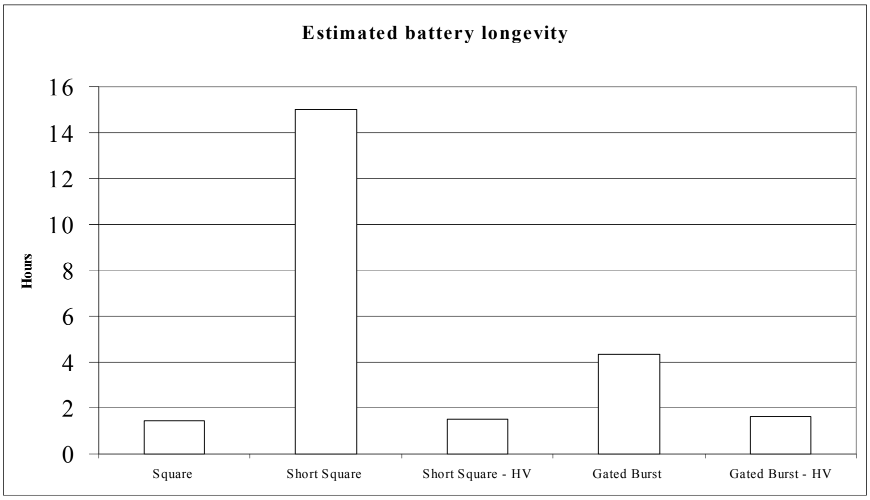


Battery longevity, based on specifications for the Smith-Root model 12b backpack electroshocker (Beaumont *et al.,* 1997) was calculated. Power was calculated from measured effective resistance of 84.7 Ω. Duration times were based upon the battery fitted to the Smith-Root 12b (24 volt, 12 Ah) at a conversion efficiency of 51% (Beaumont et al 1997). When compared against the standard square pulse waveform, longevity is markedly extended (10 times duration) by using the short square pulse. A three-fold increase in duration was achieved using the gated burst waveform Table 6.6 and Figure 6.7.

Table 6.6 Waveform power consumption and derived battery longevity

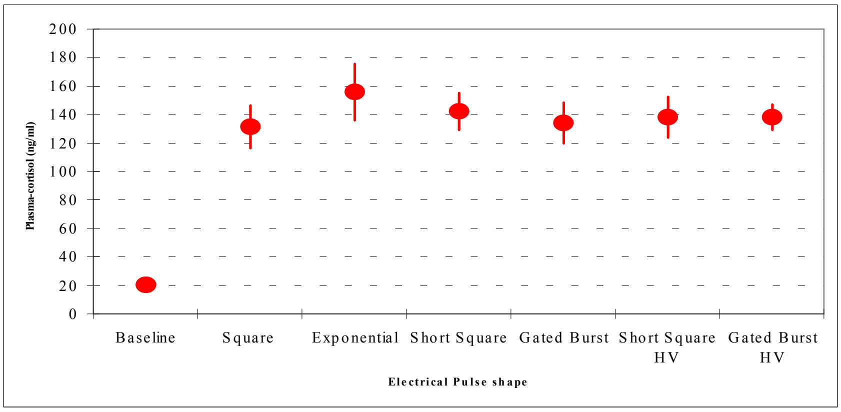
Waveform	**Power supply**	**Vrms (V)**	**Pout (W)**	**Pin (W)**	**Iin (A)**	**Duration (H)**
Square	60Hz 6ms	93.20	102.55	201.08	8.38	1.43
Short Square	60Hz 0.5ms	28.80	9.79	19.20	0.80	15.00
Short Square - HV	60Hz 0.5ms	90.80	97.34	190.86	7.95	1.51
Gated Burst	30Hz 900us on/ 900us off	53.60	33.92	66.51	2.77	4.33
Gated Burst - HV	30Hz 900us on/ 900us off	87.80	91.01	178.46	7.44	1.61

Figure 6.7: Battery longevity for different waveforms



Blood plasma cortisol levels were found to be considerably elevated above baseline levels after electric fishing. Mean levels of the combined baseline samples was 20 ng/ml (standard deviation 13 ng.ml^{-1}) compared with the mean for the pooled electric fished samples of 137 ng.ml^{-1} (standard deviation 41 ng.ml^{-1}). All individual waveforms caused significant increases ($p=<0.001$) over baseline levels but no significant differences were found between the different waveforms evaluated. Figure 6.8 shows mean plasma cortisol values for each of the waveforms evaluated.

Figure 6.8: Mean (+/- 95%CL) blood plasma cortisol levels



No instantaneous mortality in the fish was observed. Overall a mortality rate of 0.8% out of the 1400 fish used in the experiment was found (Table 6.7). Many of these mortalities however were found to have been fish used for blood sampling and indeed 0.6% out of the 0.8% mortality was accounted for by the baseline blood sampled fish, which had not been subjected to electric fishing. If mortality of fish used for blood sampling is excluded from the analysis a total mortality of 0.2% is found. Mortality was only observed in the short-square waveform and in the short-square - high voltage waveform.

Table 6.7 Fish mortality resulting from WAVE experiment

Date	Day	Fin Clip							TOTAL	CS Bleed
		Anal	**RPC**	**LPC**	**RXC**	**LXC**	**L+RPC**	**No Clip**		
30-Nov-98	Monday								**0**	
1-Dec-98	Tuesday								**0**	
2-Dec-98	Wednesday								**0**	
3-Dec-98	Thursday								**0**	
4-Dec-98	Friday				**1**				**1**	**1**
5-Dec-98	Saturday							**1**	**1**	**1**
6-Dec-98	Sunday				**1***			**1**	**2**	**1**
7-Dec-98	Monday						**1**	**1**	**2**	**2**
8-Dec-98	Tuesday			**3**					**3**	**3**
9-Dec-98	Wednesday								**0**	
10-Dec-98	Thursday				**1**		**1**		**2**	
11-Dec-98	Friday								**0**	
TOTAL		**0**	**0**	**3**	**3**	**0**	**2**	**3**	**11**	**8**
Non Cuvarian sinus bled fish					**2**		**1**		**3**	
No Fish used		250	100	250	250	250	250	50	1400	
Total Mortality		0.0%	0.0%	1.2%	1.2%	0.0%	0.8%	6.0%	0.8%	
Percent mortality of non bled fish		**0.0%**	**0.0%**	**0.0%**	**0.8%**	**0.0%**	**0.4%**	**0.0%**	**0.2%**	

* = Haemorrhage present
Shaded cells = Bled fish
CS = Number of Cuvarian Sinus bled fish

<u>Fin clips:</u>

Square wave	ANAL
Exponential pulse	RPC
Gated burst	LPC
Short Square - high voltage	RXC
Short Square	L+RPC
Gated burst - high voltage	LXC

Gross pathological examination of the fish that died revealed one fish, subjected to the short square - high voltage pulse, with a spinal haemorrhage. Necropsy examination of a sample of fish still living at the experiment termination also revealed a severe spinal haemorrhage in a fish subjected to the gated burst - high voltage waveform (Figure 6.9). X-ray examination of both these fish did not, however, reveal any damage to the spine or other bony tissue (Figure 6.10). X-ray examination of a sample of five fish from each waveform evaluated, plus five fish not subject to electric fishing, did not reveal any spinal or bony injuries likely to have been caused by the waveforms.

Figure 6.9 Fish showing spinal haemorrhage

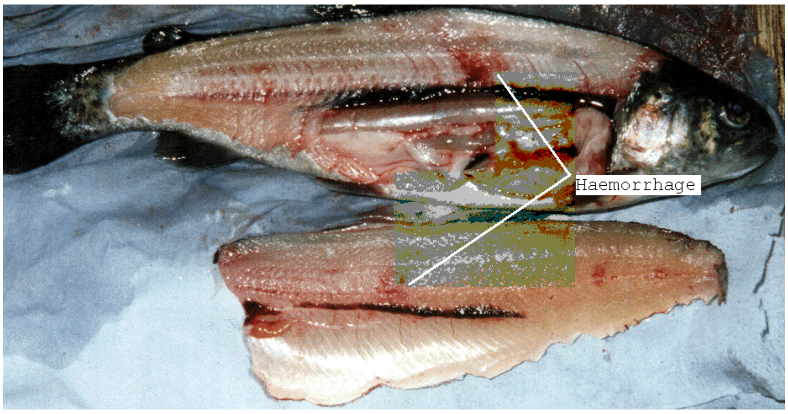
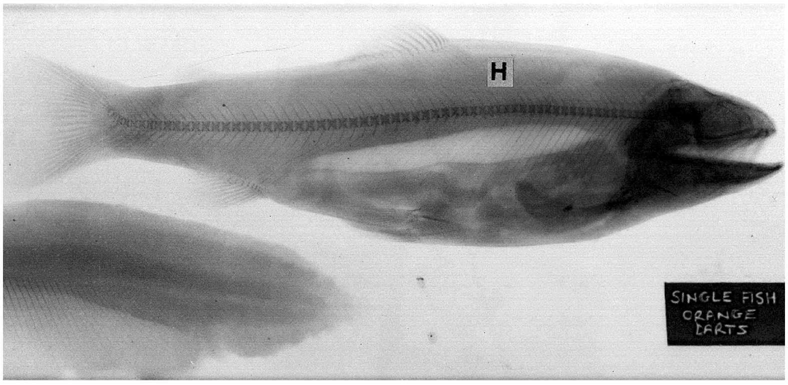


Figure 6.10 X-ray of fish shown in figure 6.9. "H" marks the position of the spinal haemorrhage. Note some resolution lost in copy process



6.3.5 Discussion

It is becoming increasingly clear that steady dc causes fewer injuries than pulsed dc, which in turn causes fewer injuries than ac (Hudy, 1985; Hollender and Carline, 1994; Dalby *et al.,* 1996; Habera *et al.,* 1996). For battery powered backpack equipment however battery life is finite. If therefore BEF equipment is to be used for extended periods (without constant battery replacement) some form of pulsing of the waveform is desirable as this is much more power efficient than generating steady dc.

Several studies have been published assessing the physiological effect of pulsed dc electrical waveforms on fish (Sharber and Carothers, 1988; McMichael, 1993; Hollender and Carline, 1994; Dalby *et al.,* 1996, *etc.*). Few if any, however, accurately quantify the electric characteristics of the waveforms being used (Snyder, 1995; Barton and Dwyer, 1997). It is also not unknown for the description of the waveforms assessed to be wrongly described (*e.g.* Hill and Willis *et al.,* 1994; Dalby *et al.,* 1996). The work of Dalby *et al.* (1996) does at least have the waveform that was used shown, a detail often lacking from many published research papers. This problem is at last receiving more attention, (Snyder 1992) and the critique of Hill and Willis (1994) by Van Zee *et al.* (1996). Another problem with many of the studies reported is that certain of the commercially available pulsing boxes have large transient voltage spikes superimposed on the specified waveform (Beaumont *et al.,* 1997 and pers. obs.). Inadequate recording of electrical details in many of the studies on electric fishing (*e.g.* no oscillograph traces) makes it difficult to identify the studies where these transients may be present. Even where voltage levels are recorded, if these are presented for rms voltage levels instead of peak voltage levels, the effect of the transients will not be adequately recorded. In studies using equipment producing transient spikes, if peak voltages are back extrapolated from mean voltages (Thompson *et al.,* 1997a) considerable errors may occur. The effect of these transients is largely ignored in discussions of waveform and electric fishing effect. Haskell *et al.* (1954) noted that the response of fish (to an electric field) was not improved by waveforms with a high initial peak and Jesein and Horcutt (1990) found that the spike produced by the equipment they were using increased with increasing water conductivity. Information is limited however and further research needs to be carried out on the impact and importance of voltage spikes.

The study described in this report has sought to quantify accurately both the capture efficiencies and physiological impact of three specific waveforms on rainbow trout. Comparisons have been made at both constant peak voltage and constant power levels. Lamarque (1990) recommended that all studies on electric fishing waveforms use a dc waveform as a standard against which the other waveforms can be compared. In this study as the specific problems associated with battery powered equipment (where steady dc is impractical to use) were being assessed, all waveforms have been compared with a standard square waveform. Waveforms used are fully documented and oscillographs shown for each of the waveforms for both constant voltage and constant power settings. Specific problems inherent with battery powered fishing equipment have been addressed by assessing catch-per-unit-power and assessing waveforms that give extended endurance for the equipment. While voltage gradients around the anode and cathode have been described no quantification of current density has been made as current density is extremely difficult to quantify in the heterogeneous electric fields produced when fishing in natural environments. In heterogeneous electric fields current density will vary depending on how far away from the anode it is measured and the conductance of objects in the immediate electrical field. This is in contrast to studies of electric fields in artificial systems using homogeneous fields where current density is uniform.

Results are presented for both constant voltage and constant power. Although the concept of power transfer was proposed by Kolz as long ago as 1989, few studies have been carried out either to verify the concept or to apply it. A notable exception is the work of Burkhardt and Gutreuter (1995) where application of the theory of constant power reduced inter site variability in electric fishing capture rates. Some uncertainties in the theory still exist however (Sharber *et al.,* 1995). The joint UK/USA study (reported in section 6.2) highlighted the fundamental breakdown of the theory when applied to pulsed dc. Additionally the factor of unknown conductivity values for the majority of freshwater fish also needs addressing. Published literature refer to values between 69 $\mu S.cm^{-1}$ (Kolz and Reynolds 1989) to 3571 $\mu S.cm^{-1}$ (Sternin *et al.,* 1972) however some variation in technique used to measure the values may make comparisons between different studies difficult. It is possible that the variable effect on different species, recorded by Burkhardt and Gutreuter (1995) and often observed by operators, could have been due to variations in fish conductivity between different fish species.

Blood plasma cortisol level changes in the farmed fish reported in this study show significant increases as a result of the fishing process. Changes in wild fish however may be even greater. Woodward and Strange (1987) found cortisol elevations greater in wild fish when compared with hatchery fish and similarly recovery rates were also shorter in hatchery fish. Stress induced mortality in wild fish could therefore be in excess of that reported in this study. Levels of blood plasma cortisol found post electric fishing in this study is comparable with those found by Mitton and McDonald (1994). In both studies elevations of plasma cortisol, above baseline, of approximately 120 to 130 $ng.ml^{-1}$ were found. Previous studies have shown much lower cortisol responses (Schreck, 1976; Mesa and Schreck, 1989), but this may be due to differences in electrical waveforms used: pulsed as opposed to steady dc (Mitton and McDonald, 1994).

Mortality and injury rates found in this study were lower than those found in many other studies (Sharber and Carothers, 1988; McMichael, 1993). It does not, however, follow that this would be the case for wild fish populations. No assessment in this study was made of long-term mortality. Dalby *et al.* (1996) found that whilst short-term mortality (7 days post-release) in rainbow trout captured by electric fishing was low (average *c.* 2%), long-term mortality (335 days) was much higher (*c.* 43%). Overall it is considered that the mortality rates recorded in the WAVE experiment are at an acceptable level for sampling wild fish populations; given that even high mortality rates have limited impact at a population level (Schill and Beland 1995). All sampling methodology is likely to result in some mortality and Bouck and Ball (1966) found that seining, angling and electroshock all produced both mortality effects and some adverse effects on rainbow trout blood chemistry (with the highest mortality rates being found for capture by angling).

The post mortem findings showing haemorrhaging of blood vessels along the spinal column are consistent with other research showing such damage as a result of electrical injury (Bardygula-Nonn *et al.,* 1995). The incidence of spinal haemorrhaging was low however and both fish discovered with such injuries had been subjected to the high voltage waveforms. McMichael (1993) in a similar study to that reported here found that injury rate was highly correlated with pulse frequency, with increasing frequency leading to increased injury rates. However in McMichael‘s study no mention is made of pulse width or rms voltages making assessment of the results in relation to power theory and other studies difficult. In contrast to many other studies (*e.g.* Dalby *et al.,* 1996) no damage to the spine or other bony tissues was observed in the WAVE experiment.

With the exception of the exponential pulse, all waveforms evaluated produced catch efficiencies well above the minimum required for adequate population estimation (Bohlin 1982, Cowx 1983). The efficiency, both in terms of absolute catch and catch-per-unit-power of the short-square pulse warrants further investigation. Although in this study the waveform was used initially as a substitute for the exponential waveform it has in fact much to commend it over the exponential waveform. The pulse duration can be accurately set, it is not water conductivity dependent on its discharge time and the peak voltage can be accurately monitored. The similar overall capture efficiency (when compared with the standard square pulse) and high catch-per-unit-power of the short square pulse waveform are extremely relevant to the use of battery powered electric fishing equipment. Bird and Cowx (1990) found that in excised trout muscle summation rates were lower and fatigue resistance higher, for 0.2 ms pulses compared to 2 ms pulses. Lamarque (1990) considered that short pulse widths (<0.25 ms) were both effective, benign in their effect on the fish and power efficient. Lamarque (1990) also recommended that these short pulses should be at frequencies of between 400 - 1000 Hz and several studies that have evaluated these short pulse widths have used high frequency repetition (Sharber *et al.,* 1994). Both the 1994 study by Sharber *et al.* and others (*e.g.* McMichael, 1993) however point to high frequencies as being injurious and it is possible that it was the high frequency rather than the narrow pulse width that caused the injury rates recorded in Sharber *et al.* (1994). Hill and Willis (1994) also, albeit unknowingly (Van Zee *et al.,* 1996), used a shorter than standard duration dc pulse width in their study on largemouth bass capture rates. In their work they compared the efficiency of *c.*9 ms pulses with the efficiency of *c.*4 ms pulses (compared to the WAVE experiment where 6 ms pulse duration was compared with 0.5 ms pulses). While they found increased capture rates for the shortened pulse duration waveform, they kept electrical current output for the two different waveforms similar. This was achieved by increasing the voltage of the short duration pulse. The results obtained by Hill and Willis (1994) therefore also call in to question the principles of Power Transfer Theory (Kolz 1989). According to Power Transfer Theory (Kolz, 1989), the two waveforms were equal in terms of power and no differences should have been apparent between waveforms. Thompson *et al.* (1997b) also recommend minimising the pulse width in order to reduce the injurious effects of electric fishing. Further studies using the short pulse waveform in a variety of natural conditions and water conductivities need to be carried out to assess fully this waveform and determine its suitability for general electric fishing use.

The use of 60 Hz pulse frequencies (with exception of the multiple pulse component of the gated burst waveform) in the WAVE experiment is in the mid-range of the frequencies in general use in the UK for electric fishing (Beaumont *et al.* 1997). Many studies indicate that the higher the pulse frequencies the more injurious the waveform is to fish (Haskell *et al*. 1954, Taylor *et al.* 1957, Lamarque 1976, Cooke *et al.* 1998). Much of the research is contradictory however (Snyder 1992) and suffers from the problems reported earlier of incomplete recording of experimental details. Researchers in the USA often use far lower pulse frequencies than in the UK (5 Hz) however rarely use frequencies above 100 HZ (pers. obs.). Given the concerns regarding high pulse frequencies, the common practice use of 100 Hz frequencies and the recent interest and use of >100 Hz frequencies in the UK needs careful consideration and an assessment made for injury rates associated with such frequencies.

In conclusion, there is increasing concern at injury rates associated with electric fishing practice (Snyder, 1995). While this study and many others have shown some injury associated with the procedure of sampling fish with electricity, it is important not to confuse individual injury rates with population injury rates. Even electrical waveforms that give high incidences of injury are likely to have a negligible impact at the population level (Schill and Beland, 1995). This population perspective should not be a cause for complacency however. Electric fishing is often the only practicable method of sampling fish and any pressure from the public or policy makers to restrict its use as a sampling method is likely to severely restrict the collection of data which may be essential for the scientific management and conservation of fish stocks. It is essential therefore that further research on both the fundamental aspects of electric fishing theory and on the use of novel waveforms, which reduce injury rates, is carried out.

7. PROTOTYPE EQUIPMENT

As part of the project it was agreed to construct a prototype BEF unit which would incorporate as many as possible of the amendments proposed in Annex C as possible. Although initially the unit was to be a non-working mock-up it was decided to incorporate working electronics derived from redundant IFE equipment. Some limited functionality of the equipment was expected due to the inclusion of non-design intended systems. The design of the additional features of the equipment may also require to be non-optimal as a result of the need to modify existing equipment. Whilst housings etc will be made bearing in mind good ergonomics and design considerations it is beyond the scope of this project for specific mouldings to be produced.

7.1 Specification of Prototype Equipment

Battery

12 V 6.5 Ah Sealed lead acid battery fitted with connector to enable field replacement. The battery is mounted in a high impact polycarbonate enclosure rated IP65.

Power Unit

The power unit is based no a Deka 3000 Electric Fishing System power conversion board. It is mounted in a high impact polycarbonate enclosure rated IP67.

Electrical Characteristics

The electrical characteristics are identical to those specified for the Deka 3000 system:

Voltage

300-600V, 4 steps

Pulse Repetition rate

30 – 80 Hz Continuous adjustment

Waveform

Pulsed, Fast rising edges with Exponential decay

Protection Features

Sounder

Pulsed 2.8kHz tone whenever electrodes are energised.

Tilt Switch

Omni-directional 30° non mercury tilt switch. Pre-set adjustment for vertical axis to enable compensation for operator “stoop”.

Immersion Switch

Solid state Electro-optic immersion sensor.

Anode Switch

2-pole anode switch provides fail-safe if either switch element fails.

Anode

1.8 m tapered fibreglass pole with "pistol grip" control and forearm support. Two pole switch rated IP67. Field replaceable anode rings diameter 230, 310, 470 mm supplied. connected to 2 m Polyurethane sheathed cable terminated with Lemo 3E series 6 pole connector (5LV + 1 HV).

Cathode

Copper braid 14 mm * 1.5 mm * 2 m connected to 2 m polyurethane sheathed cable terminated with Lemo 3E series single pole connector and strain-relief anchor.

Backpack Dimensions

Height: 900 mm
Width: 400 mm
Depth: 250 mm

The backpack is secured by means of padded shoulder straps and a waist strap. Both are adjustable and fastened by quick release plastic clips

Weights

Main Unit (including Backpack, Harnessing, Immersion Sensor, and Battery Pack: 11kg
Anode: 1.2 kg
Cathode: 0.8kg
Control Unit: 1 kg

7.2 Exceptions to Compliance with Annex C

The following items in the prototype unit are departures from the requirements of the proposed Annex C:

- **Connectors.** The Lemo connectors used in the prototype are IP66 rated, not IP67. Despite researching the market extensively, no connectors which were suitably rated for the voltage and current of the Deka power conversion electronics and sufficiently light and compact were found. IP67+ rated plastic connectors are available, but are generally rated up to 250 V.

- **Insulation**. Generally designed to meet class 2, but exceptions include isolator switch, rotary controls. The Deka 3000 power conversion unit around which the prototype was built in order to produce a "working model" is not specified with regard to insulation. However certain details of the PCB fall below that which would be required currently. With regard to the rotary controls, it is anticipated that a modern design of power converter could use simple push buttons to program functions such as voltage and pulse repetition rate eliminating any need for potentiometers or rotary switches. Such push buttons could be IP67 rated components similar to the Start and Stop buttons fitted to the control unit, or could be part of a membrane-type switch/display panel.

- **Current Limit indicator**. A Current Limit Indicator lamp is fitted but is non-functional since the power conversion circuitry of the Deka 3000 system is not a current limiting power supply. Most modern designs for power conversion circuitry incorporate a current limiting feature.

- **Flexible Cable.** The flexible cable used in the system is rated at 600 V working and is tested to 2 kV. However when set to its higher voltage settings, and under certain load conditions, output voltage transients can exceed 600 V with the Deka power conversion circuitry.

- **Anode IP rating.** The original single pole switch used in the BSE system was replaced with an IP67 rated two pole switch. Although the original BSE system is IP67 rated, from a visual inspection it would seem unlikely that the BSE electrode control head design would pass an IP67 test in its current form.

- **Control voltage**. All controls are 12 V nominal and operate at the battery terminal voltage to conform with the control circuitry of the Deka 3000 power control board. With a fully charged battery, the peak voltage in parts of the control system exceed 12 V. The 12V peak voltage requirement could be met in a new design by using a 5 or 6V (nominal) control circuit.

- **Indicator Lights.** The indicator lights use filament bulbs, as no suitable high intensity LED's were available in non conductive housings. Metal units could be used if back-potted (as with the connector sockets) but there would be a weight penalty, and they would be more difficult to service.

- **Display**. A 2 line 20 character liquid crystal display is fitted in the control unit and is driven by serial data at 1200 bD from a microcontroller in the main enclosure. However, in order to avoid isolation problems from the unspecified power conversion circuitry, the display does not provide "Live" voltage and current readings.

Figure 7.1 Prototype BEF equipment

8. ACKNOWLEDGEMENTS

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A1 OSCILLOGRAPHS OF THE VOLTAGE WAVEFORMS EVALUATED

Figure A1.1 Exponential waveform. Note: resistive load different from other waveforms shown.

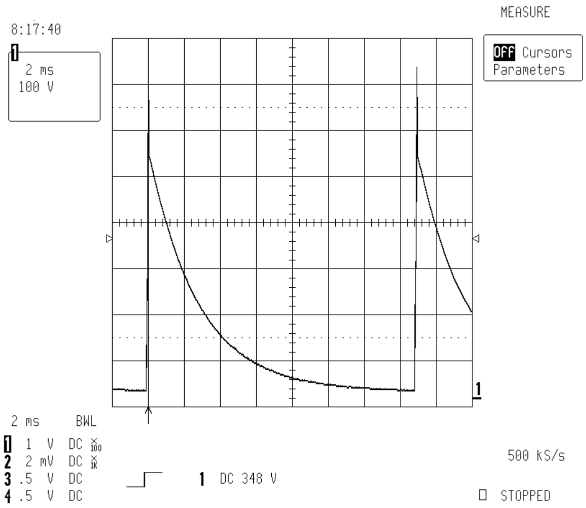


Figure A1.2 Standard square waveform.

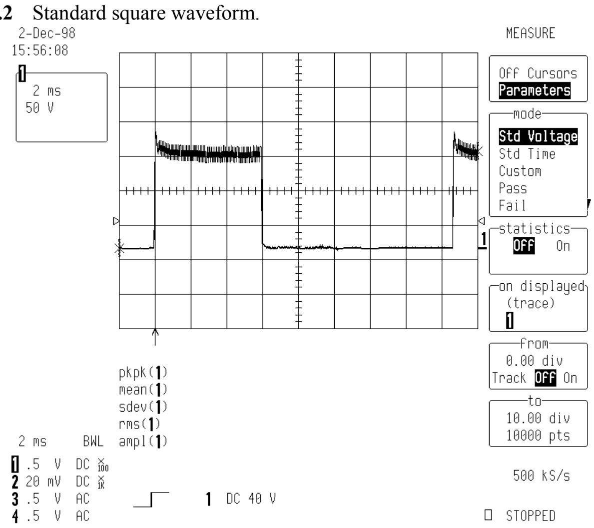


Figure A1.3 Short pulse square waveform.

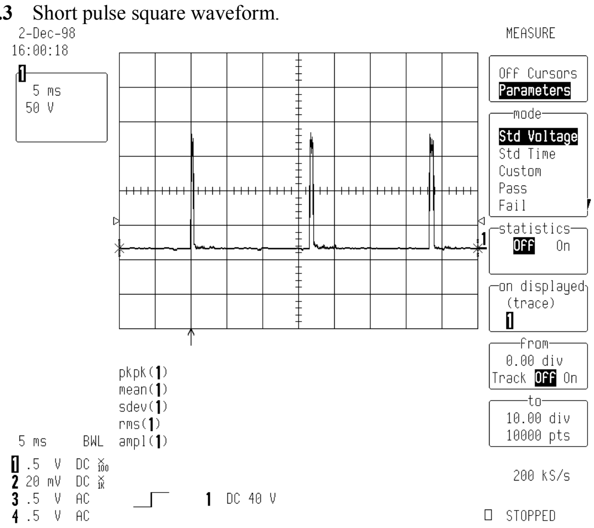


Figure A1.4 Short pulse square waveform - high voltage.

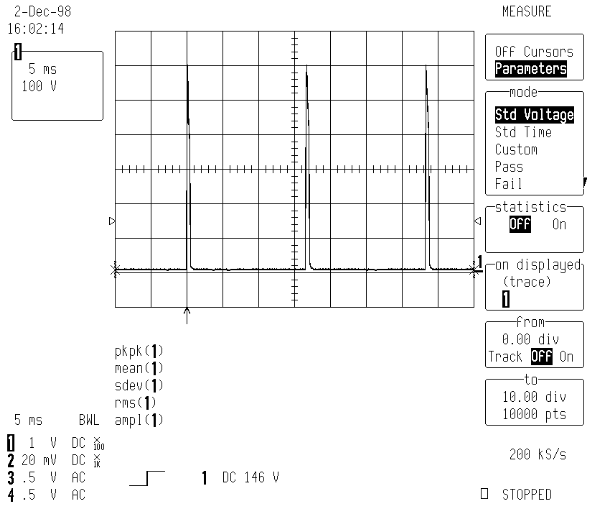


Figure A1.5 Gated burst waveform.

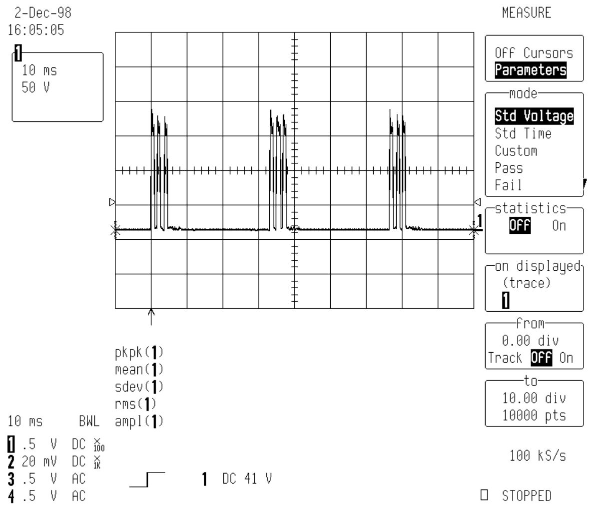


Figure A1.6 Gated burst - high voltage waveform.

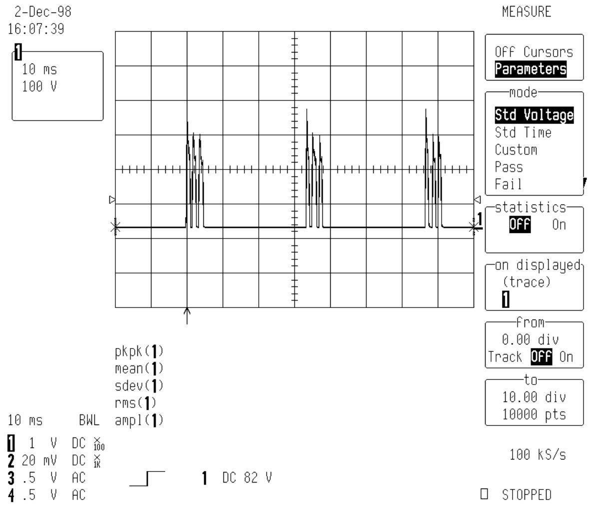


Figure A1.7 Enlarged Gated burst - high voltage waveform.

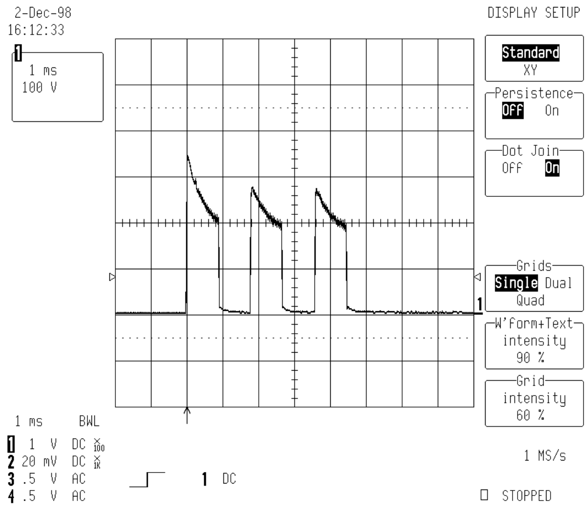
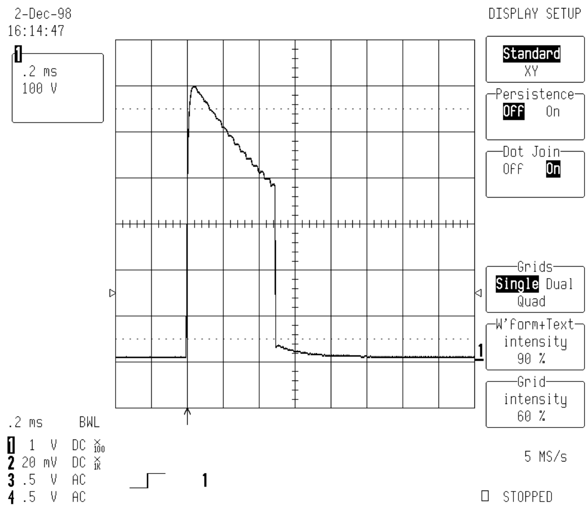


Figure A1.8 Enlarged short pulse square waveform.



A2 CHARACTERISING WAVEFORMS GENERATED BY ELECTRIC FISHING EQUIPMENT

A2.1 Notes on Voltage Measurement

A2.1.1 Direct Current (dc)

Consider a steady dc voltage applied between two electrodes. It is, by definition, constant and is equal to the potential difference between the electrodes. The power dissipated by a load connected between the two electrodes is also constant and is given by the following expression

$$P = \frac{V^2}{R} \qquad \textit{Equation A2.1}$$

Where P is the power dissipated by the load,
V is the voltage applied to the load,
R is the resistance of the load.

If the voltage is a time variant, periodic function (*e.g.* sinusoidal, pulsed, or any other complex, repetitive waveform), the voltage can be expressed in several ways. Three common parameters described below are peak, peak-to-peak, and root mean square (rms).

A2.1.2 Peak (V_{pk})

The peak voltage is the magnitude of the maximum instantaneous voltage appearing between the electrodes. Figures A2.1 to A2.4 illustrate the peak voltage of some sample waveforms.

A2.1.3 Peak-to-Peak (V_{p-p})

The peak-to-peak voltage is the difference between the positive peak (*i.e.* the maximum, instantaneous voltage) and the negative peak voltage (*i.e.* the minimum, instantaneous voltage) appearing between the electrodes. Figures A2.1 to A2.4 illustrate the peak-to-peak voltage of some sample waveforms.

A2.1.4 Root Mean Square (V_{rms})

When a load is energised by a time variant voltage, the power dissipated by the load will also be time variant. The instantaneous value of the power dissipated by the load is given by Equation A1. When considering periodic waveforms, it is customary to consider the mean value of the power over a complete cycle. For a voltage waveform, $v(t)$, with period, T, the mean power, P_{mean}, in the load over one cycle from Equation A2.1 is given by:

$$P_{mean} = \frac{1}{T} \cdot \int_{t}^{t+T} \frac{v^2(t)}{R} \cdot dt \qquad \textit{Equation A2.2}$$

Since R is not time variant this can be expressed as:

$$P_{mean} = \frac{1}{R} \cdot \frac{1}{T} \cdot \int_{t}^{t+T} v^2(t) \cdot dt \qquad \textit{Equation A2.3}$$

It may be recognised that

$$\frac{1}{T} \cdot \int_{t}^{t+T} v^2(t) \cdot dt \qquad \textit{Equation A2.4}$$

is the mean value of the square of the voltage over one complete cycle.

In order to maintain consistency with the dc case in Equation A2.1, it is common to express power in the case of a time variant voltage as:

$$P = \frac{V_{rms}^2}{R} \qquad \textit{Equation A2.5}$$

Where

$$V_{rms}^2 = \frac{1}{T} \cdot \int_{t}^{t+T} v^2(t) \cdot dt \qquad \textit{Equation A2.6}$$

Thus

$$V_{rms} = \sqrt{\frac{1}{T} \cdot \int_{t}^{t+T} v^2(t) \cdot dt} \qquad \textit{Equation A2.7}$$

This is the root mean square of the voltage and is equivalent to the value of the steady dc voltage that would dissipate the same mean power in the same load resistance. Figures A2.1 to A2.4 illustrate the rms voltage of some sample waveforms.

A2.2 Some Example Waveforms

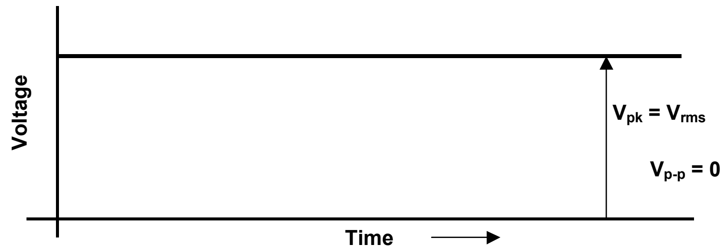


Figure A2.1 A steady dc voltage V = V_{pk} = V_{rms}.

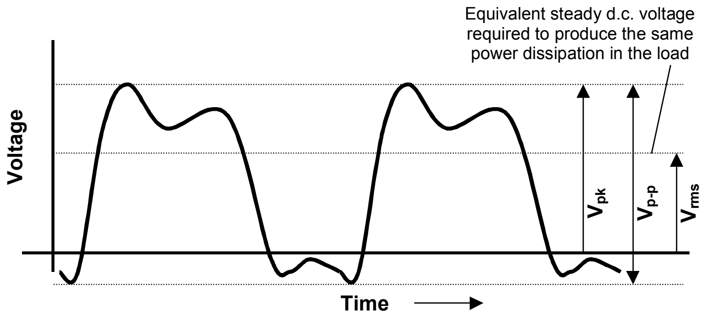


Figure A2.2 A sample periodic waveform illustrating the magnitude of V_{pk}, V_{p-p}, V_{rms}.

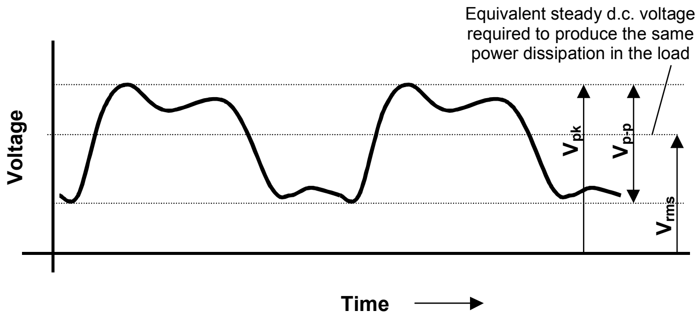


Figure A2.3 An alternative periodic waveform illustrating the magnitude of V_{pk}, V_{p-p}, V_{rms}.

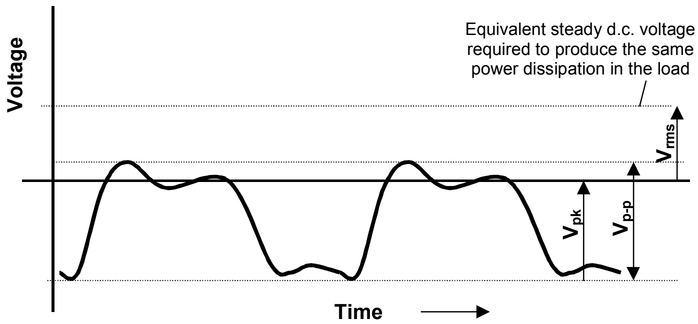


Figure A2.4 An alternative periodic waveform illustrating the magnitude of V_{pk}, V_{p-p}, V_{rms}.

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